**JAMA Otolaryngology–Head & Neck Surgery** | Original Investigation

# Ultrasonographic Evaluation of Upper Airway Structures in Children With Obstructive Sleep Apnea

Che-Yi Lin, MD, MMS; Chun-Nan Chen, MD; Kun-Tai Kang, MD, MPH; Tzu-Yu Hsiao, MD, PhD;
Pei-Lin Lee, MD, PhD; Wei-Chung Hsu, MD, PhD

Supplemental content

**IMPORTANCE** Adenotonsillar hypertrophy is an important cause of obstructive sleep apnea (OSA) in children. However, residual OSA and abnormal polysomnographic findings have been reported in up to 75% of cases after adenotonsillectomy. Other anatomical and functional factors that influence upper airway structures, including the lateral pharyngeal wall, have rarely been studied in children with OSA.

**OBJECTIVE** To determine whether the upper airway structures can be evaluated using head and neck ultrasonography and if there is an association between the ultrasonographic measurements for these structures and severity of OSA seen on polysomnography in children.

**DESIGN, SETTING, AND PARTICIPANTS** Prospective, single-center, observational study of 82 children younger than 18 years with a diagnosis of sleep-disordered breathing (20 with primary snoring, 62 with OSA, as determined by the apnea-hypopnea index) and admitted to a tertiary teaching hospital for adenotonsillectomy.

**EXPOSURES** Ultrasonography and polysomnography.

**MAIN OUTCOMES AND MEASURES** Ultrasonographic measurements of upper airway structures.

**RESULTS** Of the 82 children studied, 62 (76%) were boys; mean (SD) age, 7.7 (6.2). There was no significant difference found in tonsillar dimensions or volume between the children with OSA and those with primary snoring. However, the mean (SD) total lateral pharyngeal wall and the total neck thicknesses at the retropalatal level were both greater in children with OSA than in those with primary snoring at rest (24.9 [4.4] mm vs 21.3 [2.6] mm; difference, 3.61 mm; 95% CI of difference, 1.48-5.74 mm for lateral pharyngeal wall; and 59.9 [14.4] mm vs 49.9 [11.2] mm; difference, 10.9 mm, 95% CI of difference, 3.8-17.9 mm for the total neck).

**CONCLUSIONS AND RELEVANCE** Estimated tonsillar volume measured using ultrasonography had no relationship with the apnea-hypopnea index in childhood sleep-disordered breathing. However, the lateral pharyngeal wall was significantly thicker in children with OSA than in those with primary snoring at rest.

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**Author Affiliations:** Department of Otolaryngology, College of Medicine, National Taiwan University, and National Taiwan University Hospital and Children's Hospital, Taipei, Taiwan (Lin, Chen, Kang, Hsiao, Hsu); Institute of Clinical Medicine, College of Medicine, National Taiwan University, Taipei, Taiwan (Lin); Department of Otolaryngology, Taipei Hospital, Ministry of Health and Welfare, New Taipei City, Taiwan (Kang); Sleep Center, National Taiwan University Hospital, Taipei, Taiwan (Lee, Hsu); Department of Internal Medicine, National Taiwan University Hospital, Taipei, Taiwan (Lee).

**Corresponding Author**: Wei-Chung Hsu, MD, PhD, Department of Otolaryngology, National Taiwan University Hospital, No. 7 Chung-Shan South Road, Taipei, Taiwan (hsuwc@ntu.edu.tw).

Sleep-disordered breathing (SDB) includes a disease spectrum that ranges from primary snoring and upper airway resistance syndrome to complete upper airway obstruction, known as obstructive sleep apnea (OSA).[1] The prevalence of SDB in children ranges from 9% to 12%,[2,3] but most pediatric cases involve primary snoring or upper airway resistance syndrome, and only 1% to 3% are OSA.[4]

Direct oropharyngeal examinations are currently used to evaluate the grade of tonsillar hypertrophy, the position and size of the tongue and palate, and the lateral narrowing of the pharyngeal space attributable to tissue impingement in cases of pediatric SDB.[4] Cephalometry provides a lateral reflection of the dimensions of the soft tissue, bony structures, and angle of the upper airway.[5] It also enables evaluation of the size and proportions of adenoids in relation to the nasopharynx (adenoidal-nasopharyngeal ratio; ANR) but is limited to assessment of the parapharyngeal structures or tonsil size. Computed tomography and magnetic resonance image (MRI) provide more accurate views in 3 dimensions and allow estimation of airway volume,[6] but they are rarely used owing to their radiation exposure or high cost and prolonged noise during examination.[7,8] Drug-induced sleep endoscopy allows real-time visualization of the narrowing in upper airway[9,10] but is invasive and does not provide information for assessment of extraluminal changes.

Several mechanisms contribute to development of OSA in children, including functional anatomic and neuromuscular factors that may restrict upper airway patency.[11] Studies have demonstrated that adenotonsillar hypertrophy is an important cause of OSA in children.[12,13] Therefore, adenotonsillectomy is considered the first-line treatment for children with OSA.[14] However, only 27.2% to 50.9% of patients achieve complete resolution of symptoms,[15] and residual OSA or abnormal polysomnographic (PSG) findings have been reported in 31% to 75% of cases after adenotonsillectomy.[12,16] Obesity is also thought to be involved in development of OSA and to affect treatment outcomes.[12,17] The soft-tissue components of the parapharyngeal space, such as the lateral pharyngeal wall (LPW), soft palate, and tongue, have been thought to be an important factor that may influence the upper airway structures in adult OSA,[18] but they have rarely been studied in childhood OSA.

Compared with other imaging modalities used for sleep studies, ultrasonography (US) has potential benefits for the pediatric population owing to its noninvasiveness and lack of radiation exposure. The objectives of the present study were to evaluate the upper airway structures in children using head and neck US and to investigate the association between US measurements of these structures and severity of OSA seen on PSG in children.

## Methods

This prospective observational study was approved by the Ethics Committee of the National Taiwan University Hospital. All participants or their legal guardians provided written informed consent.

### Key Points

**Questions** Can the upper airway structures be evaluated using head and neck ultrasonography, and is there an association between ultrasonographic measurements of these structures and severity of obstructive sleep apnea seen on polysomnography in children?

**Findings** In this single-center, observational study of 82 children diagnosed as having sleep-disordered breathing and scheduled for adenotonsillectomy, there was no significant difference in tonsillar dimensions or volume between those with obstructive sleep apnea (n = 62) and those with primary snoring (n = 20). However, the mean thicknesses were greater for both total lateral pharyngeal wall (3.61 mm thicker) and total neck at the retropalatal level (10.84 mm thicker) in children with obstructive sleep apnea than in those with primary snoring.

**Meanings** Ultrasonography can be used to evaluate dynamic upper airway structures in children.

### Study Population and Demographics

Children younger than 18 years diagnosed with SDB on the basis of OSA-related symptoms and PSG who were admitted to our institution for adenotonsillectomy from January 2016 to February 2017 were recruited. The exclusion criteria were as follows: craniofacial anomaly or syndromic disorder, craniofacial neoplasm, history of craniofacial surgery (including adenoidectomy and tonsillectomy), neurologic disorder other than OSA, cervical rigidity limiting extension or flexion of the head and neck, and need for ventilatory support. Children who refused examination or cooperated poorly were also excluded.

### Physical Examination

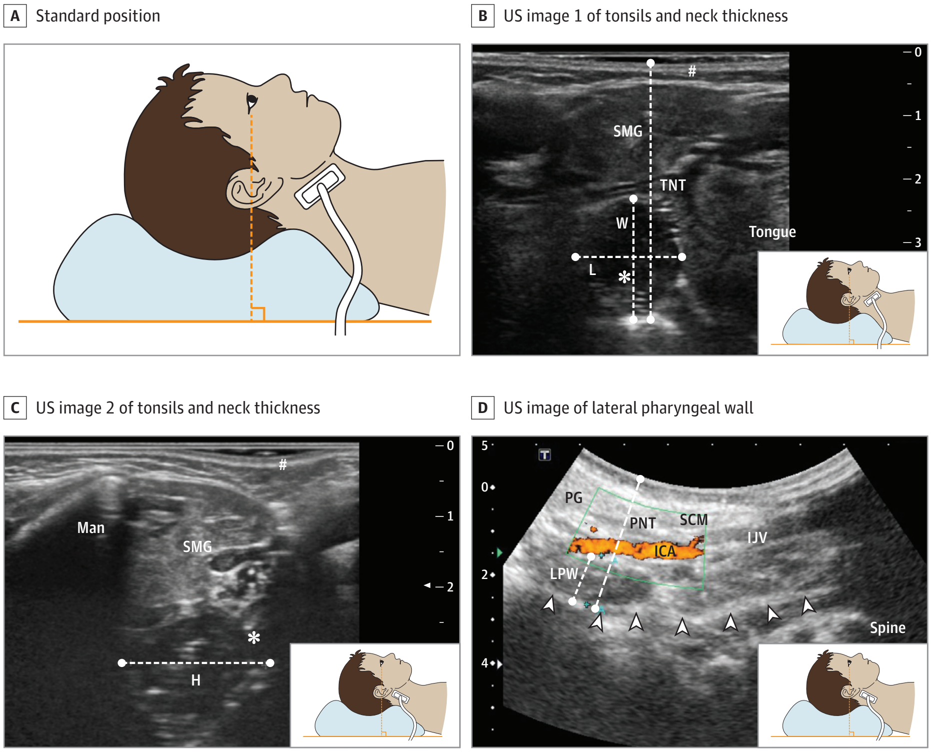
A medical history was obtained, and a physical examination was performed for each child. Children with symptoms suggesting SDB were defined as those who snored and had at least 1 of the following symptoms: mouth breathing, increased respiratory effort, persistent body movement, enuresis, daytime sleepiness, daytime inattention, and hyperactivity. Growth status was assessed using body height and weight, body mass index (BMI), and BMI percentile. Obesity was defined as a BMI above the 95th percentile, according to age and sex.

The pharyngeal airway was evaluated by direct inspection of the oral cavity and oropharyngeal area. Tonsil size was graded using the Brodsky grading scale (0-4).[19] Grades 3 and 4 were defined as tonsillar hypertrophy. The Friedman tongue position was evaluated in each child.[20] Cephalometry was applied to determine the Fujioka ANR. An ANR of 0.67 or greater was considered to indicate adenoid hypertrophy.[21,22]

### Polysomnography

Each child underwent overnight PSG (Embla sleep recorder; Natus Medical Inc) at a sleep laboratory. Sleep stages and respiratory events were evaluated using the 2012 American Academy of Sleep Medicine pediatric scoring criteria.[23] The apnea-hypopnea index (AHI) was used to categorize the children as primary snorers (AHI <1) or as having OSA (AHI ≥1).

Figure 1. Protocol for Ultrasonographic (US) Measurement of the Upper Airway Structures in a Child



A, In the standard position during US scanning, the neck of the patient is slightly extended by placing a soft pad beneath the neck, positioning the infraorbital meatal baseline perpendicular to the scanning table. B and C, Representative US images of the tonsils (asterisks) and neck thickness at the tonsillar level. The maximum length (L) and width (W) of the tonsils are recorded on the transverse scan through the submandibular gland (SMG) by placing the linear transducer parallel to the mandible (Man); the maximal height (H) of the tonsils is recorded vertically to the Man. The distance between the skin and inner surface of the tonsil in the transverse view represents the neck thickness at the tonsillar level (TNT). The proportion of the tonsillar width to the neck thickness in the transverse view is defined as the T/N ratio (W/TNT, %). Note that the transducer for these images was only lightly in contact with the skin's surface, with only minimal jelly applied (pound sign) between the transducer and skin during scanning. D, A representative US image of the lateral pharyngeal wall (LPW) in a longitudinal section. The inner surface of the pharyngeal mucosa has a curvilinear hyperechoic appearance because of the air-mucosa interface (arrowheads), which was confirmed by the vibration of swallowing. The maximum distance between the inner margin of the internal carotid artery and the inner surface of the LPW complex was measured and recorded on still US images (short dotted line). The distance between the skin to the inner surface of the LPW (long dashed line) represents the parapharyngeal neck thickness (PNT). ICA indicates internal carotid artery; IJV, internal jugular vein; PG, parotid gland; SCM, sternocleidomastoid muscle.

## US Examination of the Head and Neck

### Devices

All children underwent US examination and measurement of their upper airway structures before surgery. An Aplio-300 device (Toshiba Medical Systems) was used with a linear transducer (PLT-1204BX) at a frequency of 14 MHz, and a convex transducer (PVT-375BT) at 6 MHz in grayscale 2-dimensional mode. All measurements were performed by the same operator, who was blinded to the physical examination findings, PSG data, and clinical results.

### Positioning

Each child lay supine on the examination couch at awake status. The neck was slightly extended by placing a soft pad under the neck, and the infraorbital-meatal baseline was perpendicular to the scanning table (**Figure 1**A).

### Scanning Technique

The soft-tissue structures surrounding the upper airway were measured at the level of the oropharynx from the tonsillar region to the retropalatal parapharyngeal region. A summary of the anatomic definitions and measurements taken during US is presented in Figure 1B-D.

The maximal dimensions of the tonsils were obtained with the linear transducer parallel to the mandible just below the submandibular gland (length [L] and width [W]) and vertically to the mandible in the longitudinal view (height [H]). Measurement of soft tissue at the tonsillar level representing the *tonsillar neck thickness* (TNT) was defined as the distance from the skin to the echogenic inner surface of the tonsil in the transverse view. The *tonsillar-neck ratio* (T/N ratio), defined as the proportion of the tonsillar width to the neck thickness (W/TNT × 100%) was calculated (Figure 1B and C). To estimate the tonsillar volume, we hypothesized that tonsils are spherical.[24] The estimated tonsillar volume was calculated as follows: $4/3\pi L \times W \times H$.

We used the US methods devised by Liu et al to measure the parapharyngeal contents.[25] The oblique coronal plane of the parapharyngeal space was scanned with the convex transducer placed longitudinally on the lateral side of the neck, just below the lateral border of the occipital bone. The long axis of the internal carotid artery was identified in color mode. The LPW appeared as an echogenic air-mucosa interface on the US image, whereas the lumen of the pharynx was completely obscured by swallowed gas. The real-time vibration of swallowing further confirmed the location of the lumen of the LPW. While the child was breathing at rest, the distance between the internal carotid artery and echogenic surface of the pharynx represented LPW thickness in the oblique coronal plane. The distance from the echogenic surface of the pharynx to the skin was defined as the parapharyngeal neck thickness. The same views of the parapharyngeal space were also obtained during the Müller maneuver, in which forced inspiration is used to approach the reserve volume by maximal effort of inspiration within 3 seconds, with the mouth and nose closed. All measurements of the parapharyngeal structures were recorded on a frozen image with the LPW farthest away from the transducer, first at rest and then during the Müller maneuver (Figure 1D). To avoid any compressive effects, the surface of the transducer was only in light contact with the skin with minimal conductive jelly in between. For standardization, all measurements were marked central to the white echogenic line, which was vertical to the surface of the transducer.

### Reproducibility Test

The interoperator coefficient of variation was determined for the US measurements performed in 10 children by 2 independent operators (C.-Y.L., C.-N.C.), who were otolaryngologists well experienced in US techniques; each operator was blinded to the examination results of the other. Similarly, the intraoperator coefficient of variation was determined for 1 operator (C.-Y.L.), who repeated the measurements on each child 3 times.

## Statistical Analysis

The data were analyzed using SPSS Statistics, version 22.0 (IBM Corp). Continuous data are expressed as the mean and standard deviation and were compared between the participants diagnosed with primary snoring and those with OSA using the 2-sample *t* test. Categorical data are presented as the frequency and proportion and were compared between the study groups (primary snoring vs OSA) using the Fisher exact test. Pearson correlations between LPW thickness and the log values of AHI plus 0.01 (AHI + 0.01) were calculated. A series of multivariate logistic regression analyses, adjusted for possible confounders, including age, sex, BMI percentile, neck circumference, tonsillar hypertrophy, Friedman tongue position, and adenoid hypertrophy, was performed to identify any US parameters independently associated with the risk of OSA. All statistical analyses were 2-tailed. The result was considered statistically significant when the associating 95% confidence intervals (CIs) did not included 0 for continuous variables or 1 for binary outcomes. No adjustment of multiple testing (eg, Bonferroni correction) was made.

We assumed that the mean (SD) values of total tonsillar volume in the 20 children with primary snoring and 62 with OSA were 60 (25) mL and 64 (20) mL, respectively. The achieved power was 10.4% given the alpha level of .05. The assumed values of total LPW at rest in the primary snoring and OSA groups were 21.0 (2.5) mm and 25.0 (4.5) mm, respectively. The achieved power was 98.8% given the alpha level of .05.

Table 1. Demographic and Clinical Characteristics of the Study Participants

| Variable | Participants (N = 82)[a] |
|---|---|
| Age, y | 7.7 (2.8) |
| Male sex | 62 (76) |
| BMI percentile, % | 57.3 (32.9) |
| Obesity | 17 (20.7) |
| Tonsillar hypertrophy (grades 3-4) | 59 (72.0) |
| Friedman tongue position ≥3 | 70 (85.4) |
| Adenoid hypertrophy (ANR ≥0.67) | 57 (69.5) |
| PSG findings, % | |
| Sleep efficiency | 88.5 (7.5) |
| AHI, events/h | 9.0 (17.4) |
| Mean $SpO_2$ | 97.3 (1.6) |
| Lowest $SpO_2$ | 88.9 (6.7) |
| $SpO_2$ <90 | 0.9 (3.8) |
| Arousal index, events/h | 6.4 (8.2) |
| Comorbid medical condition | |
| Allergic rhinitis | 78 (95.1) |
| Otitis media with effusion | 16 (19.5) |
| Asthma | 9 (11.0) |

Abbreviations: AHI, apnea-hypopnea index; ANR, adenoidal nasopharyngeal ratio; BMI, body mass index; OSA, obstructive sleep apnea; PSG, polysomnography; SD, standard deviation; $SpO_2$, pulse oximeter oxygen saturation.

[a] Continuous data are presented as mean (SD) values; otherwise, data are reported as number (percentage).

# Results

## Demographic Characteristics

Eighty-two children with SDB underwent evaluation of their upper airway structures with US of the head and neck successfully before undergoing adenotonsillectomy. The male to female ratio was 3:1; 62 (76%) of the children were boys. The mean (SD) age was 7.7 (2.8) years (range, 3.5-16.2 years). The demographic and clinical characteristics of the study participants are detailed in **Table 1**.

## PSG According to OSA Severity

The study participants were categorized into a primary snoring group (AHI <1, n = 20), a mild OSA group (1 ≤ AHI < 5, n = 33), or a moderate/severe OSA group (AHI ≥5, n = 29). The demographic and clinical characteristics of the 3 groups are reported in eTable 1 in the Supplement. There was no significant difference in age and sex among groups (all the 95% CIs included 0). However, the moderate/severe OSA group had a higher prevalence of obesity than the primary snoring group. There were no participants with asthma in the moderate/severe OSA group.

Table 2. Parameters Measured by Ultrasonography at the Tonsillar Level

| Variable | Patient Group[a] Primary Snoring | Patient Group[a] OSA (AHI≥1) | Difference (95% CI)[b] |
|---|---|---|---|
| Cases, No. | 20 | 62 | NA |
| Right tonsillar length, mm | 17.4 (2.6) | 18.1 (2.7) | 0.7 (−0.7 to 2.0) |
| Right tonsillar width, mm | 17.3 (2.8) | 17.7 (2.6) | 0.4 (−1.0 to 1.8) |
| Right tonsillar height, mm | 20.9 (4.0) | 22.1 (3.3) | 1.2 (−0.6 to 3.1) |
| Right tonsillar volume, mL | 27.8 (13.8) | 30.5 (10.6) | 2.7 (−3.3 to 8.7) |
| Left tonsillar length, mm | 17.9 (2.4) | 18.6 (2.5) | 0.7 (−0.6 to 2.0) |
| Left tonsillar width, mm | 18.3 (2.7) | 18.7 (2.4) | 0.4 (−0.9 to 1.7) |
| Left tonsillar height, mm | 22.4 (3.1) | 22.1 (3.1) | −0.3 (−2.0 to 1.3) |
| Left tonsillar volume, mL | 31.8 (12.3) | 33.1 (10.5) | 1.3 (−4.5 to 7.1) |
| Total tonsillar volume, mL | 59.7 (24.7) | 63.6 (19.6) | 3.9 (−7.1 to 15.0) |
| Tonsil to neck ratio, % | 41.3 (5.1) | 40.1 (5.8) | −1.2 (−4.1 to 1.8) |

Abbreviations: AHI, apnea-hypopnea index; NA, not applicable; OSA, obstructive sleep apnea.

[a] Unless otherwise indicated, data are reported as mean (SD) values.

[b] Independent-samples *t* test.

Table 3. Parameters Measured by Ultrasonography at the Retropalatal Level

| Variable | Patient Group[a] Primary Snoring | Patient Group[a] OSA (AHI≥1) | Difference (95% CI)[b] |
|---|---|---|---|
| Cases, No. | 20 | 62 | NA |
| Total neck thickness (R), mm | 49.0 (11.2) | 59.9 (14.4) | 10.8 (3.8 to 17.9) |
| Total neck thickness (M), mm | 76.9 (8.7) | 88.5 (15.7) | 11.7 (3.2 to 20.2) |
| Total neck thickness change (M − R), mm | 4.8 (2.9) | 9.4 (4.4) | 4.6 (2.2 to 7.0) |
| Percentage neck thickness change ([M − R]/R) | 10.6 (8.0) | 15.4 (7.5) | 4.8 (0.3 to 9.3) |
| Right LPW (R), mm | 10.5 (1.7) | 12.2 (2.3) | 1.7 (0.6 to 2.8) |
| Left LPW (R), mm | 10.7 (1.2) | 12.7 (2.4) | 2.0 (0.8 to 3.1) |
| Total LPW (R), mm | 21.3 (2.6) | 24.9 (4.4) | 3.6 (1.5 to 5.7) |
| Right LPW (M), mm | 11.7 (1.7) | 14.5 (2.8) | 2.8 (1.3 to 4.4) |
| Left LPW (M), mm | 12.4 (1.4) | 15.3 (3.1) | 2.9 (1.3 to 4.6) |
| Total LPW (M), mm | 24.1 (2.9) | 29.9 (5.5) | 5.8 (2.8 to 8.8) |
| LPW change (M − R), mm | 2.8 (1.4) | 4.5 (2.6) | 1.7 (0.2 to 3.1) |
| Percentage LPW change ([M − R]/R) | 13.6 (7.3) | 18.0 (9.8) | 4.5 (−1.1 to 10.1) |

Abbreviations: AHI, apnea-hypopnea index; LPW, lateral pharyngeal wall; M, Müller; NA, not applicable; OSA, obstructive sleep apnea; R, rest.

[a] Unless otherwise indicated, data are reported as mean (SD) values.

[b] Independent-samples *t* test.

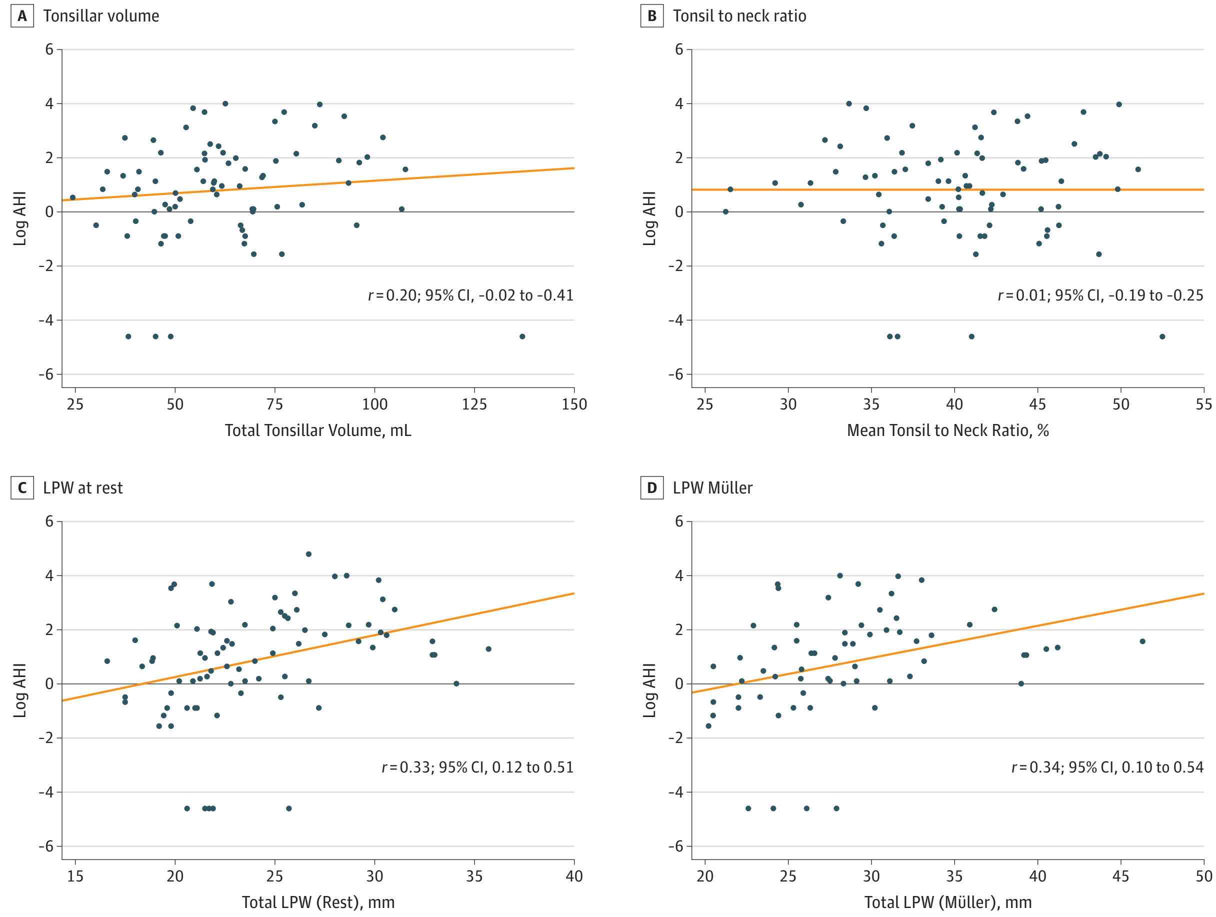
## US Measurement of Upper Airway Structures

**Tables 2** and **3** summarize the US data obtained for the upper airway structures according to the presence or absence of OSA. At the tonsillar level, there was no statistically significant difference in tonsillar measurements (L, W, H) between the primary snoring and OSA groups (all the 95% CIs included 0). Furthermore, there was no significant difference in the estimated tonsillar volume or mean T/N ratio between the groups (all the 95% CIs included 0, Table 2). The results at the tonsillar level by OSA severity are detailed in eTable 2 in the Supplement. No difference was found among the 3 OSA groups.

At the retropalatal level, the mean total neck thickness of the parapharyngeal space both at rest and during the Müller maneuver were significantly greater in children with OSA than in those with primary snoring (59.9 mm vs 49.0 mm; difference, 10.9 mm; 95% CI of difference 3.8-17.9 mm at rest; and 88.5 mm vs 76.9 mm; difference, 11.6 mm; 95% CI of difference, 3.2-20.2 mm during the Müller maneuver). The change in total neck thickness and the percentile change were also significantly higher in children with OSA than in those with primary snoring (9.4 mm vs 4.8 mm; difference, 4.6 mm; 95% CI of difference, 2.2-7.0 mm for total neck thickness; and 15.4% vs 10.6%; difference, 4.8%; 95% CI of difference, 0.3%-9.3% for percentile change). The total bilateral (ie, right and left) LPW thickness was significantly greater in children with OSA than in those with primary snoring, both at rest and during the Müller maneuver (24.9 mm vs 21.3 mm; difference, 3.6 mm; 95% CI of difference, 1.5-5.7 mm at rest; and 29.9 mm vs 24.1 mm; difference, 5.8 mm; 95% CI of difference, 2.8-8.8 mm during the Müller maneuver). The total change in bilateral LPW thickness between the resting state and during the Müller maneuver was greater in children with OSA than in those with primary snoring (4.5 mm vs 2.8 mm; change of 1.7 mm; 95% CI of change, 0.2-3.1 mm), even though the percentile change was not significantly different (18.0% vs 13.6%; difference, 4.4%; 95% CI of difference, −1.1% to 10.1%) (Table 3). eTable 3 in the Supplement details the results at the retropalatal level by OSA severity. Most parameters were significantly different between primary snoring and mild OSA groups and between primary snoring and moderate/severe OSA groups (most of the 95% CIs did not include 0). However, no difference between mild OSA and moderate/severe OSA was found (all of the 95% CIs included 0).

Pearson correlations for the log AHI values and LPW thickness are shown in **Figure 2**. The total tonsillar volume and mean T/N ratio were not correlated with the AHI (*r* = 0.20; 95% CI,

Figure 2. Pearson Correlations



Illustrated are the Pearson correlations between the log AHI value and the total tonsillar volume (A), the mean tonsil to neck ratio (B), total LPW thickness at rest (C), and total LPW thickness during the Müller maneuver (D). AHI indicates apnea-hypopnea index; LPW, lateral pharyngeal wall.

−0.02 to 0.41; and *r* = 0.01; 95% CI, −0.19 to 0.25, respectively). In contrast, the total LPW thickness, both at rest and during the Müller maneuver, was positively correlated with the AHI values (*r* = 0.33; 95% CI, 0.12-0.51; and *r* = 0.34; 95% CI, 0.10-0.54, respectively).

### Independent Associations Between US Parameters and OSA

The results of the multivariate logistic regression analyses are detailed in eTable 4 in the Supplement. After adjusting for sex, age, BMI percentile, tonsillar grade, Friedman tongue position, and adenoid hypertrophy, our data showed that total neck thickness and change in neck thickness at the retropalatal level between the resting position and during the Müller maneuver were independent structural risk factors for OSA (odds ratio [OR], 1.08; 95% CI, 1.01-1.15 at rest; and OR, 1.46; 95% CI, 1.07-2.00 during the Müller maneuver). The LPW thickness, both at rest and during the Müller maneuver, was also a positive independent structural risk factor for OSA (ORs ranged from 1.47 to 2.49, and the 95% CIs did not include 1), although the percentile of the change in LPW thickness between measurement at rest and during the Müller maneuver had no association with childhood OSA. The other variables, including all the tonsillar parameters, had no significant association with childhood OSA.

### Reproducibility

In a 2-way random effects model, the intraclass correlations for interoperator reliability were 0.974 (95% CI, 0.900-0.994), 0.928 (95% CI, 0.749-0.982), and 0.976 (95% CI, 0.911-0.994) for the right LPW, left LPW, and total LPW, respectively. The intraclass correlations for intraoperator reliability were 0.988 (95% CI, 0.967-0.997) and 0.967 (95% CI, 0.911-0.991) for the right LPW and left LPW, respectively.

## Discussion

According to recent studies, upper airway structure and neuromuscular control are the major mechanisms of OSA in both adults and children.[5,26] While hypertrophy of the adenoids and tonsils remains the primary cause of obstruction at the level of the nasopharynx and oropharynx in children,[17] the extraluminal lymphoid tissue, muscle, and parapharyngeal fat pad may also play a role in the maintenance of muscle tone and patency of the upper airway in the lateral dimension.[26]

Ultrasonography is becoming the most useful imaging tool for bedside measurement of the head and neck as well as the upper airway structures. In 2000, Siegel et al[27] reported the first use of real-time US in 5 patients. Ultrasonography of the pharynx was synchronized with PSG, which enabled the apneic events recorded by PSG to be correlated with the simultaneous real-time US findings for the trans-submental tongue base. The reliability of US measurement has been confirmed by several studies. Liu et al[25] reported a good correlation between US and MRI measurements of the LPW and also found that the LPW was thicker in adults with OSA when measured by US. Prasad et al[28] also confirmed the reliability of US measurements of most head and neck structures using computed tomography. Using US measurements, Lahav et al[29] reported that the distance of the lingual arteries through the tongue base correlated with the severity of OSA in adults. Shu et al[30] reported significant shortening of the retropalatal region during the Müller maneuver using submental US measurement in adults with severe OSA and also provided good prediction models for severe OSA with adjustment for neck circumference. Using submental US, Chen et al[31] determined that tongue-base thickness and changes induced by the Müller maneuver are related to OSA in adults.

In addition to the benefit of operating in real time, US has the advantages of being noninvasive and nonirradiating, and it produces better image resolution (with fewer artifacts) of the anatomic structures of the head and neck in children than in adults because children have thinner soft tissue and less adipose tissue. In our study, we believed that the LPW and tonsils were the ideal regions for US evaluation of the upper airway structures in children because the transducer could be applied directly to these areas in the lateral cervical region, and the structures could be detected accurately by identifying specific landmarks in the lateral neck. To our knowledge, this is the first study to demonstrate the use of US imaging for assessment of the upper airway structures in pediatric OSA.

The influence of tonsil size on OSA in children is variable and remains controversial. Currently, tonsil size is usually assessed using the Brodsky grading scale.[19] In several studies, tonsillar hypertrophy has been reported to be a predictor of OSA or as being associated with AHI in children, given that the tonsils physically occupy the airway space in the oropharynx.[32,33] However, in a systematic review, no relationship was found between the severity of OSA and tonsil size using the Brodsky grading scale.[34] This grading scale for tonsil size is a subjective tool for measurement of the oropharyngeal space; it does not measure true tonsil size and may not be accurate in uncooperative patients or if there is a strong swallowing reflex. Howard and Brietzke[35] published a study that revealed that the objective tonsillar weight was a predictor of severity of pediatric OSA. Our study demonstrates that the entire shape of the tonsil could be described and its size could be assessed quantitatively and accurately by using US. Specifically, the lateral dimension of each tonsil, including the portion buried within the tonsillar fossa, could be measured using a trans-submandibular approach during the transverse scan. Our data revealed that there was no difference in tonsillar volume, as measured by US, and also no difference in the proportions of the lateral dimensions of the tonsils as related to neck thickness (T/N ratio) between primary snorers and those with OSA. These quantitative results for tonsil size in children with SDB are in agreement with those of studies that reported no association of tonsillar grade with OSA in children.[34]

The LPW, which is composed of several muscle groups, including the hypoglossus, styloglossus, stylohyoid, stylopharyngeus, palatoglossus, palatopharyngeus, and pharyngeal constrictor muscles, could play a role in restriction of the upper airway in OSA. These muscles, together with the surrounding lymphoid tissue and fat pad, form the LPW complex. An increase in the size of the soft-tissue structures in the LPW complex may lead to a decrease in the volume of the upper airway, causing compression and collapse of the upper airway space by decreasing the lateral dimension of the upper airway lumen at the oropharyngeal level.[5,18,36] The Müller grade of the retropalatal space during fiber-optic endoscopy determines the collapsibility of the LPW and has been reported to be significantly high in nonobese adults.[37] Some MRI studies have also demonstrated that the soft-tissue mass surrounding the upper airway could reduce upper airway size in the retropalatal and retroglossal regions in patients with OSA in comparison with controls.[38] Lateral narrowing of the oropharyngeal space because of enlargement of the LPW may also be involved in the pathogenesis of OSA in adults and has been associated with an increased likelihood of the disease in adulthood.[39] Using US measurements, Liu et al[25] also found that the thickness of the LPW was an independent predictor of severity of OSA in men. The results of our study revealed that the LPW thickness was also higher in children with OSA, and both the LPW thickness during the Müller maneuver and the change in LPW thickness between the resting state and during the Müller maneuver were also associated with OSA in children, after adjustment for age, sex, BMI percentile, tonsillar grading, and adenoid size. Furthermore, the total neck thickness at the retropalatal level at rest and the change in thickness between the resting state and during the Müller maneuver were also associated with OSA in children. These ultrasonic findings (including those depicted in Figure 2C and D) demonstrate that the thicker the LPW is, the greater the collapse of the parapharyngeal structures will be in children with OSA. In addition, LPW might be able to provide an evidence basis for some modified surgical techniques beyond adenotonsillectomy, such as lateral pharyngoplasty or superior pharyngeal constrictor activation.[36,40] The use of US to measure parapharyngeal components might ultimately be used to predict the surgical outcomes of OSA in children.

## Limitations

The major limitation of this study is low power due to small sample size. Therefore, the sample size may be too small to detect significant findings, especially in the parameters at the tonsillar level. A larger study is needed. One limitation of our assessment method is that the margins of fatty tissue deposition in the cervical region cannot be evaluated in the same way as those of other muscle structures because of variability in the echogenicity of fatty tissue. However, we believe that the entire thickness of the muscle layers can be identified well by US in children. Another method limitation is that the position of the neck during US examination was not exactly the same as the patient's sleeping position; the slight neck extension during US examination could expose deeper cervical soft-tissue structures that may be partially shadowed by the mandible.[25] Even though the clinical utility of the Müller maneuver is controversial, we still tried to use the forced deep-inspiration technique to induce the maximum collapsibility of the LPW and parapharyngeal content under US. However, it was very important to ensure cooperation on the part of the children during the examination, so this study needed to be conducted with the children awake.

## Conclusions

Ultrasonography of the head and neck is useful for evaluation of the upper airway structures in children. Using this imaging method, we found that the tonsillar volume estimated by US was not associated with AHI in children. However, the LPW was thicker in children with OSA than in their counterparts with primary snoring. Therefore, LPW thickness may be an independent predictor of OSA in children. Measurement of the upper airway structures using US can help to clarify the role of the LPW in pediatric sleep apnea.

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*Drafting of the manuscript:* Lin, Hsu.
*Critical revision of the manuscript for important intellectual content:* All authors.
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