

Predictive Value of Neck-to-Height Ratio in Children with Moderate/Severe Obstructive Sleep Apnea: A Retrospective Cross-Sectional Study

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Objective: Obstructive Sleep Apnea (OSA) is a common sleep-disordered breathing condition in children. Moderate/severe OSA can lead to a series of complications, including growth restriction and neurocognitive impairment, severely impacting children's physical and mental health. The gold standard for diagnosing OSA is polysomnography (PSG). Given the limitations of PSG in large-scale screening and the insufficient accuracy and compliance of existing screening tools, exploring simple and reliable screening tools for moderate/severe OSA holds significant clinical importance. This study aims to systematically compare the predictive efficacy of neck-to-height ratio (NHR), waist-to-height ratio (WHtR), hip-to-height ratio (HHR), and BMI Z-score for moderate/severe pediatric OSA, providing more accurate and convenient indicators for clinical screening.

Methods: We retrospectively analyzed data from 685 children aged 3–16 years who underwent PSG. Using age, gender, tonsil size, and adenoid size as covariates, receiver operating characteristic (ROC) analysis was used to assess the discriminatory ability of NHR, WHtR, HHR, and BMI Z-score in the overall cohort and within age and gender subgroups.

Results: NHR demonstrated the highest predictive efficacy in the overall cohort (AUC=0.781), significantly outperforming other indices. Subgroup analysis revealed that NHR maintained excellent predictive performance in children above 10 years, with AUC values of 0.777 in boys and 0.913 in girls.

Conclusion: The NHR may serve as a useful adjunctive screening tool for moderate/severe OSA in children above 10 years, showing moderate predictive value and outperforming traditional indices such as WHtR, HHR, and BMI Z-score.

Keywords: neck-to-height ratio, obstructive sleep apnea, children, anthropometric indices, polysomnography

Introduction

Obstructive Sleep Apnea (OSA) is a disorder of breathing during sleep characterized by prolonged partial upper airway obstruction and/or intermittent complete obstruction (obstructive apnea) that disrupts normal ventilation during sleep and normal sleep patterns.¹ The American Academy of Pediatrics guidelines indicate that the prevalence of OSA ranges from 1.2% to 5.7% in pediatrics.^{1,2} Studies on pediatric populations indicate that untreated pediatric OSA, particularly moderate/severe cases, is more likely than mild OSA to cause abnormal brain development and neurocognitive impairment, and may lead to restricted growth, learning difficulties, and behavioral disorders.^{2,3} Furthermore, moderate/severe OSA is closely associated with maxillofacial dysplasia, metabolic syndrome, hypertension, and may even increase the risk of cardiovascular events in adulthood.^{4–7}

Although polysomnography (PSG) is currently the gold standard for diagnosing OSA,¹ its complex operation, high cost, and requirement for specialized sleep centers limit its application in large-scale clinical screening. Questionnaires, home-based monitoring, and routine physical examinations are widely used as initial screening tools for pediatric OSA, their limited accuracy, variable compliance, and inconsistent performance in children substantially restrict their ability to

reliably guide PSG referrals.^{8–10} Therefore, simple, objective and easily obtainable predictors are needed to better identify children at high risk who warrant further PSG evaluation.

Previous studies have shown that Body Mass Index (BMI) correlates with OSA severity, particularly among adolescents and obese children, in whom higher BMI levels are positively associated with increased OSA risk.^{11–13} However, as a general indicator of obesity, BMI fails to reflect localized fat distribution or thickening of soft tissues surrounding the upper airway,^{14,15} thus limiting its predictive value for pediatric OSA. Neck fat deposition may directly increase mechanical load on the upper airway, making neck circumference (NC) a potentially more specific indicator than general obesity measures.^{16–18} In children, particularly those with only mild adenotonsillar enlargement, excess neck adiposity could contribute to upper airway collapsibility and increase OSA risk. To account for the confounding effect of somatic growth in children, we employed height-normalized ratios—such as neck-to-height ratio (NHR), waist-to-height ratio (WHtR), and hip-to-height ratio (HHR)—which adjust for body size and enable meaningful comparisons across different developmental stages.^{13,19,20} Although previous studies have reported the potential value of NC in screening for OSA in adults and children,^{11,12,21–23} research systematically comparing the diagnostic efficacy of these circumference-to-height ratios for identifying moderate-to-severe OSA in children remains relatively limited, and most existing studies have focused on adolescent populations and obesity groups.

Importantly, systematic head-to-head comparisons of these ratios for OSA across different age subgroups and between sexes in the general pediatric population remain scarce. The lack of stratified analysis by age and gender limits the understanding of whether the screening performance of these indicators varies according to developmental stage and biological sex. Considering the age at which hypertrophic adenoid and tonsil tissue may spontaneously regress, as well as differences in fat distribution around puberty, we selected age 10 as the cutoff point for subgroup analysis. Therefore, based on diagnostic results from PSG with clear staging, there is an urgent need for systematic evaluation and comparison of these convenient anthropometric indicators across different age and gender subgroups to assess their practical efficacy in identifying OSA in pediatric populations, thereby providing more reliable early screening tools for clinical practice.

In summary, this study compares the predictive performance of NHR, WHtR, HHR and BMI Z-score for identifying children at risk of OSA, aiming to inform the development of simple and clinically applicable screening indicators.

Methods

Study Design and Study Population

This retrospective study enrolled 685 children who underwent PSG examinations using Alice 6 (Phillips Inc, USA) at the Department of Otolaryngology, Head and Neck Surgery at Capital Center for Children's Health, Capital Medical University between February 2022 and March 2023. Children with a history of tonsillectomy and/or adenoidectomy, a history of positive airway pressure therapy, neuromuscular disorders, severe craniofacial deformities, chronic pulmonary disease, sickle cell disease, or metabolic disorders were excluded from the study. The study was approved by the Ethics Committee of the Children's Hospital Capital Institute of Pediatrics. The informed consent was obtained from all participants, together with their parents informed written consent.

PSG and Disease Severity Grading

Subjects underwent PSG and were classified according to the severity of OSA based on the Chinese guideline for the diagnosis and treatment of childhood obstructive sleep apnea (2020).

Grouping subjects based on the obstructive apnea-hypopnea index (OAHI) within the PSG metrics, with subjects categorized as no/mild OSA group: OAHI $\leq$ 5 events/hour and moderate/severe OSA group: OAHI $>$ 5 events/hour.¹

Anthropometric Indicators

The same trained sleep technologist measure weight, height, neck circumference (NC), waist circumference (WC), and hip circumference (HC) in children the morning after PSG according to standardized protocol.^{24–26} Age and sex were collected from the electronic medical records. And then BMI Z-score, the ratio of NC to height, WC to height and HC to height were calculated.

Adenoid and Tonsil Grading Method

The subjects were examined in a supine position by an experienced technician using a pediatric 2.9-mm fiberoptic nasopharyngoscopy (PENTAX medical VNL8–J10). An experienced clinician graded adenoid size based on nasopharyngoscopy images using a percentage 4°-grading system and tonsil size according to the Brodsky grading criteria.

Statistical Analysis

All statistical analyses were run in R (version 4.5). The *t*-test was used to compare mean differences between the no/mild OSA and moderate/severe OSA groups. Using age, gender, tonsil size, and adenoid size as covariates, receiver operating characteristic (ROC) analysis was employed to evaluate the discriminative efficacy of body mass index (BMI) Z-score, neck circumference (NC), neck-to-height ratio (NHR), waist-to-hip ratio (WHtR), and hip-to-height ratio (HHR) in predicting moderate to severe OSA. The area under the curve (AUC) and its 95% confidence interval, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated.

To further explore the impact of demographic characteristics on predictive performance, participants were stratified by age (<10 years old and ≥10 years old) and gender (male and female) to compare the accuracy of each indicator in predicting moderate/severe OSA across different subgroups.

p value < 0.05 was considered statistically significant.

Results

We completed the data collection and analysis following the workflow shown in [Figure 1](#). Participants' characteristics according to OSA severity are presented in [Table 1](#). A total of 685 children aged between 3 and 16 years underwent PSG along with anthropometric assessments. The no/mild OSA group comprised 518 participants (299 males, 219 females), while the moderate/severe OSA group included 167 (114 males, 53 females), and boys account for a larger proportion. Compared to the no/mild OSA group, children with moderate/severe OSA demonstrated significantly younger age and lower height. In contrast, their BMI Z-score was significantly higher. Moreover, indicators reflecting localized fat distribution and body shape structure—including NC, NHR, WHtR, and HHR—were all significantly elevated in the moderate/severe OSA group.

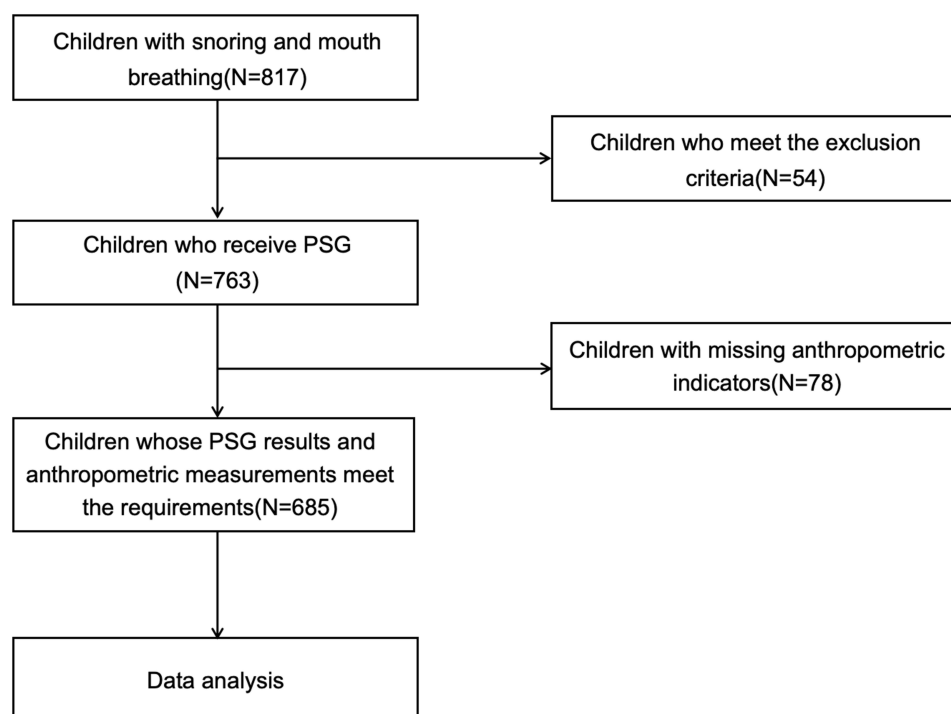


Figure 1 Patient enrollment and study scheme.

Table 1 The Demographic Characteristics and the Anthropometric Indicators

	No/Mild OSA (n=518)	Moderate/Severe OSA (n=167)	P value
Age	6.48 ± 0.12	5.98 ± 0.23	0.035
Male/Female	299/219	114/53	0.015
Height (cm)	122.23 ± 0.77	118.22 ± 1.61	0.015
Weight (kg)	26.00 ± 0.60	27.41 ± 1.41	0.289
BMI (kg/m ²)	16.37 ± 0.15	17.80 ± 0.39	<0.001
NC (cm)	26.91 ± 0.14	27.85 ± 0.32	0.003
NHR	0.22 ± 0.00	0.24 ± 0.00	<0.001
WC (cm)	59.82 ± 0.45	61.70 ± 1.08	0.062
WHtR	0.49 ± 0.00	0.52 ± 0.01	<0.001
HC (cm)	66.71 ± 0.51	67.60 ± 1.14	0.423
HHR	0.55 ± 0.00	0.57 ± 0.00	<0.001

Abbreviations: BMI, body mass index; NC, neck circumference; WC, waist circumference; HC, hip circumference; NHR, neck-to-height ratio; WHtR, waist-to-height ratio; HHR, hip-to-height ratio.

After adjusting for age, gender, and adenoid and tonsil size, ROC curves were used to evaluate the predictive efficacy of various indicators for moderate/severe OSA. (Figure 2). For anthropometric indicators, the AUC for the NHR was 0.781 (95% CI: 0.742–0.820; $p < 0.01$), significantly higher than the AUC for the BMI Z-score (0.711 [95% CI: 0.667–0.754]; $p < 0.01$), WHtR (0.745 [95% CI: 0.701–0.788]; $p < 0.01$), HHR (0.743 [95% CI: 0.701–0.786]; $p < 0.01$). The sensitivity of NHR was 77% (95% CI: 71–84%), specificity was 67% (95% CI: 63–71%), PPV was 43% (95% CI: 37–49%), and NPV was 90% (95% CI: 87–93%) (Table 2 and Figure 2A).

To further explore the predictive effectiveness of relevant indicators across different pediatric groups, this study conducted subgroup analyses by age and gender. The subgroup sample sizes are as follows: Girls ≥ 10 years ($n=24$), Boys ≥ 10 years ($n=51$), Girls < 10 years ($n=248$), Boys < 10 years ($n=362$). Among girls above 10 years old, the NHR

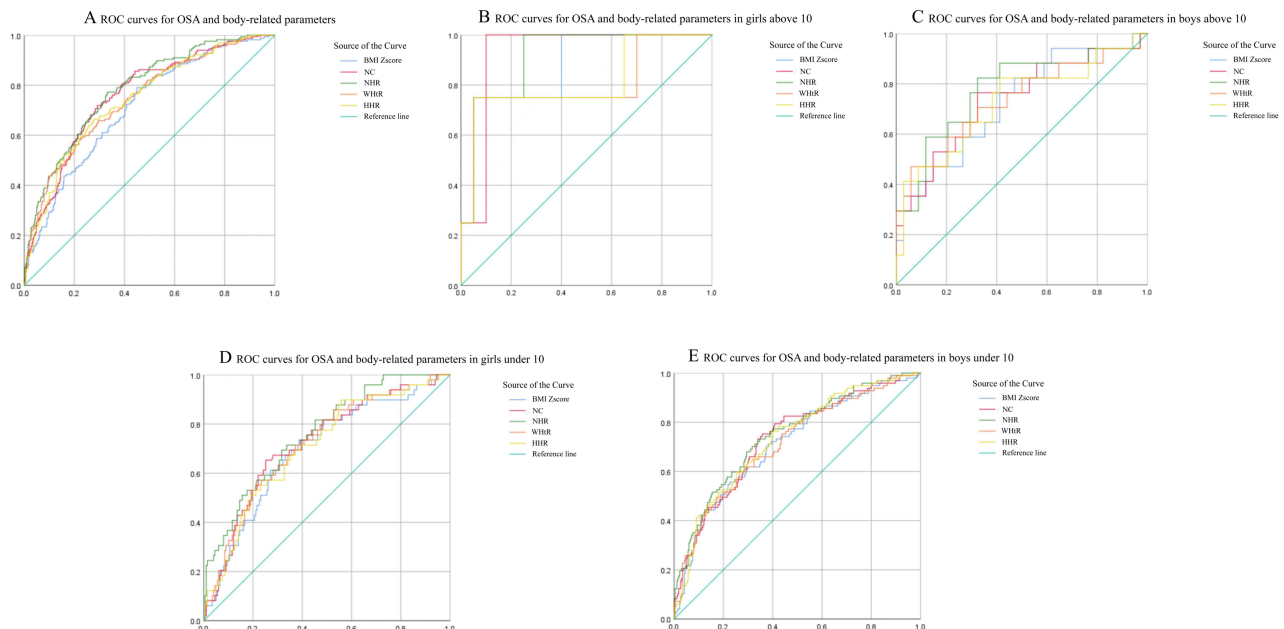


Figure 2 ROC curves for moderate/severe OSA across subgroups. (A) ROC curves for OSA and body-related parameters. (B) ROC curves for OSA and body-related parameters in girls above 10. (C) ROC curves for OSA and body-related parameters in boys above 10. (D) ROC curves for OSA and body-related parameters in girls under 10. (E) ROC curves for OSA and body-related parameters in boys under 10.



Table 2 Predictive Performance of Anthropometric Indices for Moderate-to-Severe OSA Across Subgroups

	AUC	95% CI	P value	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
BMI Z-score							
All	0.711	0.667–0.754	<0.01	79(73–85)	55(51–59)	36(31–41)	89(86–92)
Girls above 10	0.875	0.692–1.000	0.02	75(32–100)	95(86–100)	75(33–100)	95(86–100)
Boys above 10	0.725	0.575–0.875	<0.01	82(64–100)	53(36–70)	47(29–65)	86(71–100)
Girls under 10	0.696	0.614–0.777	<0.01	74(61–86)	61(55–68)	32(23–41)	90(85–95)
Boys under 10	0.712	0.651–0.773	<0.01	56(46–66)	77(72–82)	47(38–57)	83(78–88)
NC							
All	0.761	0.720–0.802	<0.01	72(65–79)	71(67–75)	44(38–50)	89(86–92)
Girls above 10	0.925	0.814–1.000	<0.01	100(100–100)	90(77–100)	67(29–100)	100(100–100)
Boys above 10	0.735	0.582–0.888	<0.01	77(56–97)	68(52–83)	54(34–74)	85(72–99)
Girls under 10	0.719	0.640–0.798	<0.01	65(52–79)	75(69–81)	39(29–50)	90(85–94)
Boys under 10	0.746	0.689–0.804	<0.01	75(67–84)	64(58–70)	44(36–51)	88(83–92)
NHR							
All	0.781	0.742–0.820	<0.01	77(71–84)	67(63–71)	43(37–49)	90(87–93)
Girls above 10	0.913	0.782–1.000	0.01	100(100–100)	75(56–94)	44(12–77)	100(100–100)
Boys above 10	0.777	0.631–0.923	<0.01	82(64–100)	68(52–83)	56(37–76)	89(76–100)
Girls under 10	0.757	0.686–0.829	<0.01	71(59–84)	66(60–73)	34(25–44)	90(86–95)
Boys under 10	0.731	0.672–0.789	<0.01	68(59–77)	71(65–76)	46(38–54)	86(81–90)
WHtR							
All	0.745	0.701–0.788	<0.01	66(59–73)	71(67–74)	42(36–48)	87(83–90)
Girls above 10	0.800	0.503–1.000	0.063	75(32–100)	95(86–100)	75(33–100)	95(86–100)
Boys above 10	0.734	0.575–0.892	<0.01	47(23–71)	94(86–100)	80(55–100)	78(65–91)
Girls under 10	0.718	0.639–0.796	<0.01	71(59–84)	63(56–70)	32(23–41)	90(85–95)
Boys under 10	0.715	0.655–0.776	<0.01	60(50–70)	74(68–79)	45(37–54)	83(79–88)
HHR							
All	0.743	0.701–0.786	<0.01	67(59–74)	72(68–76)	44(37–50)	87(84–90)
Girls above 10	0.812	0.535–1.000	0.053	75(32–100)	95(86–100)	75(33–100)	95(86–100)
Boys above 10	0.725	0.566–0.883	<0.01	82(64–100)	59(42–75)	50(32–69)	87(73–100)
Girls under 10	0.706	0.627–0.786	<0.01	90(81–98)	44(37–51)	28(21–36)	95(90–99)
Boys under 10	0.730	0.673–0.788	<0.01	76(68–85)	60(54–66)	41(34–48)	87(82–92)

Abbreviations: BMI Z-score, body mass index Z score; NC, neck circumference; NHR, neck-to-height ratio; WHtR, waist-to-height ratio; HHR, hip-to-height ratio; AUC, area under the curve; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.

demonstrated the strongest predictive performance, with an AUC value of 0.913 (95% CI: 0.782–1.000; $p=0.01$) significantly higher than that of BMI Z-score (0.875[95% CI: 0.692–1.000]; $p=0.02$), WHtR (0.800[95% CI: 0.503–1.000]; $p=0.063$), HHR (0.812[95% CI: 0.535–1.000]; $p=0.053$). (Table 2 and Figure 2B) Its sensitivity was 100% (95% CI: 100–100%), specificity was 75% (95% CI: 56–94%), PPV was 44% (95% CI: 12–77%), and NPV was 100% (95% CI: 100–100%). (Table 2) In girls under 10 years of age, the AUC for NHR was 0.757 (95% CI: 0.686–0.829; $p<0.01$), which was also superior to BMI Z-score (0.696[95% CI: 0.614–0.777]; $p<0.01$), WHtR (0.718 [95% CI: 0.639–0.796]; $p<0.01$), and HHR (0.706[95% CI: 0.627–0.786]; $p<0.01$). (Table 2 and Figure 2D) Its sensitivity was 71% (95% CI: 59–84%), specificity was 66% (95% CI: 60–73%), PPV was 34% (95% CI: 25–44%), and NPV was 90% (95% CI: 86–95%) (Table 2).

Similarly, in boys above 10 years old, the AUC for NHR was 0.777 (95% CI: 0.631–0.923; $p<0.01$), with a sensitivity of 82% (95% CI: 64–100%), specificity of 68% (95% CI: 52–83%), PPV was 56% (95% CI: 37–76%), and NPV was 89% (95% CI: 76–100%). NHR's AUC was higher than that of BMI z-score (0.725[95% CI: 0.575–0.875]; $p<0.01$), WHtR (0.734[95% CI: 0.575–0.892]; $p<0.01$), and HHR (0.725[95% CI: 0.566–0.883]; $p<0.01$). (Table 2 and Figure 2C).

Moreover, in boys under the age of 10, the AUC for the NHR was 0.731 (95% CI: 0.672–0.789); $p < 0.01$), significantly higher than the AUC for BMI Z-score, WHtR, HHR, which was (0.712[95% CI: 0.651–0.773]; $p < 0.01$), (0.715[95% CI: 0.655–0.776]; $p < 0.01$), (0.730[95% CI: 0.673–0.788]; $p < 0.01$). (Table 2 and Figure 2E) Its sensitivity was 68% (95% CI: 59–77%), specificity was 71% (95% CI: 65–76%), PPV was 46% (95% CI: 38–54%), and NPV was 86% (95% CI: 81–90%) (Table 2).

Discussion

This study systematically evaluated the screening efficacy of multiple indicators for children with moderate/severe OSA. Results indicate that NHR showed the strongest discrimination ability in the total cohort and demonstrated particularly robust predictive performance among children older than 10 years. In contrast, its predictive value diminished in younger age groups, with significantly higher predictive efficacy compared to the traditional indicator BMI Z-score.

These findings suggest that, compared to generalized obesity, neck fat deposition may have a more direct pathophysiological association with increased mechanical load on the upper airway in the development of OSA.^{16–18}

Previous studies have primarily focused on adolescent populations, with few conducting age-stratified analyses.^{13,27} However, this study observed that the NHR demonstrated superior predictive efficacy in children above 10 years of age after adjusting for adenotonsillar size, suggesting the influence of age-related physiological differences. In younger children, adenotonsillar hypertrophy is the primary cause of OSA,^{1,2,28} and anthropometric indicators demonstrate relatively weaker predictive efficacy in this age group once these critical anatomical factors are statistically controlled. Conversely, in older children—particularly those approaching or undergoing puberty—adenotonsillar tissue undergoes physiological regression with age.²⁹ This shift diminishes the primary role of anatomical factors in upper airway obstruction, while the relative contribution of obesity to OSA pathogenesis increases.^{30,31} In this context, NHR more accurately reflects the burden of soft tissue surrounding the upper airway, thereby demonstrating higher predictive performance in children over 10 years of age.

Gender differences also warrant attention. Our research findings indicate that boys have a higher risk of moderate/severe OSA than girls. However, despite this higher disease prevalence, the predictive performance of the NHR was more pronounced in girls aged 10 years and older, suggesting that disease risk and the discriminative ability of an anthropometric indicator do not necessarily coincide.

In adults, pronounced sex differences in OSA prevalence and severity have been well documented, with OSA being 2–3 times more prevalent in men than in women,³² and the prevalence in postmenopausal women approaching that of age-matched men.³³ Experimental and clinical studies in adults have suggested that androgens may increase the risk of snoring and OSA indirectly by promoting upper-body or neck fat accumulation and reducing upper airway muscle compliance,^{34,35} whereas estrogens are thought to help preserve upper airway muscle tone and reduce airway collapsibility during sleep.^{36,37} These observations suggest a potential protective role of female sex hormones, such as estrogen and progesterone, in maintaining upper airway stability.³⁸

Although direct evidence in pediatric populations is limited, hormonal changes occurring around puberty may contribute to sex-specific differences in the relationship between body habitus and airway anatomy. In pubertal and postpubertal girls, estrogen-related modulation of fat distribution may result in a more proportional and stable relationship between neck morphology and overall body size, allowing NHR to more accurately reflect upper airway vulnerability. Additionally, the incidence of adenoid hypertrophy during childhood is relatively high in boys,³⁹ potentially leading to impaired nasal airflow and subsequent mouth breathing. Prolonged mouth breathing alters the balance of maxillofacial muscles, resulting in a narrow maxillary arch and high palate. This indirectly affects pharyngeal morphology, increasing the risk of narrowing.^{40,41} The greater anatomical heterogeneity of the upper airway in boys may diminish the relative contribution of neck-based physical measurements. These factors may partially explain why, despite boys having a higher overall risk of OSA, the NHR demonstrates superior predictive performance in girls aged 10 years and older.

Overall, compared to previous studies, this research is the first to compare the predictive efficacy of multiple anthropometric indicators for moderate-to-severe OSA. The NHR measurement is simple and cost-effective, making it a scalable tool for identifying children with moderate/severe OSA during pediatric physical examinations or in primary care settings. It offers valuable evidence to support early detection and timely intervention. This approach can optimize diagnosis and treatment decisions, enhance resource utilization efficiency, and reduce long-term adverse outcomes such as neurobehavioral and

cardiovascular complications caused by delayed OSA diagnosis. However, it should be emphasized that the NHR is intended to serve as a simple and practical screening indicator to facilitate risk stratification and guide referral for further evaluation, rather than as a replacement for polysomnography, which remains the diagnostic gold standard for pediatric OSA.

Despite these findings, this study has certain limitations. First, as a single-center retrospective study, the representativeness of the sample may be limited. The sample sizes in some subgroups were relatively small, resulting in wider confidence intervals for certain estimates and limiting the statistical power to detect subtle differences between indicators. This is particularly important when interpreting the finding that the AUC value for the NC (0.925[95% CI: 0.814–1.000]; $p < 0.01$) was slightly higher than that for the NHR (0.913[95% CI: 0.782–1.000]; $p = 0.01$) in the group of girls aged 10 years and older. The significant overlap in confidence intervals indicates this difference lacks statistical significance, likely reflecting random variation due to small sample size rather than true predictive value of NC. Second, although we adjusted for tonsil and adenoid size, residual confounding from unmeasured factors such as maxillofacial characteristics cannot be entirely ruled out. Additionally, the NHR threshold requires further validation through prospective studies in children at different developmental stages. Future research should integrate imaging examinations and biomarker detection to construct multidimensional predictive models.

Conclusion

This study demonstrates that the NHR exhibits moderate predictive capability for identifying moderate/severe OSA in children above 10 years old. Its efficacy surpasses that of indicators such as the WHtR, HHR, and BMI Z-score in both overall and age-stratified analyses. This suggests that the NHR may serve as an adjunctive assessment tool in pediatric OSA screening, holding potential for clinical application.

Data Sharing Statement

The data are available from the corresponding authors upon reasonable request.

Ethics Approval and Informed Consent

Ethical approval for this study was obtained from the Capital Center for Children's Health, Capital Medical University in Beijing, China (Ethical Review NO.: SHERLL2025108), based on the principles of the Declaration of Helsinki. The informed consent was obtained from all participants, together with their parents informed written consent.

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Author Contributions

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Xiaoyi Wang-Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing.

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Jun Tai-Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing.

All authors took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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