The Role of Overnight Oximetry in Assessing the Severity of Obstructive Sleep Apnoea in Typically Developing Children – A Multicentre Study

Authors: Anna C Selby[1,2], Elise Buchan[3], Matthew Davies[4], Catherine M Hill[1,2], Ruth N Kingshott[5], Ross Langley[3], Julia McGovern[3], Calum Presslie[3], Emily Senior[6], Supriya S Shinde[2], Ho Ming Yuen[1], Martin P Samuels[4], Hazel J Evans[2]

Institutions:

[1] Faculty of Medicine, University of Southampton

[2] Child Health, University Hospital Southampton NHS Foundation Trust

[3] Royal Hospital for Children Glasgow

[4] Great Ormond Street Hospital, London

[5] Sheffield Children's Hospital NHS Foundation Trust

[6] Guy's and St Thomas' Hospital, London

Corresponding author: Dr Anna Selby

Child Health, Southampton General Hospital, Tremona Road, Southampton, SO16 6YD
annaselby@doctors.org.uk

Funding Statement

This work received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Author Contributions

Study design and conception- AS, HJE, MPS, RNK and RL. Data acquisition- SS, MD, ES, EB, JM and CP. Data analysis and interpretation- AS, HJE, HMY, MPS, RNK, RL and CMH. Drafting of manuscript- AS, HJE and RNK. All authors reviewed/critiqued the manuscript, approved the final version and agree to be accountable for all aspects of the work.

Key messages

What is already known the topic:

Polysomnography (PSG) and cardiorespiratory polygraphy (CRP) are the preferred tools for investigating obstructive sleep apnoea (OSA) in children. They are, however, expensive and limited to specialist centres. There is limited evidence regarding the ability of nocturnal pulse oximetry (NPO), which is cheaper and more accessible, to diagnose OSA in typically developing (TD) children.

What this study adds:

This study has evaluated the ability of a range of NPO indices to predict OSA in TD children. It was found that raised ODI3 and ODI4 (the number of 3% and 4% oxygen desaturations from baseline/hour, respectively) can predict OSA with high specificity but variable sensitivity.

How this study might affect research, practice or policy:

NPO may be a suitable alternative to PSG/CRP for diagnosing moderate-severe OSA but low sensitivities to detect mild OSA mean that confirmatory PSG/CRP is needed if NPO is normal.

Abstract

Background and objective: Cardiorespiratory polygraphy (CRP) is the predominant technology used to diagnose obstructive sleep apnoea (OSA) in tertiary centres in the UK. Nocturnal pulse oximetry (NPO) is, however, cheaper and more accessible. This study evaluated the ability of NPO indices to predict OSA in typically developing (TD) children.

Methods: Indices from simultaneous NPO and CRP recordings were compared in TD children (aged 1-16 years) referred to evaluate OSA in three tertiary centres. OSA was defined as an obstructive apnoea-hypopnoea index (OAHI) ≥1 event/hour. Receiver operating characteristic curves assessed the diagnostic accuracy of NPO indices including ODI3, ODI4, delta 12s index and minimum oxygen saturations. Two by two tables were generated to determine the sensitivities and specificities of whole number cut-off values for predicting OAHIs ≥1, 5 and 10 events/hour.

Results: Recordings from 322 TD children, 197 male (61.2%), median age 4.9 years (range 1.1 -15.6) were reviewed. OAHI was ≥1/h in 144 (44.7%), ≥5/h in 61 (18.9%) and ≥10/h in 28 (8.7%) cases. ODI3 and ODI4 had the best diagnostic accuracy. ODI3 ≥7/h and ODI4 ≥4/h predicted OSA in TD children with sensitivities/specificities of 57.6%/85.4% and 46.2%/91.6%, respectively. ODI3 ≥8/h was the best predictor of OAHI≥ 5/h (sensitivity 82%, specificity 84.3%).

Conclusion: Raised ODI3 and ODI4 predict OSA in TD children with high specificity but variable sensitivity. NPO may be an alternative to diagnose moderate-severe OSA if access to CRP is limited. Low sensitivities to detect mild OSA mean that confirmatory CRP is needed if NPO is normal.

Introduction

Obstructive sleep apnoea (OSA) is the commonest form of sleep disordered breathing (SDB) in typically developing (TD) children, affecting 1-3%. [1] It causes numerous problems including cognitive impairment and behavioural difficulties. [1] Overnight polysomnography (PSG), which determines sleep stages using electroencephalogram is considered the gold standard test for diagnosing OSA. [2,3] Cardiorespiratory polygraphy (CRP), which estimates sleep time is recognised as an acceptable alternative [2] with good diagnostic capability in populations with a modest to high pre-test probability of OSA. [4] Use of PSG and CRP is limited to specialist centres due to their complexity and cost. Attention has therefore focused on nocturnal pulse oximetry (NPO), which can be undertaken at home or in hospital, is simpler to report and relatively inexpensive. [3,5,6]

The ability of NPO to detect OSA in children has been evaluated in multiple studies [7-14] with superior diagnostic accuracy (particularly specificity) for detecting moderate/severe OSA compared to mild OSA. [9,11-13] Sensitivity and specificity levels varied depending on the NPO parameters evaluated and cut-offs used; potentially because some studies included children with co-morbidities. These children experience more challenging, multifactorial SDB with obstructive and non-obstructive components, which NPO cannot differentiate. [3] The heterogeneity of the population in previous studies means the results may not be applicable to specific groups of children in clinical practice. It remains unclear which NPO indices best predict OSA compared to CRP and PSG. Previous studies have used receiver operating characteristic (ROC) curves to report indices with optimum combined sensitivity and specificity. [12,14] There is, however, a need to understand the sensitivities and specificities of NPO indices to predict OSA over a range of cut-off values. Furthermore, not all previous studies used motion-resistant oximeters with shorter averaging times, [15] which provide improved diagnostic accuracy. [16]

This study aimed to report sensitivities and specificities of commonly used NPO indices over a range of values to determine the optimum cut-off values for predicting OSA in TD children.

Methods

Study design

This study retrospectively compared simultaneous CRP and NPO recordings of consecutive children at three UK centres between May 2016-May 2021 inclusive. Centres included University Hospital Southampton NHS Foundation Trust, Great Ormond Street Hospital for Children, London, and the Royal Hospital for Children Glasgow, which provide tertiary sleep services. Studies (undertaken at home or in hospital) were included for TD children aged 1-16 years referred to evaluate OSA. Children with co-morbidities including obesity (BMI standard deviation score >3), haemoglobin disorders and those on oxygen therapy or non-invasive ventilation were excluded. Studies were excluded if less than 4 hours of artefact free data (from either NPO or CRP) was obtained.

Data collection

CRP was recorded using SOMNOscreen [SOMNOmedics, Germany] (Southampton and Glasgow); SOMNOtouch [SOMNOmedics, Germany] (Southampton) or Embla [Natus, USA] (London). Respiratory effort was measured using thorax and abdominal respiratory inductance bands (RIP), alongside the derived RIP sum channel for surrogate marker analysis if required. Oxygen saturations (SpO_2) and pulse rate were measured by Nonin integrated probe. Electrocardiogram, body position, movement and nasal pressure flow were routinely recorded, while video, audio and transcutaneous carbon dioxide (CO_2) were recorded in some children. All children underwent simultaneous standalone NPO [Masimo, USA] or oxicapnography via transcutaneous monitoring [TCM4 and TCM5; Radiometer with inbuilt Masimo oximetry) with a 2 second averaging time.

CRP recordings were scored by sleep physiologists according to American Academy of Sleep Medicine (AASM) rules. [17,18] Each 30 second epoch was classified as ‘estimated sleep’ or ‘wake’. Oxygen desaturations ≥3% were autoscored and then reviewed manually. Apnoeas were scored if there was ≥90% flow reduction from baseline for ≥2 breaths. They were classified as ‘obstructive’ if

respiratory effort continued during absent flow, 'mixed' if part of the event had continued and part had cessation of respiratory effort, and 'central' if there was cessation of respiratory effort with an associated ≥3% desaturation or if the central apnoea lasted ≥20 seconds. Hypopnoeas were scored if there was ≥30% reduction in baseline flow for ≥2 breaths with an associated ≥3% desaturation. The RIP sum was used as a surrogate for nasal pressure flow if the flow sensor was removed by the child. Physiologists were not blinded.

Outcomes

The following NPO parameters were recorded: mean baseline SpO_2 (%), number of 3% (ODI3) and 4% (ODI4) oxygen desaturations from baseline/hour, minimum SpO_2 (%), delta 12s index as a measure of variability over 12 seconds (D12) and percentage of analysis time with SpO_2 <94, 92 and 90%. Visi-Download software (Stowood Scientific, UK) was used for analysis. This reports the above variables including whole number desaturations > 3% or 4% i.e. ODI3 refers to desaturations >4.0% and ODI4 refers to desaturations >5.0%. Visi-download software uses artefact rejection software to identify oximetry trace sections of probe disconnection and low signal confidence. These and probable wake sections (from diary cards or live monitoring of studies) were removed.

CRP data was downloaded using Domino software (Somnomedics) and Remlogic software (Embla). In this analysis, the mixed/obstructive apnoea-hypopnoea index (OAHI) (events/hour) was the outcome of interest.

Definitions

OSA was defined as OAHI ≥1/h, moderate OSA as OAHI ≥ 5/h and severe OSA as OAHI ≥10/h. [3]

Statistical analysis

Data were stored in Microsoft Excel and analysed using SPSS [version 28]. Normally distributed variables were summarised by mean and standard deviation. Non-normally distributed variables were summarised by median and 5^{th}-95^{th} centiles. Groups were compared using the independent samples t-test (normally distributed data) or the Mann Whitney U-test (non-normally distributed data).

Receiver operating characteristic (ROC) curves were used to assess the diagnostic accuracy of ODI3, ODI4, D12, minimum SpO_2 and % time with SpO_2 < 94, 92 and 90% to predict OAHI ≥1, 5 and 10/h. An area under the curve (AUC) of 0.7-0.8 was considered acceptable, 0.8-0.9 as excellent and >0.9 as outstanding. [19] Two by two tables were generated to determine the sensitivity and specificity of whole number cut-off values of ODI3, ODI4 and minimum SpO_2. Positive and negative predictive values (PPV and NPV) were also calculated. For D12 and % time with SpO_2 <94, 92 and 90%, optimum cut-off values were derived from ROC curve co-ordinates. Further analysis was not undertaken for variables where AUC was less than 0.7. A sensitivity/specificity of 65-80% was considered 'moderate', a sensitivity/specificity of 80-90% as 'high' and a sensitivity/specificity of 90-100% as 'very high'. [1]

Ethical approval

The study was registered with University Hospital Southampton NHS Foundation Trust as a service evaluation (QI/0007).

Results

Participants

322 children were included; 197 (61.2%) were male. The median age of participants was 4.9 years (range 1.1 to 15.6). There were 144 children (44.7%) with OAHI ≥1/h, 61 (18.9%) with OAHI ≥5/h and 28 (8.7%) with OAHI ≥10/h.

The mean baseline SpO_2 of participants with OSA was 97.3% and was similar across severities (table 1). Median ODI3 ranged from 4.13/h in those without OSA to 8.08/h in those with OAHI ≥1/h and 19.72 in those with OAHI ≥10/h. The median ODI4 was 1.83/h in children without OSA compared to 3.67/h in those with OSA (p<0.001). It was greatest in children with OAHI ≥10/h at 10.27/h. Mean D12 was 0.33 in children without OSA compared to 0.46 in those with OSA (p<0.001) and 0.67 in those with OAHI ≥10/h (p<0.001).

ODI3 as a predictor of OSA

For ODI3, AUC ranged from 0.77 (95% CI 0.72-0.82, p<0.005) for predicting OAHI ≥1/h to 0.90 (95% CI 0.83-0.98, p<0.005) for predicting OAHI ≥10/h (figure 1). ODI3 ≥7/h was associated with the best combination of sensitivity (57.6%) and specificity (85.4%) for predicting OAHI ≥1/h. For OAHI ≥5/h, ODI3 ≥ 8/h provided high sensitivity (82.0%) and high specificity (84.3%) (table 2). The associated PPV and NPV were 54.9% and 95.2%, respectively (table S1). For OAHI ≥10/h, ODI3 ≥11/h provided optimum combined sensitivity (85.7%) and specificity (85.4%) (table 2).

ODI4 as a predictor of OSA

For ODI4, AUC ranged from 0.76 (95% CI 0.71-0.82, p<0.005) for predicting OAHI ≥1/h to 0.90 (95% CI 0.82-0.98, p<0.005) for predicting OAHI ≥10/h (figure 2). ODI4 ≥2/h provided the highest combined sensitivity and specificity for predicting OSA. However, when considering only ODI4 cut-offs with specificity >80%, ODI4 ≥4/h provided the highest combined sensitivity (46.2%) and specificity (91.6%) for predicting OAHI ≥1/h (table 2). For OAHI ≥5/h, ODI4 ≥4/h provided moderate sensitivity (75.4%) and high specificity (86.5%) with PPV and NPV of 56.8% and 93.8%, respectively (table S1). For OAHI ≥10/h, ODI4 ≥5/h provided high sensitivity (85.7%) and specificity (85.7%) (table 2).

Delta 12s index (D12) as a predictor of OSA

The ability of D12 to predict OSA was moderate with AUC of 0.7 (95% CI 0.64-0.76, p<0.005). However, diagnostic accuracy was better for more severe OSA; AUC for OAHI ≥5/h was 0.82 (0.75-0.88, p<0.005) and for OAHI ≥10/h it was 0.85 (95% CI 0.75-0.94, p<0.005) (figure S1).
D12 ≥0.44 provided the optimum combined sensitivity (51.0%) and specificity (85.4%) for predicting OAHI ≥1/h (table 3). For OAHI ≥5/h, D12 ≥0.44 was also associated with the highest combined sensitivity (73.8%) and specificity (79.2%). For OAHI ≥10/h, D12 ≥0.50 provided optimum combined sensitivity and specificity with values of 78.6% and 87.4%, respectively.

Minimum saturations (SpO_2) as a predictor OSA

The diagnostic accuracy of minimum SpO_2 for identifying children with OAHI ≥1/h was poor with AUC of 0.65 (95% CI 0.59-0.71, p<0.005). AUC was higher for OAHI ≥5/h (0.76, 95% CI 0.69-0.83, p<0.005) and OAHI ≥10/h, (0.79, 95% CI 0.68-0.89, p<0.005) (figure S2). The sensitivity and specificity values for minimum SpO_2 as a predictor of OAHI ≥5/h and 10/h are shown in table S2.

Percentage of analysis time with saturations (SpO_2) < 94, 92 and 90%

The diagnostic accuracy of percentage of time with SpO_2 <94, 92 and 90% was poor for OAHI ≥1/h with AUCs of 0.69, 0.69 and 0.66, respectively (figures S3-S5). Diagnostic accuracy was, however, good for severe OSA with AUCs of 0.84, 0.86 and 0.82, respectively (figures S3-S5). Tables S3-S5 show the optimum cut-off values for predicting OAHI ≥5 and 10/h.

Discussion

This study explored the ability of NPO indices to predict OSA in TD children with suspected OSA. Previous studies evaluating the diagnostic accuracy of NPO to predict OSA included children with and without co-morbidities and focused primarily on optimum combined sensitivity/specificity. Based on area under the ROC curve, ODI3 and ODI4 had the best diagnostic accuracy. For all NPO indices, AUC was greater for more severe OSA. For minimum SpO_2 and % time with SpO_2 <94, 92 and 90%, AUC was <0.7 for OAHI ≥1/h, suggesting that these indices cannot accurately predict mild OSA.

ODI3 >7/h and ODI4 > 4/h are the recommended cut-offs for abnormality in children over 2 years of age. [1,15,20] We found that ODI3 ≥7/h and ODI4 ≥4/h predicted OSA in children with high specificity (85.4% and 91.6%, respectively) but poor sensitivity (57.6% and 46.2%, respectively). However, our findings suggest that ODI3 ≥8/h is a more appropriate intervention threshold than ODI3 ≥7/h because ODI3 ≥8/h was associated with superior specificity for OAHI ≥5/h. For OAHI ≥10/h, we recommend using cut-off values of ≥11/h for ODI3 and ≥5/h for ODI4. In keeping with our findings, previous studies evaluating the role of NPO in diagnosing OSA, have also demonstrated superior diagnostic accuracy for severe compared to mild OSA. [9,11,12]

Optimum cut-off points may depend on the population studied. Van Eyck et al found that ODI3>4.31/h predicted OAHI>1/h with sensitivity and specificity of 50% and 93%, respectively in 130 obese children. [21] In our sample of non-obese TD children, specificity >90% was only achieved with ODI3 cut-offs of ≥8. In children with Down syndrome, Hill et al demonstrated that D12 >0.555 was the best NPO predictor of OAHI ≥5/h (sensitivity 92%, specificity 65%). [14] We found, however, that a lower cut-off (D12 ≥0.44) was a better predictor of OAHI ≥5/h (sensitivity 73.8%, specificity 79.2%). These differences highlight the importance of studying different patient groups and interpreting findings in clinical context. When interpreting PPV and NPV, disease prevalence is an important consideration. Low prevalences of moderate-severe OSA in our cohort may explain the low PPV for

ODI3 and ODI4 for predicting OAHI≥5/h and OAHI≥10/h. However, high NPVs in our cohort mean that moderate-severe OSA can be ruled out in 95.2% and 93.8% of children with ODI3 <8/h and ODI4 <4/h. It is unsurprising that minimum SpO_2 and time with SpO_2 <94, 92 and 90% were less accurate predictors of OSA, as these probably relate to other physiological functions such as lung capacity and ventilation-perfusion matching.

Strengths and Limitations

To our knowledge, this is the largest study to date to explore the role of NPO in diagnosing OSA in TD children. Clinicians can use the results to determine optimum cut-off points for diagnosing OSA or referring for further investigation dependent on their patient population. Use of simultaneous NPO and CRP recordings ensures results are directly comparable, without influence of night-to-night variability.

There are limitations to this study: firstly, selection bias; children with severe OSA who were diagnosed based on symptoms and NPO alone are not represented. Secondly, CRP rather than PSG was used to diagnose OSA. Therefore, sleep time was estimated and OAHIs may have been under-estimated due to underscoring of hypopnoeas not associated with desaturations. If PSG had been used, the classification of different levels of OSA may have been different. All studies were, however, scored according to AASM guidelines [17,18] and use of CRP to diagnose OSA in children is an accepted approach. [2,22]

The findings of this study only apply to data obtained from Masimo or TCM Masimo oximeters and analysed using Visi-Download software. This is, however, one of the most used software packages for analysing NPO data so the study results are still widely applicable. Further work could be undertaken to determine whether any other parameters e.g. mean SpO_2 nadir are predictors of OSA or whether a score combining different parameters improves diagnostic accuracy. Furthermore,

diagnostic accuracy could potentially be improved by SpO_2 measures with another sensor focusing on arousals e.g. a mandibular motion device. [23] The ability of NPO to predict OSA in different patient groups e.g. children with severe obesity and neuromuscular disorders also needs further exploration.

Summary

This study provides unique data on the diagnostic accuracy of NPO to predict OSA in non-obese TD children. By presenting sensitivities and specificities for a range of whole number cut-off values, our findings allow clinicians to decide how to use NPO results within their clinical practice. For example, this data may be useful to centres using NPO pre-operatively for children with suspected severe OSA secondary to adenotonsillar hypertrophy (as recommended by the British Thoracic Society guideline for diagnosing and monitoring paediatric SDB). [1] Increased use of NPO to diagnose OSA would reduce the burden on healthcare resources given that PSG and CRP are more expensive and limited to specialist centres. Our results suggest that ODI3 and ODI4 are good predictors of moderate-severe OSA in TD children and that NPO may be a suitable alternative to PSG/CRP for diagnosing this. However, low sensitivities to detect mild OSA mean NPO cannot rule out mild OSA. Confirmatory PSG/CRP is therefore needed if NPO is normal in TD children with suspected OSA.

References

1. Evans HJ, Gibson NA, Bennett J, et al. British Thoracic Society Guideline for Diagnosing and Monitoring Paediatric Sleep-Disordered Breathing. Thorax 2023; 78 (Suppl 2): 1-27.
2. Kaditis AG, Alonso Alvarez ML, Boudewyns A, et al. Obstructive sleep disordered breathing in 2-to-18-year old children: diagnosis and management. Eur Resp J 2016; 47 (1): 69-94.
3. Garde AJB, Gibson N, Samuels MP, et al. Recent advances in paediatric sleep disordered breathing. Breathe 2022; 0: 220151.
4. Riha RL, Celmina M, Cooper B, et al. ERS technical standards for using type III devices (limited channel studies) in the diagnosis of sleep disordered breathing in adults and children. Eur Resp J 2023; 61: 2200422.
5. Kapur VK, Auckley DH, Chowdhuri S, et al. Clinical Practice Guideline for Diagnostic Testing for Adult Obstructive Sleep Apnea: An American Academy of Sleep Medicine Clinical Practice Guideline. Journal of Clinical Sleep Medicine 2017; 13: 479-504.
6. Twiss J, Chawla J, Davey MJ, et al. Overnight oximetry for evaluating paediatric obstructive sleep apnoea: Technical specifications and interpretation guidelines. Journal of Paediatrics and Child Health 2019; 55: 1279.
7. Brouilette RT, Morielli A, Leimanis A, et al. Nocturnal pulse oximetry as an abbreviated testing modality for pediatric obstructive sleep apnoea. Pediatrics 2000; 105 (2): 405-12.
8. Ehsan Z, He S, Huang G, et al. Can overnight portable pulse oximetry be used to stratify obstructive sleep apnoea risk in infants? A correlation analysis. Paediatr Pulmonol 2020; 55 (8): 2082-2088.
9. Jonas C, Thavagnanam S, Blecher G, et al. Comparison of nocturnal pulse oximetry with polysomnography in children with sleep disordered breathing. Sleep Breath 2020; 24 (2): 703-7.
10. Kirk VG, Bohn SG, Flemons WW, et al. Comparison of home oximetry monitoring with laboratory polysomnography in children. Chest 2003; 124 (5): 1702-8.
11. Ma JR, Huang JJ, Chen Q, et al. Value of pulse oximetry watch for diagnosing paediatric obstructive sleep apnea/hypopnea syndrome. Acta Otolaryngol 2018; 138 (2): 175-179.
12. Tsai CM, Kang CH, Su MC, et al. Usefulness of desaturation index for the assessment of obstructive sleep apnoea syndrome in children. Int J Pediatr Otorhinolaryngol 2013; 77 (8): 1286-90.
13. Villa MP, Pietropaoli N, Supino MC, et al. Diagnosis of Pediatric Obstructive Sleep Apnoea Syndrome in Settings with Limited Resources. JAMA Otolaryngol Head Neck Surg 2015; 14 (11): 990-6.
14. Hill CM, Elphick HE, Farquhar M, et al. Home oximetry to screen for obstructive sleep apnoea in Down Syndrome. Arch Dis Child 2018; 103: 962-967.
15. Ong JWY, Williams D, Gavlak J, et al. Observational study to define reference ranges for the 3% oxygen desaturation index during sleep in healthy children under 12 years using oximetry motion-resistant technology. Arch Dis Child 2021; 106: 583-586.

16. Trang H, Boureghda S, Leske V. Sleep desaturation: comparison of two oximeters. Pediatric Pulmonology 2004; 37(1): 76-80.

17. Berry RB, Abreu AR, Bibbs ML, et al. The AASM Manual for Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications, version 2.6. Darrien, American Academy of Sleep Medicine, 2020. Available from: https://aasm.org/clinical-resouces/scoring-manual/

18. Berry RB, Brooks R, Gamaldo CE, et al. for the American Academy of Sleep Medicine. The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications, v*ersion* 2.4. Darien: American Academy of Sleep Medicine, 2017. Available from: https://aasm.org/clinical-resouces/scoring-manual/

19. Mandrekar JN. Receiver Operating Characteristic Curve in Diagnostic Test Assessment. J Thorac Oncol 2010; 5: 1315-1316.

20. Urschitz MS, Wolff J, Von Einem V, et al. Reference values for nocturnal home pulse oximetry during sleep in primary school children. Chest 2003; 123(1): 96-101.

21. Van Eyck A, Lambrechts C, Vanheeswijck L, et al. The role of nocturnal pulse oximetry in the screening for obstructive sleep apnea in obese children and adolescents. Sleep Med 2015; 16(11): 1409-12.

22. Farquhar M, Urquhart DS, Russo K, et al. Arch Dis Child Educ Pract Ed 2020; 105: 136.

23. Martinot J, Cuthbert V, Le-Dong NN, et al. Clinical validation of a mandibular movement signal based system for the diagnosis of pediatric sleep apnea. Pediatric Pulmonology 2022; 57: 1904–1913.

Table 1: Summary of NPO results in study participants

	All children (n=322)	OAHI < 1/h (n=178)	OAHI ≥ 1/h (n=144)	OAHI ≥ 5/h (n=61)	OAHI ≥ 10/h (n=28)
Mean baseline SpO2 (%)*	97.2 ± 5.51	97.0 ± 7.35	97.3 ± 1.19 (p= 0.651)	97.0 ± 1.26 (p=0.968)	96.9 ± 1.47 (p=0.924)
Minimum SpO2 (%)**	90.0 (78.2-95.0)	91.0 (82.0-95.0)	89.0 (73.5-95.0) (p<0.001)	85.0 (69.0-93.9) (p<0.001)	82.5 (49.8-95.2) (p<0.001)
ODI3 (events/h) **	4.29 (0.84-22.85)	4.13 (0.80-11.52)	8.08 (1.24-31.38) (p<0.001)	13.30 (2.53-38.87) (p<0.001)	19.72 (2.43-50.37) (p<0.001)
ODI4 (events/h) **	1.91 (0.29-11.73)	1.83 (0.23-5.29)	3.67 (0.36-18.88) (p<0.001)	7.00 (1.22-25.46) (p<0.001)	10.27 (0.78-34.83) (p<0.001)
Delta 12s index (D12) *	0.39 ± 0.20	0.33 ± 0.12	0.46 ± 0.25 (p<0.001)	0.58 ± 1.50 (p<0.001)	0.67 ±0.38 (p<0.001)
% time with SpO_2 < 94% **	0.11 (0.00-5.01)	0.08 (0.00-1.48)	0.25 (0.00-15.63) (p<0.001)	1.06 (0.00-19.19) (p<0.001)	1.87 (0.00-31.65) (p<0.001)
% time with SpO_2 < 92% **	0.03 (0.00-1.28)	0.01 (0.00-0.26)	0.07 (0.00-3.66) (p<0.001)	0.37 (0.00-8.89) (p<0.001)	0.63 (0.00-12.22) (p<0.001)
% time with SpO_2 < 90% **	0.00 (0.00-0.64)	0.00 (0.00-0.12)	0.02 (0.00-1.64) (p<0.001)	0.11 (0.00-3.19) (p<0.001)	0.29 (0.00-1.70) (p<0.001)

*Data reported as mean ± standard deviation.

**Data reported as median (5^{th}-95^{th} centiles).

p-values refer to comparison of each group with children without OSA. (OAHI<1/h).

Table 2: Sensitivity and specificity values for a range of whole number ODI3 and ODI4 cut-off values for predicting OAHI ≥ 1, 5 and 10/h

ODI3 ≥ (events/h)	OAHI ≥ 1/h		OAHI ≥ 5/h		OAHI ≥ 10/h	
	Sensitivity	**Specificity**	**Sensitivity**	**Specificity**	**Sensitivity**	**Specificity**
5	65.3% (94/144)	75.3% (134/178)	86.9% (53/61)	67.4% (176/261)	96.4% (27/28)	62.2% (183/294)
6	61.1% (88/144)	81.5% (145/178)	83.6% (51/61)	73.2% (191/261)	89.3% (25/28)	67.3% (198/294)
7	**57.6% (83/144)**	**85.4% (152/178)**	83.6% (51/61)	77.8% (203/261)	89.3% (25/28)	71.4% (210/294)
8	51.4% (74/144)	90.4% (161/178)	**82.0% (50/61)**	**84.3% (220/261)**	89.3% (25/28)	77.6% (228/294)
9	46.5% (67/144)	92.1% 164/178)	77.0% (47/61)	87.0% (227/261)	89.3% (25/28)	81.0% (238/294)
10	42.4% (61/144)	93.8% (167/178)	68.9% (42/61)	88.5% (231/261)	85.7% (24/28)	83.7% (246/294)
11	40.3% (58/144)	94.9% (169/178)	65.6% (40/61)	89.7% (234/261)	**85.7% (24/28)**	**85.4% (251/294)**
12	31.9% (46/144)	93.5% (170/178)	52.5% (32/61)	91.6% (157/260)	71.4% (20/28)	88.4% (260/294)
13	27.8% (40/144)	96.1% (171/178)	50.8% (31/61)	93.9% (245/261)	71.4% (20/28)	90.8% (267/294)
ODI4 ≥ (events/h)	**OAHI ≥ 1/h**		**OAHI ≥ 5/h**		**OAHI ≥ 10/h**	
	Sensitivity	**Specificity**	**Sensitivity**	**Specificity**	**Sensitivity**	**Specificity**
2	**72.0% (103/143)**	**69.1% (123/178)**	90.2% (55/61)	60.4% (157/260)	92.9% (26/28)	54.9 % (161/293)
3	55.2% (79/143)	80.9% (144/178)	83.6% (51/61)	76.2% (198/260)	89.3% (25/28)	70.0% (205/293)
4	46.2% (66/143)	91.6% (163/178)	**75.4% (46/61)**	**86.5% (225/260)**	89.3% (24/28)	80.9% (237/293)
5	38.5% (55/143)	93.8% (167/178)	68.9% (42/61)	90.8% (236/260)	**85.7% (24/28)**	**85.7% (251/293)**
6	32.2% (46/143)	96.1% (171/178)	59.0% (36/61)	93.5% (243/260)	75.0% (21/28)	89.1% (261/293)
7	25.2% (36/143)	96.6% (172/178)	50.8% (31/61)	95.8% (249/260)	67.9% (19/28)	92.2% (270/293)

Values with the optimum combined sensitivity and specificity are highlighted in bold.

Table 3: Sensitivity and specificity values for a range of delta 12s (D12) index cut-off values for predicting OAHI ≥ 1, 5 and 10/h

D12 ≥	OAHI ≥ 1/h		OAHI ≥ 5/h		OAHI ≥ 10/h	
	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
0.37	66.4%	66.3%	83.6%	60.0%	89.3%	55.6%
0.38	62.9%	69.7%	80.3%	63.5%	89.3%	59.4%
0.39	60.8%	75.3%	78.7%	68.1%	85.7%	63.5%
0.40	58.0%	75.8%	77.0%	69.6%	85.7%	65.2%
0.41	55.9%	78.7%	77.0%	72.7%	85.7%	67.9%
0.42	54.5%	80.3%	77.0%	74.6%	85.7%	69.6%
0.43	51.7%	82.6%	75.4%	77.3%	85.7%	72.4%
0.44	**51.0%**	**85.4%**	**73.8%**	**79.2%**	82.1%	74.1%
0.45	44.8%	86.5%	68.9%	82.3%	82.1%	77.8%
0.46	43.4%	87.6%	68.9%	83.8%	82.1%	79.2%
0.47	39.2%	88.8%	65.6%	86.2%	78.6%	81.9%
0.48	37.8%	91.6%	62.3%	88.1%	78.6%	84.0%
0.49	35.0%	92.1%	59.0%	89.2%	78.6%	85.7%
0.50	32.9%	93.3%	57.4%	90.8%	**78.6%**	**87.4%**
0.51	31.5%	93.3%	55.7%	91.2%	75.0%	87.7%
0.52	30.8%	94.4%	54.1%	91.9%	71.4%	88.4%

Values with the optimum combined sensitivity and specificity are highlighted in bold.