CT Characterization and Comparison with Polysomnography for Obstructive Sleep Apnea Evaluation

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Abstract

Purpose: We hypothesized that computed tomography (CT) combined with portable polysomnography (PSG) may visualize anatomical data related to obstructive sleep apnea (OSA). This study aims to evaluate computed tomographic findings during sleep apnea and assess their associations with PSG data and patient characteristics.

Patients and Methods: We designed a prospective cross-sectional study in patients with OSA. The patients were scanned during awake states and apneic episodes. Associations of predictor variables, i.e. PSG data [respiratory disturbance index (RDI)] and patient characteristics [body-mass index (BMI), neck circumference (NC) and waist circumference (WC)], and outcome variables, i.e. CT findings during apneic episodes, were assessed by logistic regression analysis. CT findings during apneic episodes were categorized as to: level of obstruction, single-level [retropalatal (RP) or retroglossal (RG)] or multi-level (mixed RP and RG); degree of obstruction (partial or complete); and pattern of collapse [complete concentric collapse (CCC) or other patterns].

Results: Fifty-eight adult patients with OSA were scanned. The mean ± standard deviation (SD) RDI, BMI, NC, and WC were 41.6 ± 28.55, 27.80 ± 5.43 kg/m², 38.3 ± 4.3 cm, and 93.8 ± 13.6 cm, respectively. There were no variables observed which distinguished between the presence of single- and multi-level airway obstruction in this study. A high RDI (≥30) was associated with the presence of complete obstruction and CCC [odds ratios (95% confident interval) were 6.33 (1.55–25.90) and 3.77 (1.02–13.91) compared to those with lesser RDIs, respectively].

Conclusion: Increased RDI appears to be an important variable for predicting the presence of complete obstruction and CCC during sleep apnea. Scanning during apneic episodes, using low-dose volumetric CT combined with portable PSG, provided better anatomic and pathologic findings in OSA than detected with scans during awake state.
Introduction

Obstructive sleep apnea (OSA) syndrome is a common disorder affecting at least 2 to 4% of the adult population. Repetitive cessation of breathing during sleep due to collapse of the upper airway causes signs, symptoms and consequences such as increased risk of cardiovascular disease [1]. Full-night polysomnography is recommended as a standard method for diagnosis of the sleep-related breathing disorder OSA [2]. The diagnosis of OSA is confirmed by a respiratory disturbance index [RDI, the number of obstructive events (apneas, hypopneas + respiratory event-related arousals) per hour on PSG] of greater than 15, or greater than 5 in a patient who reports any OSA symptoms [3]. OSA severity is defined as mild (RDI more than or equal to 5 and less than 15), moderate (RDI more than or equal to 15 and less than or equal to 30), or severe (RDI more than 30) [1].

For deciding an appropriate OSA therapeutic approach, patients should be included in the discussion of treatment options [1]. Continuous positive airway pressure (CPAP) is the standard treatment for moderate to severe OSA, and is an optional therapeutic method for mild OSA [4]. However, CPAP can only be effective if used regularly, that is at least 4 hours/night [5]. CPAP failure may occur in 25-50% of patients because they discontinue therapy, largely within the first 4 weeks [6]. Alternative non-CPAP therapies of OSA, e.g. behavioral treatments, oral appliances, upper airway surgery, maxillomandibular advancement (MMA), and implanted upper airway stimulation (UAS), are recommended to patients who decline to use CPAP [1, 7]. Behavioral treatment options include weight loss (10% or more of body weight), exercise, positional therapy, and avoidance of alcohol and sedatives before bedtime [1]. Custom-made oral appliances are indicated for use in patients with mild to moderate OSA who fail treatment with both CPAP and behavioral strategies [8]. Upper airway surgery can be considered as a primary treatment in patients with mild OSA who have severely obstructing airways that are surgically correctible (e.g. tonsillar or adenoid hypertrophy) [1]. MMA, i.e. pharyngeal space enlargement by moving maxilla and mandible forward to reduce pharyngeal collapsibility [9, 10], is currently the most effective craniofacial surgical technique for the treatment of OSA in adults [11, 12]. The diagnosis of OSA and its severity should be determined by PSG prior to surgeries. Implanted UAS therapy, i.e. closed-loop hypoglossal nerve implants, offers an alternative in patients with moderate to severe OSA and CPAP failure [7]. Clinical indication for UAS requires the absence of complete concentric collapse (CCC) of the upper
airway during drug-induced sleep endoscopy (DISE), i.e. nasopharyngoscope visualization of the upper airway under sedation [13].

Due to the inability of real-time monitoring devices to localize obstruction levels within the upper airway, level-specific treatment approaches, such as various upper airway surgeries and oral appliances, show relatively low success rates compared with CPAP [14-16]. Recent advanced imaging modalities of upper airway geometry, e.g. DISE [17] or computational fluid dynamic analyses based on magnetic resonance imaging (MRI) [18] or computed tomography (CT) [19], have been used to evaluate treatment success. DISE, MRI, and CT are also applied for defining possible surgical sites in the upper airway. DISE is an alternative diagnostic tool for locating the obstruction site in patients [20] which generates qualitative information, e.g. level, degree, and direction of upper airway collapse [21]. MRI is a non-ionizing radiation scanner providing high resolution imaging including upper airway soft tissue; however, it is slow and costly [22-25]. CT is a fast way to scan, revealing the causes and sites of obstruction [26, 27]. Nonetheless, there is limited published research that assesses upper airway changes during sleep apnea.

The purpose of this study was to evaluate CT findings, including level of obstruction, degree of obstruction, and pattern of collapse, in patients during sleep apnea. We hypothesized that the CT findings observed during apneic episodes may demonstrate greater and more relevant upper airway pathologies than those observed during awake state, and may be associated with OSA severity. The specific aim of the study was to identify associations between PSG data (RDI) or patient characteristics [body-mass index (BMI), neck circumference (NC) and waist circumference (WC)] and CT variables of interest (CT findings during apneic episodes) using logistic regression analysis.

Materials/methods

1. Study design/sample

To address the research purpose, we designed and implemented a prospective cross-sectional study. The study population was composed of all patients presenting for evaluation and management of OSA in August 2011 through November 2016. To be included in the study sample, patients had to be diagnosed with OSA (had sleep-related symptoms [1] and an RDI of more than 5) using standard overnight in-
laboratory PSG (Sandman Elite, Nellcor Puritan Bennett, Pleasanton, CA, USA) at the Ramathibodi Hospital Sleep Disorder Center. The RDI was interpreted according to American Academy of Sleep Medicine (AASM) diagnostic criteria [28]. Patients were excluded as study subjects if they had an infiltrative lesion in the upper airway. Prior to participating in the research study, all patients gave written consent using forms and processes which were approved by the Committee on Human Rights Related to Research Involving Human Volunteers, Faculty of Medicine, Ramathibodi Hospital, Mahidol University, in accordance with the Declaration of Helsinki.

2. Variables

Predictor variables were PSG data (RDI) and other variables, i.e. patient characteristics (BMI, NC, and WC), that may influence the outcome. Outcome variables were abnormal CT findings during apneic episodes. The CT findings during apneic episodes were categorized as to: level of obstruction, degree of obstruction, and pattern of collapse.

3. Data collection methods

3.1) Signal-triggering, computed tomographic image acquisition

Prior to performing CT scanning, a portable PSG recorder (Titanium; Embla System, Broomfield, CO, USA) was used for the assessment of sleep by recording EEG, EOG, nasal/oral airflow, thoraco-abdominal efforts, O₂ saturation, and heart rate. After confirming that patients met the minimal requirements for diagnosis of OSA [29], they were induced to sleep in supine position on the CT table using 10 mg zolpidem hemitartrate. This drug is commonly used in a PSG study because it does not affect the apnea/hypopnea index, oxygen desaturation index, or the lowest SaO₂ [30]. Low-dose, volumetric axial scan without contrast agent, using 80 kVp and 20 mAs (500 msec, 40 mA) and causing only 0.07 mSv per a scan, was performed using a 320-slice CT scanner (Aquilion ONE™, Toshiba Medical Systems Corporation, Nasu, Japan) at the Advanced Diagnostic Imaging Center (AIMC), Ramathibodi Hospital, Bangkok, Thailand. The CT image resolution was 512 x 512 pixels (0.39 x 0.39 mm²) and the shift between one cross-sectional image and the subsequent image was 1 mm. Scout images (anterior and lateral views) were obtained to determine the scanning area covering the upper wall of nasal cavity and the hyoid bone. Patients could maintain their sleep cycle phases during the examination because volumetric scanning (i.e., acquire 16 cm of anatomy in a single rotation) was
performed to eliminate the effect of CT table movement. Axial images of the patients' upper airways were scanned in two states, i.e. awake state and apneic episode. The PSG technician interpreted the physiologic signals which distinguish awake state and apneic episode, and informed the radiographer in the CT console room using the RemLogic software version 2.0. Multiplanar, reformatted sagittal and coronal images were then generated. Finally, three-dimensional (3D) images were created using Vitrea RX post-processing software version 3.0.1 (Toshiba Medical Systems Corporation, Nasu, Japan).

3.2) Image-based, upper airway evaluation

We evaluated the following qualitative upper airway outcome variables, level of obstruction, degree of obstruction, and pattern of collapse. Levels of obstruction were defined as either single-level [airway obstruction observed in the retropalatal (RP) or retroglossal (RG) regions] or multi-level (airway obstruction observed in both RP and RG regions). The RP region is defined as the uvulo-palatal complex region, i.e. the airway from paranasal sinus to the tip of uvula. The RG region is defined as the tongue base area, i.e. airway from the tip of uvula to the lower border of hyoid bone. Degree of obstruction was categorized as partial or complete obstruction. Patterns of collapse included complete concentric collapse (CCC) or other patterns, e.g. antero-posterior (AP) or lateral collapses.

4. Data analyses

The commercial statistics software package SPSS version 18.0 (SPSS, Inc, an IBM Company, Chicago, Illinois, USA) was used for statistical analyses. We used the Pearson Chi-square test to assess the relationships between the predictor variables RDI, BMI, NC, and WC and the qualitative computerized tomographic OSA outcome variables [i.e. level (single-level or multi-level), degree (partial or complete), and pattern (CCC or other)]. A P value <0.05 was considered statistically significant for between-group comparisons and used for selecting terms as initial candidates for the bivariate logistic regression analysis. Finally, multivariate logistic regression analysis was employed to find independent associations between these two groups of variables using a forward, stepwise selection method.

Results

Fifty-eight adult patients with OSA were scanned during both awake states and apneic episodes. The mean ± standard deviation (SD) RDI of the patient subjects was 41.68 ± 28.55. The means ± SD
values of patient characteristics including BMI, NC, and WC were $27.80 \pm 5.43 \text{ kg/m}^2$, $38.3 \pm 4.3 \text{ cm}$, and $93.8 \pm 13.6 \text{ cm}$, respectively. During apneic episodes, we observed levels (single-level or multi-level), degrees (partial or complete), and patterns (CCC or other) of airway obstruction in the patients. Single-level obstructions in the RP region (Fig. 1) were observed in 44.8% of patients, while multi-level obstructions (mixed RP and RG obstruction) (Fig. 2) were found in 55.2%. CT images revealed anatomical findings related to narrowing or obstruction of the airways, e.g. enlarged soft palate and uvula (Fig. 1), tongue displacement (Fig. 2), and enlarged palatine tonsils (Fig. 3). Complete obstructions were observed more frequently than partial obstructions (74.1% vs 25.9%). Complete obstruction was commonly associated with CCC (53.4%), followed less frequently by complete AP collapse (19.0%) and complete lateral collapse (1.6%). CCC was observed to be multi-level (67.7%) and single-level (32.3%) presented in Figs. 4 and 5, respectively. Partial obstruction was most often associated with partial concentric collapse (73.3%), and less so with partial AP collapse (20.0%) and partial lateral collapse (0.7%). Three-dimensional images of the upper airways from different patients with partial obstructions in single- or multi-levels are presented in Fig. 6.

The quantitative terms of RDI, BMI, NC, and WC were converted to qualitative ones by constructing curves of diagnostic yield, i.e., a receiver operating characteristic (ROC) curve, to determine the optimal cut-off points for each variable to maximize its diagnostic yield. Tables 1-3 present comparisons of level of obstruction (single-level and multi-level), degree of obstruction (partial and complete), and pattern of collapse (CCC and other) among patients with lower and higher values of RDI (<30 and ≥30), BMI (<25 and ≥25 kg/m²), NC (<36 and ≥36 cm), and WC (<88 and ≥88 cm). No variables were found to significantly distinguish between the presence of single-level or multi-level obstructions in this study (Table 1). The presence of complete obstruction was statistically associated with one variable, as the upper airway completely collapsed more often in the patients with RDI ≥30 ($p = 0.001$) (Table 2). The presence of CCC was observed more frequently in patients with NC ≥36 cm ($p = 0.021$) and RDI ≥30 ($p = 0.009$) (Table 3). A forward stepwise, multivariate, logistic regression analysis showed that an RDI ≥30 [adjusted odds ratio (OR) = 6.33, 95% confidence interval (CI) = 1.55–25.90] was independently associated with the presence of complete obstruction (Table 2). Moreover, an RDI ≥30 (adjusted OR =
3.77, 95% CI = 1.02–13.91) was independently associated with the presence of CCC (Table 3). No independent association between RDI ≥30 and multi-level obstruction was observed in this study.

**Discussion**

The purpose of this study was to assess CT findings (i.e. level, degree, and pattern of upper airway obstruction) of patients with OSA during apneic episodes. The investigators hypothesized that CT combined with portable PSG may reveal more relevant upper airway pathology during these apneic episodes than during the awake state. This approach may avoid resource-intensive overnight stays and deliver more precise results on the location of obstructions. The specific aim of the study was to identify associations between RDI, BMI, NC, and WC (predictors) and CT findings (outcomes).

The most common level of upper airway obstruction was the uvulo-palatal complex region, followed by the tongue base area. Multi-level obstruction was more frequently observed during an apneic episode (55.2%) than in the awake state (14.7%). Complete obstruction was seen more often in patients with high RDI values. CCC was frequently observed during apneic episodes. We found that CT could demonstrate the presence of CCC in patients during sleep apnea and that this was significantly associated with severe OSA (RDI ≥30).

Previous studies investigated by DISE [21, 31] commonly found upper airway obstructions in the uvulo-palatal complex region. Several studies [21, 31, 32], which used DISE to assess the upper airway of patients, report a significant positive association between the occurrence of a multi-level collapse and the severity of OSA. However, higher values of RDI were not associated with the presence of multi-level obstruction in our study. This discrepancy might result from the differences in data acquisition between CT and DISE modalities. The super-fast, volumetric CT scanning performed in our study demonstrated multi-level obstruction in a single scan, whereas DISE investigations of different levels were not simultaneous since they used an endoscope inserted through the upper airway during each apneic episode. A multi-level approach to the surgical treatment of OSA [e.g. uvulopalatopharyngoplasty with surgery on the tongue, radiofrequency ablation, mid-line glossectomy, tongue advancement, or tongue suspension] is required when upper airway collapse occurs at several sites [33]. CT scanning during apnea may support the development of an adequate multi-level surgical plan. Ravesloot [31] reported that complete obstruction is associated with severe OSA, which our findings confirmed. Complete collapse
may be more difficult than partial collapse to correct with surgery, and similarly may limit the success of other non-CPAP therapy such as oral appliance use [21]. Hence, demonstrating complete collapse of the upper airway with CT may help clinicians to identify severe OSA. Previous studies found that the absence of palatal CCC during DISE may predict therapeutic success with implanted UAS [13, 34]. Visualizing CCC using CT may assist surgeons in predicting severe OSA and success of UAS implantation therapy, which is a good technique for treatment of AP collapse [34]. Nasal obstruction causes increased nasal resistance to airflow, which influences the patient’s initial acceptance of CPAP as treatment for OSA [35, 36]. To increase this acceptance, nasal surgery in the patients with nasal obstruction should be performed before CPAP treatment [37]. Our study scanned the upper airway from upper wall of nasal cavity to hyoid bone, a total length of about 16 cm. We found that 48.3% of patients with OSA had some nasal obstruction due to deviated nasal septum and/or turbinate hypertrophy. Therefore, a single CT scan can demonstrate anatomical deformities anywhere from the nasal cavity to the hypopharynx and thus assist surgeons in the selection of patients for nasal surgical procedures [1], e.g. septoplasty, nasal valve surgery, or turbinate reduction, prior to initiating CPAP.

Low-dose volumetric CT provides upper airway images which augment the physiologic data recorded by portable PSG. Super-fast volumetric scanning is a non-invasive technique (no need for contrast medium injection nor endoscope insertion) which reveals multi-level upper airway collapse with only a single axial scan (16 cm-wide coverage with 0.35 second per rotation). This reduces the risk of table movement (patients can maintain their sleep phase) and minimizes patients’ radiation exposure dose. CT images can be reconstructed as 3D geometric models which can be used for advanced computational fluid dynamic analyses to i) evaluate airflow characteristics inside the upper airway of patients with OSA [38-41], ii) assess outcomes of different treatment approaches (e.g. maxilla-mandibular advancement surgery [19, 42, 43], oral appliance [18], and mandibular advancement devices [44]), and iii) for planning upper airway surgery [45]. For CT scanning, utilizing both supine and non-supine positions should be considered [46] because patient position affects the patterns of the upper airway collapse. However, the present study assessed airway changes only in supine position, which is generally the most symptomatic for patients with OSA. The studies were performed during the early night, allowing us to observe the effects of airway obstruction in patients only during non-rapid eye movement (non-REM)-
related events similar to the timing of other OSA image-based diagnostic modalities (MRI and DISE). Only full-night PSG can comprehensively perform REM sleep analysis. Despite this, the proposed combination of CT and portable PSG demonstrated abnormalities of upper airway morphology which are likely related to OSA. The efficacy of the combined CT and portable PSG for assisting clinicians for OSA management decisions should be studied in future work.

Conclusion

CT scanning during apneic episodes revealed multi-level obstruction better than scanning while awake. High values of RDI were independently associated with complete obstruction and complete concentric collapse of the upper airway during sleep apnea. Associations between computerized tomographic upper airway measures (e.g. length, cross-sectional area, and volume of upper airway) and RDI will be examined further in future studies.

Acknowledgments

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Table 1. Univariate and multivariate logistic regression analyses for predicting the presence of multi-level obstruction.

<table>
<thead>
<tr>
<th>Level of obstruction†</th>
<th>Multi-level</th>
<th>Single-level</th>
<th>P-value</th>
<th>Crude OR (95% CI)</th>
<th>Adjusted OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDI</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>≥30</td>
<td>22 (68.8)</td>
<td>18 (69.2)</td>
<td>0.969</td>
<td>0.98 (0.32-2.99)</td>
<td>-</td>
</tr>
<tr>
<td>&lt;30*</td>
<td>10 (31.3)</td>
<td>8 (30.8)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>BMI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥25</td>
<td>23 (71.9)</td>
<td>18 (69.2)</td>
<td>0.826</td>
<td>1.14 (0.37-3.53)</td>
<td>-</td>
</tr>
<tr>
<td>&lt;25*</td>
<td>9 (28.1)</td>
<td>8 (30.8)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>NC</td>
<td></td>
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</tr>
<tr>
<td>≥36</td>
<td>24 (75.0)</td>
<td>21 (84.0)</td>
<td>0.408</td>
<td>0.57 (0.15-2.17)</td>
<td>-</td>
</tr>
<tr>
<td>&lt;36*</td>
<td>8 (25.0)</td>
<td>4 (16.0)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>WC</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>≥88</td>
<td>22 (68.8)</td>
<td>20 (80.0)</td>
<td>0.339</td>
<td>0.55 (0.16-1.89)</td>
<td>-</td>
</tr>
<tr>
<td>&lt;88*</td>
<td>10 (31.3)</td>
<td>5 (20.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Data was presented in number (percent).
*Reference
OR = Odds ratio, CI = Confidence interval, RDI = Respiratory disturbance index, BMI = Body-mass index, NC = Neck circumference, WC = Waist circumference.
Table 2. Univariate and multivariate logistic regression models for predicting the presence of complete obstruction.

<table>
<thead>
<tr>
<th>Degree of obstruction†</th>
<th>Complete</th>
<th>Partial</th>
<th>P-value</th>
<th>Crude OR (95% CI)</th>
<th>Adjusted OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDI</td>
<td></td>
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<tr>
<td>≥30</td>
<td>35 (81.4)</td>
<td>5 (33.3)</td>
<td>0.001</td>
<td>8.75 (2.34-32.76)</td>
<td>6.33 (1.55-25.90)</td>
</tr>
<tr>
<td>&lt;30*</td>
<td>8 (18.6)</td>
<td>10 (66.7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>≥25</td>
<td>30 (69.8)</td>
<td>11 (73.3)</td>
<td>0.794</td>
<td>0.84 (0.23-3.13)</td>
<td>-</td>
</tr>
<tr>
<td>&lt;25*</td>
<td>13 (30.2)</td>
<td>4 (26.7)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>NC</td>
<td></td>
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<tr>
<td>≥36</td>
<td>35 (83.3)</td>
<td>10 (66.7)</td>
<td>0.174</td>
<td>2.50 (0.65-9.60)</td>
<td>-</td>
</tr>
<tr>
<td>&lt;36*</td>
<td>7 (16.7)</td>
<td>5 (33.3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥88</td>
<td>32 (76.2)</td>
<td>10 (66.7)</td>
<td>0.472</td>
<td>1.60 (0.44-5.80)</td>
<td>-</td>
</tr>
<tr>
<td>&lt;88*</td>
<td>10 (23.8)</td>
<td>5 (33.3)</td>
<td></td>
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</tbody>
</table>

†Data was presented in number (percent).
*Reference
OR = Odds ratio, CI = Confidence interval, RDI = Respiratory disturbance index, BMI = Body-mass index, NC = Neck circumference, WC = Waist circumference.
Table 3. Univariate and multivariate logistic regression models for predicting the presence of complete concentric collapse (CCC)

<table>
<thead>
<tr>
<th>Pattern of obstruction†</th>
<th>CCC</th>
<th>Other</th>
<th>P-value</th>
<th>Crude OR (95% CI)</th>
<th>Adjusted OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDI</td>
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<tr>
<td>≥30</td>
<td>26 (83.9)</td>
<td>14 (51.9)</td>
<td>0.009</td>
<td>4.83 (1.43-16.34)</td>
<td>3.77 (1.02-13.91)</td>
</tr>
<tr>
<td>&lt;30*</td>
<td>5 (16.1)</td>
<td>13 (48.1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>≥25</td>
<td>25 (80.6)</td>
<td>16 (59.3)</td>
<td>0.074</td>
<td>2.87 (0.88-9.29)</td>
<td>-</td>
</tr>
<tr>
<td>&lt;25*</td>
<td>6 (19.4)</td>
<td>11 (40.7)</td>
<td></td>
<td></td>
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<tr>
<td>NC</td>
<td></td>
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</tr>
<tr>
<td>≥36</td>
<td>28 (90.3)</td>
<td>17 (65.4)</td>
<td>0.021</td>
<td>4.94 (1.17-20.83)</td>
<td>-</td>
</tr>
<tr>
<td>&lt;36*</td>
<td>3 (9.7)</td>
<td>9 (34.6)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>WC</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥88</td>
<td>26 (83.9)</td>
<td>16 (61.5)</td>
<td>0.057</td>
<td>3.25 (0.94-11.24)</td>
<td>-</td>
</tr>
<tr>
<td>&lt;88*</td>
<td>5 (16.1)</td>
<td>10 (38.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Data was presented in number (percent).
*Reference
OR = Odds ratio, CI = Confidence interval, RDI = Respiratory disturbance index, BMI = Body-mass index, NC = Neck circumference, WC = Waist circumference.
Figure 1. Single-level complete obstructions in the RP region (arrows) presented as sagittal and 3D images in the same patient. A, sagittal CT during awake state; B, sagittal CT during apneic episode; C, 3D image during awake state; D, 3D image during apneic episode.

Figure 2. Multi-level complete obstructions in the RP and RG regions (arrows) presented as sagittal and 3D images in the same patient. A, sagittal CT during awake state; B, sagittal CT during apneic episode; C, 3D image during awake state; D, 3D image during apneic episode.

Figure 3. Complete obstruction related to enlarged palatine tonsils (arrows) presented as axial cross-sectional and 3D images in the same patient. A, axial CT during awake state; B, axial CT during apneic episode; C, 3D image during awake state; D, 3D image during apneic episode.

Figure 4. Multi-level complete concentric collapse (CCC) in the RP and RG regions (arrows) presented as axial cross-sectional and 3D images in the same patient. A, axial CT at RP region during awake state; B, axial CT at RP region during apneic episode; C, axial CT at RG region during awake state; D, axial CT at RG region during apneic episode; E, 3D image during awake state; F, 3D image during apneic episode.

Figure 5. Single-level complete concentric collapse (CCC) in the RP region (arrows) presented as axial cross-sectional and 3D images in the same patient. A, axial CT during awake state; B, axial CT during apneic episode; C, 3D image during awake state; D, 3D image during apneic episode.

Figure 6. Partial obstructions scanned during apneic episodes in different patients. A, single-level partial obstruction; B, multi-level partial obstruction.