

Does Neck-to-Waist Ratio Predict Obstructive Sleep Apnea in Children?

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Objectives: Central adiposity and large neck circumference are associated with obstructive sleep apnea (OSA) in adults but have not been evaluated in children as predictors of OSA. Study objectives were to determine whether (1) anthropometric measures including neck-to-waist ratio are associated with OSA in older children; (2) body fat distribution, measured by neck-to-waist ratio, is predictive of OSA in overweight/obese children.

Methods: Cross-sectional study involving children 7-18 years scheduled to undergo polysomnography at a tertiary care children's hospital. OSA was defined as total apnea-hypopnea index > 5 events/h and/or obstructive apnea index > 1 event/h. Recursive partitioning was used to select candidate predictors of OSA from: age, sex, height and weight percentile, body mass index (BMI) z-score, neck-to-waist ratio, tonsil size, and Mallampati score. These were then evaluated using log binomial models and receiver operator characteristic analysis.

Results: Two hundred twenty-two participants were included;

133 (60%) were overweight/obese, 121 (55%) male, 47 (21%) had OSA. Neck-to-waist ratio (relative risk [RR] 1.97 per 0.1 units, 95% CI 1.48 to 2.84) and BMI z-score (RR 1.63 per unit, 95% CI 1.30 to 2.05) were identified as independent predictors of OSA. Considering only overweight/obese children, neck-to-waist ratio (RR 2.16 per 0.1 units, 95% CI 1.79 to 2.59) and BMI z-score (RR 2.02 per unit, 95% CI 1.25 to 3.26) also independently predicted OSA. However, in children not overweight/obese, these variables were not predictive of OSA.

Conclusions: Neck-to-waist ratio, an index of body fat distribution, predicts OSA in older children and youth, especially in those who were overweight/obese.

Keywords: sleep, obesity, body fat distribution, screening, obstructive sleep apnea

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Childhood obesity is a worldwide epidemic. Obstructive sleep apnea (OSA) is more prevalent in children with obesity (13% to 66%),¹⁻⁴ than those who are non-obese (1.2% to 5.7%).⁵ OSA is associated with significant morbidity, including learning and behavioral difficulties, cardiovascular disease, metabolic dysfunction, and impaired quality of life.⁵

The pathophysiology of OSA in children is classically related to dynamic upper airway narrowing, most often from adenotonsillar hypertrophy, as well as dysfunction of complex neuromotor control mechanisms regulating upper airway patency.⁶ OSA prevalence in young children peaks between the ages of 3 and 6 years, when adenoid and tonsillar size are largest relative to the size of the airway.^{7,8} The prevalence of OSA in older children (> 7 years), in whom adenotonsillar hypertrophy is a less important risk factor, may be associated with obesity.⁹ As in adults, the underlying pathophysiology is likely related to increased fat deposition in the neck, which reduces upper airway size or increases pharyngeal resistance.¹⁰ Central distribution of adiposity is a particularly potent risk factor for OSA in adults.^{11,12}

In adults, large neck circumference (NC) identifies individuals at increased risk of OSA.¹³⁻¹⁶ One prospective study has

BRIEF SUMMARY

Current Knowledge/Study Rationale: Obstructive sleep apnea (OSA) is associated with obesity in older children. Central adiposity and large neck circumference are associated with increased OSA risk in adults but have not been evaluated in children as predictors of OSA.

Study Impact: Neck-to-waist ratio, an index of body fat distribution, predicts obstructive sleep apnea (OSA) in older children and youth, especially in those with overweight/obesity. Neck-to-waist ratio is higher in those with OSA than those without, except in those with extreme obesity (BMI > 99th percentile).

shown that NC corrected for height was a better predictor of OSA than symptoms or body mass index (BMI).¹⁵ In children, body fat distribution measurements have only been evaluated prospectively in select populations as a screening tool for OSA. In older (11 ± 2.6 years) overweight (BMI > 85th percentile) and obese children (BMI > 95th percentile), abdominal obesity and total fat mass were associated with central sleep apnea, but not OSA.¹⁷ Waist circumference (WC) was associated with sleep disordered breathing in a cohort of children ages 5-12 years.¹⁸ Similar to adults, a retrospective study evaluated NC to predict

OSA in children 1.5-18 years and found it correlated better with the apnea-hypopnea index (AHI) than BMI.¹⁹ Anthropometric measurements that are easily measured and predictive of OSA would be ideal for practitioners to prioritize referrals for definitive diagnosis with polysomnography (PSG).

The purpose of this cross-sectional study was to determine whether NC and WC identified children at higher risk of OSA. We hypothesized that, as in adults, anthropometric measurements would predict OSA in older children and youth, where tonsillar hypertrophy is less of a contributor to OSA pathophysiology. Further, we hypothesize that body fat distribution, as measured by neck-to-waist ratio may be most predictive of OSA in children with overweight and obesity.

METHODS

Study Design

This cross-sectional study, which was part of a larger prospective cohort study, involved children presenting for PSG at the Children's Hospital of Eastern Ontario, from May 2008 to March 2012. A sleep lab technologist scheduled to perform the sleep study obtained informed consent for participation from parents of all children. Additionally, assent (or consent where appropriate) was obtained for children older than 8 years. Ethics approval was obtained from the hospital research ethics board (Protocol # 08/22X).

Study Population

All consenting children aged 7-18 years, referred to the PSG laboratory by primary care physicians or subspecialists for evaluation of suspected sleep disordered breathing and scheduled during the time period of the study were enrolled. Children with a previous diagnosis of OSA, tracheostomy, or receiving positive airway pressure treatment were excluded. Children identified after PSG as having central sleep apnea, incomplete PSG, or missing or biologically implausible anthropometric measurements were excluded from the analysis.

Measurements

Demographic variables including height, weight, NC, and WC were measured and recorded by the sleep laboratory technologist prior to PSG on the night of testing. NC was measured at the most prominent part of the thyroid cartilage, according to our published protocol, which gives a repeatability coefficient 1.3 cm.²⁰ WC was measured at the point equidistant between the iliac crest and the lowest rib.²¹ Tonsil size was assessed by a trained physician and reported as a dichotomous outcome, i.e., touching or nearly touching in the midline (tonsils occupying > 75% of oropharynx [TT/TNT]) versus "not." In addition, the physician recorded a Mallampati score describing the extent to which the base of the tongue masked visibility of pharyngeal structures (score 1-4).²² The sleep lab technologist was blinded to the physician's assessment. Both were blinded to the final interpretation of the sleep study scored by a sleep physician.

Polysomnograms were performed and scored according to American Association of Sleep Medicine pediatric standards.²³ This included monitoring of 4 electroencephalogram leads, electro-oculogram, submental and tibial electromyogram, in

addition to chest and abdominal wall inductance plethysmography, airflow measurements (nasal pressure), oxygen saturation, transcutaneous and end-tidal carbon dioxide measurements, and video and audio recordings. The sleep physician scoring the polysomnograms was blind to the measurements of the predictor variables described previously. OSA was considered to be present if the obstructive apnea index (OAI) was ≥ 1 event/h or the total AHI was > 5 events/h. The strict definition of OSA used here satisfies conditions identified in most pivotal studies of clinically significant pediatric OSA prevalence and treatment²⁴ and was selected since the ultimate goal is to identify individuals with moderate-severe OSA to prioritize them for definitive testing.

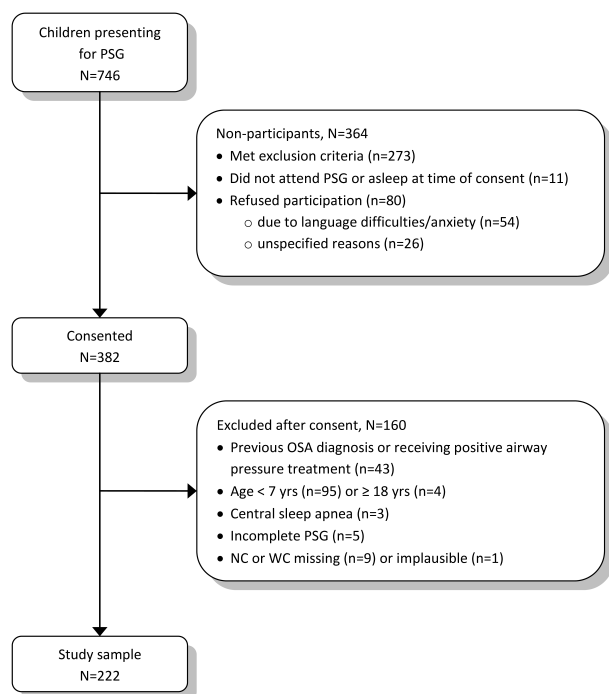
Statistical Analyses

As a preliminary analysis, a recursive partitioning algorithm²⁵ was used to identify potential predictor variables (with associated cutoffs) of OSA. Recursive partitioning was chosen because it relaxes the restrictive assumptions required for logistic regression and is helpful in situations where complex relationships between variables are present,²⁶ which was suspected based on prior knowledge in this field. To reduce the risk of over-fitting the data, the algorithm was constrained to form categories with ≥ 20 people and a maximum of 2 levels of subdivision. The algorithm assessed: age, sex, height and weight percentiles, along with BMI z-scores (age-adjusted dimensionless measures), tonsil size, and Mallampati score. Measures of relative body fat distribution were considered, including NC and WC; however, age- and sex-adjusted percentiles were not available for the full age range and population of interest for WC. Neck-to-waist ratio was included because it is a dimensionless measure.

Next, the variables identified by the recursive partitioning analysis (neck-to-waist ratio and BMI z-score) were tested using log binomial models to obtain adjusted risk ratios (RR) for OSA. Interaction terms were also considered. Neck-to-waist ratios were centered and scaled prior to inclusion in the log binomial model, so that main effects could be more easily interpreted and would correspond to meaningful differences in the exposure variable (e.g., a change of 0.1 units). Subgroup analysis was conducted of participants who were overweight/obese (BMI ≥ 85 th percentile) and those who were not. Due to concerns about a possible "ceiling effect" in those with BMI percentile > 99 , a log binomial analysis was also conducted in the subgroup of overweight and obese individuals with BMI 95th-99th percentile.

To assess the predictive performance of these models, receiver operating characteristic (ROC) analysis was used. Using fitted probabilities from log binomial models and evaluating all possible thresholds for presence of OSA, ROC curves can be constructed.²⁷ The C-statistic,²⁸ which estimates the area under the ROC curve, was used as a measure of the predictive performance of each of the models used here. The Delong method²⁹ was used to test for statistically significant differences between C-statistics.

Additionally, a Wilcoxon rank sum test was used to compare neck-to-waist ratios in groups with and without OSA, amongst those with BMI 85th-99th percentile and those with BMI > 99 th percentile. Throughout this work, 95% confidence

Figure 1—Flow diagram of enrolment, inclusion, and exclusions for the study.

intervals were used, and 2-sided p -values ≤ 0.05 were judged to be statistically significant.

Correlations (Spearman) between BMI z-score and neck-to-waist ratio were determined for the whole study population, as well as for the subgroup of overweight and obese subjects (BMI \geq 85th percentile), in order to examine trends in these variables that might explain the log binomial model results.

RESULTS

A total of 746 children presenting for PSG were approached regarding study participation. Of 382 consenting individuals, 160 were excluded for previous OSA or central sleep apnea, receiving positive airway pressure treatment, being outside the age range of interest, incomplete PSG, or missing anthropometric measurements. The final study sample included 222 participants (**Figure 1**). One hundred twenty-one of the participants (55%) were male, 35 (16%) were overweight (BMI 85th-95th percentile), and 98 (44%) were obese (BMI > 95th percentile, **Table 1**). Forty-seven participants (21%) had OSA according to the set definition. Those excluded did not differ from participating individuals in sex distribution, but were significantly younger.

The recursive partitioning algorithm identified that amongst the whole study population, with the exception of those with extreme obesity (BMI z-score > 2.53, corresponding to a BMI > 99.4th percentile), a neck-to-waist ratio > 0.38 was associated with a 22% risk of OSA, whereas a neck-to-waist ratio ≤ 0.38 was associated with a 7% risk of OSA. The recursive partitioning algorithm did not identify neck-to-waist ratio as important to predict OSA risk among those with BMI

Table 1—Demographics and baseline characteristics of 222 children undergoing polysomnography.

Characteristic	
Age, years; median (range)	12.1 (7.0–17.9)
Male; n (%)	121 (54.5%)
BMI z-score (kg/m ²); mean (SD)	1.03 (1.49)
Neck Circumference (cm); median (IQR) [range]	32.0 (29.0–36.0) [15.4–50.0]
Waist Circumference (cm); median (IQR) [range]	79.5 (66.3–97.8) [48.0–170.0]
Neck-to-waist ratio; median (IQR) [range]	0.41 (0.37–0.44) [0.26–0.58]
Tonsils touching/nearly touching; n (%)	43 (19.8%)*
Total AHI, (events/h); median (IQR) [range]	1.3 (0.4–3.6) [0–153.4]
Minimum O ₂ sat, (%); median (IQR) [range]	91.0 (86.0–93.3) [0–97.8]@
Obstructive apnea index (events/h); median (IQR) [range]	0 (0–0.16) [0–87.9]
Mallampati score; n (%)	
1	72 (33%)
2	68 (32%)
3	58 (27%)
4	17 (8%)

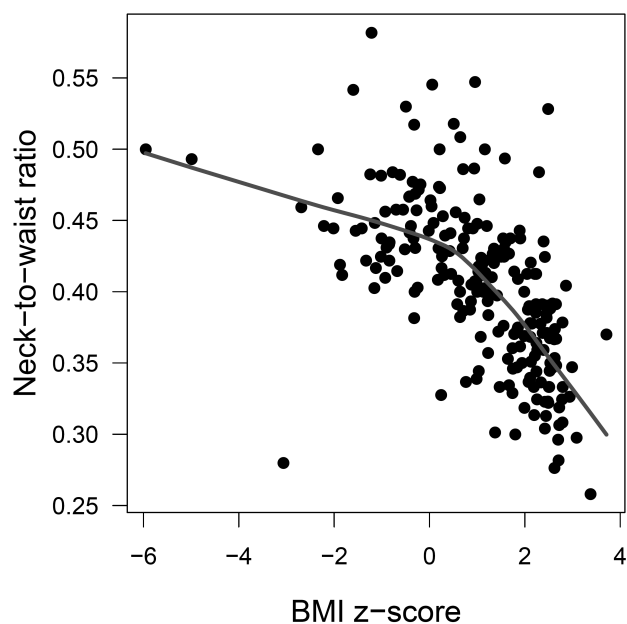
* 5 missing values. @ 3 missing values. SD, standard deviation; IQR, inter-quartile range; BMI, body mass index; AHI, apnea-hypopnea index.

z-score > 2.53. No other candidate variables were selected by the recursive partitioning algorithm as important for OSA prediction.

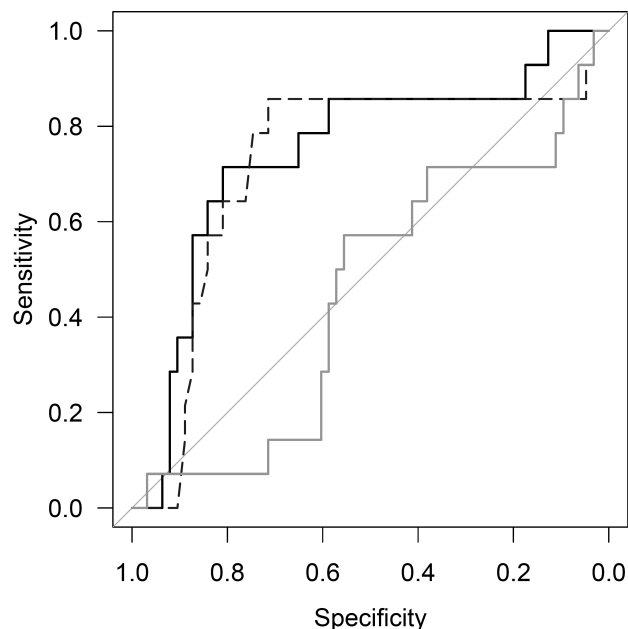
Multivariate log binomial modeling was conducted in the whole sample as well as subgroups defined by overweight/obesity status. In each case, neck-to-waist ratio and BMI z-score were tested as predictors of OSA. When the whole population was considered (**Table 2A**), both neck-to-waist ratio and BMI z-score were found to be independent statistically significant predictors of OSA, with a C-statistic of 0.68. There was no statistical interaction between the variables. The Spearman correlation between BMI z-score and neck-to-waist ratio was -0.68. At higher BMI z-scores, neck-to-waist ratio decreased sharply (**Figure 2**).

In the overweight/obese subgroup (**Table 2B**), multivariate log binomial modeling determined that the risk of OSA was significantly associated with both increased BMI z-score and neck-to-waist ratio, with a C-statistic of 0.70. In contrast, among the non-overweight, non-obese subgroup (**Table 2C**), risk of OSA was not significantly associated with either variable, with a C-statistic of 0.64.

To exclude a possible “ceiling effect” in those with BMI percentile > 99, analysis was also conducted in the subgroup of overweight and obese individuals with BMI percentile between 85 and 99 (**Table 2D**). Multivariate log binomial modelling did not reveal neck-to-waist ratio or BMI z-score as significant predictors of OSA; however, the p -value for neck-to-waist ratio was close to significant at 0.06, whereas the p -value for BMI z-score was 0.35 and the sample size in this group was small. The C-statistic for this model was 0.74. When neck-to-waist ratio

Figure 2—Scatterplot of neck-to-waist ratio versus BMI z-score.

A loess scatterplot smoother curve⁴¹ has been superimposed.

Figure 3—Receiver operator characteristic (ROC) curves.

Receiver operator characteristic (ROC) curves from logistic regression models in the subset of patients with BMI percentiles 85-99, of BMI-z (light gray line, C-statistic = 0.45), Neck-to-waist (dotted line, C-statistic = 0.72), and model with both (black line, C-statistic = 0.74). Note that the C-statistic is equivalent to the area under an ROC curve.

and BMI z-score were considered separately, the C-statistic for neck-to-waist ratio, 0.72, was higher than for BMI z-score, 0.45 ($p < 0.001$). **Figure 3** shows the ROC curves for these different models. For illustrative purposes, using neck-to-waist ratio > 0.41 to predict OSA in this subgroup yielded a sensitivity

Table 2—Estimates for OSA from log binomial models using factors identified by recursive partitioning.**A. Whole study population (N = 222)**

Variable	Relative Risk (95% CI)	p-value
BMI z-score (per unit)	1.63 (1.30–2.05)	< 0.001
Neck-to-waist ratio (per 0.1 units)	1.97 (1.48–2.84)	< 0.001

B. Overweight or obese subgroup (BMI \geq 85th percentile) (N = 125)

Variable	Relative Risk (95% CI)	p-value
BMI z-score (per unit)	2.02 (1.25–3.26)	0.004
Neck-to-waist ratio (per 0.1 units)	2.16 (1.79–2.59)	< 0.001

C. Subgroup not overweight or obese (N = 97)

Variable	Relative Risk (95% CI)	p-value
BMI z-score (per unit)	1.74 (0.98–3.11)	0.06
Neck-to-waist ratio (per 0.1 units)	1.48 (0.60–3.71)	0.43

D. Subset of overweight or obese subgroup (Table 2B), restricted to BMI 85th-99th percentile (N = 77)

Variable	Relative Risk (95% CI)	p-value
BMI z-score (per unit)	1.78 (0.53–5.92)	0.35
Neck-to-waist ratio (per 0.1 units)	2.59 (1.00–7.30)	0.06

of 86% and specificity of 71%. Furthermore, neck-to-waist ratio was also significantly higher among those with OSA compared to those without ($p = 0.01$) when compared using a Wilcoxon rank sum test. This result did not hold in those whose BMI was above the 99th percentile ($p = 0.33$, **Figure 4**).

When age and sex were included in the log binomial models, the estimated RRs did not greatly change. Sex and age were not significant predictors of OSA in the whole group, nor in subgroups of overweight/obese or non-overweight/obese children and youth.

DISCUSSION

The study found that in children and youth 7 years and older, higher BMI z-score and neck-to-waist ratio were independent predictors of OSA in overweight/obese children but not in non-overweight/obese children. It is therefore possible that body fat distribution could explain some of the variation in OSA prevalence reported in the literature among overweight/obese children and youth.

Incorporating the neck-to-waist ratio as a predictor variable for OSA is a novel aspect of our approach and provides additional information for risk stratification beyond just BMI, particularly in the group of overweight/obese children that excludes those with the most extreme BMIs (BMI $>$ 99th percentile). For these children, neck-to-waist ratio is a stronger predictor of OSA than BMI z-score. Furthermore, neck-to-waist ratio, a dimensionless measure, is also more reflective of relative distribution of body fat than a single measure of neck or waist size, which has been used in other studies.^{14,15,17,18,30}

Neck-to-waist ratio is an attractive measure because it can be easily assessed in a clinic setting. Given the limited availability

of PSG, variables to predict OSA that may be assessed in a primary care practitioner's office may expedite an urgent PSG for definitive diagnosis and referral for treatment in individuals determined to be at high risk. The utility of neck-to-waist ratio as a predictor of OSA is illustrated in the subgroup with BMI percentile between 85 and 99, where a threshold of neck-to-waist ratio > 0.41 is sensitive enough to be considered as a screening test and specific enough to help prioritize patients for polysomnography.

Large neck-to-waist ratio is consistent with the typical phenotype seen in adults, in whom obesity is a major predictor of OSA^{10,31} and central distribution of adiposity confers greater OSA risk.^{12,15,32} In adolescents, visceral adiposity is associated with OSA risk in some,³² although not all studies,³³ and enlarged neck circumference has been associated with increased upper airway collapsibility.³⁴

Recursive partitioning identified those with the highest BMI (> 99 th percentile) as being a distinct sub-population. In this group, neck-to-waist ratios are lower (Figure 2), indicating that adiposity is accumulated in the lower as opposed to upper body. This finding was confirmed by the log binomial models, in which neck-to-waist ratio was not predictive of OSA in this subgroup of the most obese individuals. Nonetheless, this group's overall risk of OSA is high and related to degree of total adiposity, as shown in the recursive partitioning model.

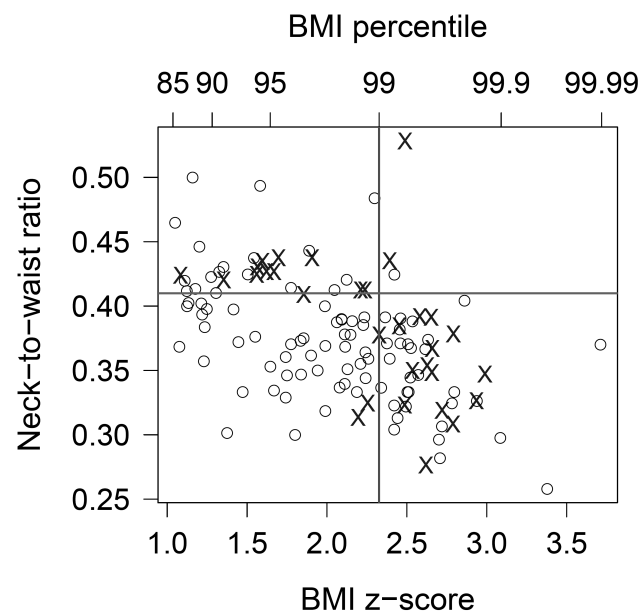
OSA risk is reported to be greater in males than females, with sex-based differences in prevalence more prominent in those 13 years and older.^{35,36} In the present study, OSA risk was not different between sexes or according to age.

This study has limitations. The subjects were referred for evaluation of suspected sleep disordered breathing and had a higher prevalence than the general population. However, the types of patients referred to our PSG laboratory do not differ from those at other tertiary care pediatric PSG laboratories across Canada.³⁷ There is a high prevalence of obese patients, although this reflects our referred patient population. Pubertal status was not assessed in our study, although age (to which pubertal status is linked) did not emerge as a predictor of OSA. Information on race was not collected in this study, but could influence risk of OSA and body fat distribution.^{38,39} Finally, although our study did not reveal Mallampati score and tonsil size as predictors of OSA, a recent retrospective study has shown them to be significant predictors of pediatric OSA, particularly when Mallampati score is measured supine.⁴⁰ The interplay of these factors with BMI and body fat distribution, as well the reliability of scoring and assessing Mallampati and tonsil scores, require further evaluation in future studies.

CONCLUSION

This study indicates that body fat distribution is a contributor to OSA risk in children and youth ≥ 7 years, particularly among those who are overweight and obese. In this group, neck-to-waist ratio is an independent predictor of OSA, in addition to BMI z-score, except in those with extreme obesity (BMI > 99 th percentile, equivalent to a BMI z-score of 2.33). A threshold of neck-to-waist ratio > 0.41 has sufficient sensitivity and specificity to be considered as a predictor of OSA

Figure 4—Neck-to-waist ratio versus BMI z-score.



Note that the top axis is labeled in terms of BMI percentile. The gray vertical line indicates the 99th percentile of BMI. The gray horizontal line indicates the neck-to-waist ratio threshold of 0.41 obtained by inspection of the ROC curve in the subgroup with BMI percentile between 85 and 99.

risk, but would require prospective validation in a larger overweight/obese pediatric population before being incorporated in OSA screening strategies.

ABBREVIATIONS

- AHI, apnea-hypopnea index
- BMI, body mass index
- OSA, obstructive sleep apnea
- NC, neck circumference
- ROC, receiver operator characteristic
- RR, risk ratio
- TT/TNT, tonsils touching or tonsils nearly touching
- WC, waist circumference

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