

Home-based Screening for Obstructive Sleep Apnea in Children

Dylan Bertoni¹ and Amal Isaiiah^{1,2}

1. Department of Otorhinolaryngology—Head and Neck Surgery, University of Maryland School of Medicine, Baltimore, MD, USA;

2. Department of Pediatrics, University of Maryland School of Medicine, Baltimore, MD, USA

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Pediatric obstructive sleep apnea (OSA) is the most severe form of sleep disordered breathing, characterized by repeated airway obstruction and desaturation during sleep. The current diagnostic gold standard is overnight polysomnography (PSG), which stratifies the severity of OSA based on the apnea hypopnea index (AHI). The first line of treatment is tonsillectomy and adenoidectomy, which leads to the resolution, or the improvement of, the condition in the majority of the children. Children with severe OSA (defined as AHI >10) are at an elevated risk of perioperative adverse events, and are typically monitored overnight following tonsillectomy and adenoidectomy. However, only a small number of children undergo a preoperative PSG due to the high cost, and relatively low number, of certified sleep centers. Thus, there is a strong need for an improved screening pathway for children with OSA. While home sleep apnea testing (HSAT) has become central to the diagnosis of OSA in adults, there is a paucity of data validating the use of HSAT in children. The purpose of this review is to highlight and examine recent developments in physiological monitoring that could improve the diagnostic and screening strategies for pediatric OSA.

Keywords

Pediatric obstructive sleep apnea, polysomnography, home sleep apnea testing

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Corresponding Author: Amal Isaiiah, Department of Otorhinolaryngology—Head and Neck Surgery, University of Maryland School of Medicine, 16 S Eutaw St, Suite 500, Baltimore, MD 21201, USA. E: aisaiiah@som.umaryland.edu

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Sleep disordered breathing in children comprises a spectrum of abnormal breathing patterns associated with increased airflow resistance and sleep disruption. Sleep disordered breathing is categorized by severity into primary snoring, upper airway resistance syndrome, and obstructive sleep apnea (OSA). Pediatric OSA has a prevalence of up to 5% in children.¹ The most common cause of increased upper airway resistance and pharyngeal collapse is attributed to enlarged lymphoid tissue within the tonsils and adenoids.² Additional risk factors include obesity,³ and neuromuscular⁴ or craniofacial disorders.⁵ The most common symptoms reported by parents of children with OSA are snoring and difficulty breathing during sleep. Other nighttime symptoms include gasping, restless sleep, frequent awakenings, enuresis, and sweating.⁶ During the daytime, parents may also report difficulty waking the child and excess sleepiness, but children more commonly experience behavioral impairments such as aggression, impulsivity, and hyperactivity;^{7,8} or neurocognitive impairments such as deficits in attention, executive function, and language.⁹ Untreated OSA has also been associated with detrimental effects on growth and development,¹⁰ memory,¹¹ and quality of life¹² in children, therefore supporting its prompt diagnosis and management.

Pediatric OSA is diagnosed and stratified by standard overnight polysomnography (PSG).¹³ This is performed at certified sleep centers, and is scored by trained technicians according to guidelines published by the American Academy of Sleep Medicine (AASM).¹⁴ PSG measures the following during sleep: sleep stage, cardiac rhythm, oxygen saturation, muscle tone, body position, movement, and airflow. Currently, the AASM¹⁴ and the American Academy of Pediatrics¹⁵ recommend PSG for children with symptoms of sleep disordered breathing, while the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS) recommends the screening of high-risk children.¹⁶ The severity of OSA is scored using the apnea hypopnea index (AHI), defined as the frequency of partial or complete reduction in airflow per hour. The most common classification system categorizes OSA as mild, moderate, and severe, based on the AHI thresholds of 1, 5, and 10 events per hour, respectively.¹²

The treatment of OSA depends on the severity and etiology of the obstruction. The standard of treatment is tonsillectomy and adenoidectomy, which leads to the resolution, or improvement, of the condition in the majority of children.¹⁵ Mild OSA may sometimes be managed with pharmacotherapy, such as intranasal steroids, to reduce upper airway inflammation.¹⁷ In children with persistent OSA after tonsillectomy and adenoidectomy, or in children with other complex comorbidities, additional surgery or treatment, such as continuous positive airway pressure (CPAP), may play a role.^{18–22} While CPAP is the standard of treatment of OSA in adults, non-compliance observed in children negatively impacts the management of persistent OSA.²³

Table 1: Summary of differences between polysomnography and home sleep apnea testing

Metric	PSG	HSAT
Cost	High (\$1,000–4,000)	Low*
Convenience	Inconvenient/cumbersome	Convenient/easy to use
Safety	Safe	Safe
Accessibility	Difficult to access/schedule, long wait times	Easily accessible
Personnel	Additional technicians needed for implementation/interpretation	No additional personnel required
Diagnostics	Gold-standard for diagnosis, reference for sensitivity/specificity/accuracy	Not clinically validated, lower sensitivity/specificity/accuracy

*Relative to standard PSG, cost savings between 22% and 42% have been reported with HSAT use in adults with OSA. Downstream costs of a 12% HSAT failure rate resulting in PSG were not included. HSAT = home sleep apnea testing; OSA = obstructive sleep apnea; PSG = polysomnography.

Due to the increased risk of perioperative respiratory complications associated with anesthesia, children with severe OSA defined by $AHI \geq 10$ are observed overnight following surgery,¹⁶ which requires a preoperative PSG that costs \$1,000–4,000.^{24,25} Furthermore, the inadequate number of sleep laboratories and trained personnel may lead to long wait times in some areas, which partially explains the preoperative utilization of PSG remaining below 10%.²⁶ Clinical parameters, such as parental history and physical examination findings are poor predictors of the presence and/or severity of OSA.^{27,28} Furthermore, seemingly healthy children could be diagnosed with very severe OSA,²⁹ and treatment-related changes in OSA outcomes are not causally attributable to changes in OSA severity as measured by PSG, supporting an improved screening pathway for children with OSA.³⁰

Home sleep apnea testing (HSAT) involves the use of portable or wearable sensors during sleep at home to screen for OSA with or without a PSG. Generally, HSAT requires significantly fewer resources and may provide clinical benefit at a lower cost.³¹ However, the AASM does not support the universal use of HSAT in children due to lack of data supporting its validity in an unsupervised environment.³¹ Furthermore, the application of probes with cables in children may pose a hazard. Finally, the use of AHI as an objective parameter to define treatment candidacy, as well as to measure the efficacy of its treatment, places a major barrier for its expanded use as a comparable metric has not been defined in this population. The purpose of this review is to highlight and examine some of the recent strategies being proposed as potential screening or diagnostic tools for pediatric OSA, and to emphasize the need for further research to validate the use of HSAT.

Screening technologies

The central theme of HSAT is to replicate the accuracy of in-lab testing while remaining safe and easy-to-use at home. This is commonly achieved by specific polysomnographic channels or their combinations. These signals can be separated by domains of interest according to the Sleep, Cardiovascular, Oximetry, Position, Effort, and Respiratory (SCOPER) acronym.^{32,33} Each section of this review will address these domains and their feasibility as HSAT for children, either on their own or as a combination, instead of a regular, overnight, laboratory-based PSG. A summary of key differences between PSG and HSAT is shown in *Table 1*.

Sleep

Standard PSG combines electroencephalography (EEG) with electromyography and electrooculography to determine sleep stage and distinguish between asleep and awake states. The electrical activity

measured by leads attached to the scalp, chin/neck musculature, and around the eyes, is scored by a technician.³⁴ While home EEG recordings are technically possible, the need for application of the conducting gel to reduce impedance levels and the potential for injury from loose wires are likely to prevent its widespread use.³⁵ Collop et al.³² recommend the inclusion of sensors in the sleep domain, because ideally the ultimate index used to assess the severity of sleep disordered breathing will depend upon the amount of time spent asleep, rather than the amount of time spent recording. Alternative options for assessing sleep/wake states include video monitoring^{36,37} and actigraphy. Actigraphy uses accelerometers to measure movement data. Clinically validated actigraphs are useful for the estimation of parameters such as the total sleep time and sleep efficiency.^{38–40} Actigraphy could be used to estimate sleep/wake states when PSG is unavailable.^{41,42} In other studies, a polyvinylidene difluoride (PVDF) sensor in bedsheets, when combined with wrist actigraphy, detected sleep/wake states in up to 90% of the instances when compared to PSG. Furthermore, the heart rate and respiratory rate measured by the sheet sensor had overall accuracy exceeding 95%.⁴³

Sleep quality has also been assessed with clinically validated parental questionnaires such as the Pediatric Sleep Questionnaire,⁴⁴ the Epworth Sleepiness Scale,⁴⁵ the OSA Score,⁴⁶ and the OSA-18.⁴⁷ These questionnaires have shown mixed results with predicting the presence of OSA, and cannot accurately determine OSA severity.²⁸ However, eliminating redundant items in these questionnaires has been shown to improve their predictive performance for OSA severity,⁴⁸ and data mining and machine learning algorithms may also improve their accuracy.⁴⁹

Cardiovascular

The chronic airflow obstruction and hypoxemia that occur in children with OSA have been associated with detrimental effects on the heart, such as right and left ventricular dysfunction,⁵⁰ elevated blood pressure,⁵¹ and autonomic dysfunction.⁵² The long-term effects of OSA on cardiac health are not well established,⁵³ and preoperative assessments of cardiac function using echocardiography or electrical activity by electrocardiography are not associated with risk reduction.^{54,55} Heart rate variability is a measurement of these inter-beat variations in cardiac rhythm and has been shown to change predictably among children with OSA.⁵⁶ Furthermore, treatment of OSA with tonsillectomy and adenoidectomy has been shown to significantly change heart rate variability parameters, although these changes were not found to be causally mediated by changes in AHI.⁵⁷ Signal analysis of an at-home electrocardiogram (ECG) could be adopted as a screening tool for children with OSA.^{58,59}

Peripheral arterial tonometry (PAT) measures changes in pulse wave amplitude in the finger, representing sympathetic activation in the vasculature resulting from changes in local oxygen levels. In adults, HSAT with PAT has been shown to predict PSG parameters with acceptable accuracy.⁶⁰ The Watch-PAT® (Itamar Medical, Tel-Aviv, Israel) uses both PAT and actigraphy. The Watch-PAT demonstrated very high correlation with AHI in adults,⁶¹ as well as in adolescents;⁶² although its accuracy was only 61% in younger children.⁶³ The sensitivity and specificity of the Watch-PAT vary depending on the threshold set for detecting AHI.^{64,65} Unfortunately, the algorithm used in Watch-PAT is proprietary. Furthermore, the physiology of the autonomic nervous system may change with age, and therefore cannot be generalized for use in all age groups.⁶⁶

Oximetry

Pulse oximetry uses red or infrared light passed through a finger-tip, toe-tip, or earlobe, to measure the amount of oxygen carried by hemoglobin.⁶⁷ Airflow obstruction is associated with peripheral hypoxia, which is detected using oximetry. Overnight oximetry curves alone could be used to identify OSA with a positive predictive value of 97%, and an inter-observer agreement of 80%.⁶⁸ However, when these criteria were used in obese children, the sensitivity and specificity were 58% and 88%, respectively, and the positive predictive value dropped to 69%.⁶⁹ Wearable devices such as the Pulse Oximetry Watch (CloudCare HealthCare Ltd, Chengdu, China) demonstrated poor sensitivities and specificities (<75%) with an AHI threshold of ≤ 15 .⁷⁰ Phone-based oximeters that utilize the phone camera flash and lens with an external plug-in probe can effectively measure oximetry in pediatric patients,⁷¹ and analysis of these recordings yielded an accuracy of 87%, a sensitivity of 80%, and a specificity of 92%.⁷² While oximetry data from a controlled setting can provide useful information, the feasibility of oximetry at home raises concern as parental experience may impact data collection.⁷³ Night-to-night at-home recordings of pulse oximetry were highly consistent with correlations of 90%, although variability increased with younger children.⁷⁴ Difficulties with home oximetry recordings could be overcome by recording over multiple nights.

Position

Sleep-related arousals are a component of the definition of a hypopnea, and therefore contribute to the severity of OSA determined by the AHI. Conventional PSG utilizes body position sensors to track movements and changes in position following arousals.³⁴ Body movement is greatly reduced or eliminated during deep stage 3 and rapid eye movement (REM) sleep relative to lighter sleep stages and awake states, which facilitates identification of the sleep stage. Examples of clinically validated actigraphs include the Motionlogger® Sleep Watch (Ambulatory Monitoring, Ardsley, NY, USA) and Actiwatch-2® (Philips Respironics, Amsterdam, The Netherlands). Actigraphy can achieve reasonably high sensitivity (88–92%) and accuracy (84–86%), but is limited by low specificity (46–66%).^{75,76} While actigraphy is limited in its ability to predict OSA, it is effective at evaluating sleep/wake states in children.⁷⁷ Commercial devices and smartphone applications are associated with poor accuracy.^{76,78} Other position sensors include in-bed sensors, in-pillow sensors, and belts placed around the body.^{79,80}

Effort

The gold standard for effort measurement, which is central to PSG, is esophageal manometry. Due to its invasive nature, it has been

replaced by belt sensors utilizing piezoelectric, polyvinylidene fluoride (PVDF), or respiratory inductance plethysmography (RIP). The sensors in piezoelectric or PVDF belts are located in a portion of the strap and are dependent on the transmission of force along the belt, whereas the entire RIP belt is the sensor.⁸¹ The AASM recommends either dual RIP belts, dual PVDF belts, or a combination of the two for detection of respiratory effort.³⁴ These belt sensors are comfortable and could be implemented in an in-home setting. Dual RIP belts have been combined with oximetry to develop a screening tool for pediatric OSA, with a correct classification rate of 83%.⁸² Recently, PVDF sensors have been compared to RIP in children, finding no significant differences in detecting respiratory events.⁸³ Additionally, suprasternal pressure sensors, such as the PneaVoX (Cidelec, Sainte Gemmes sur Loire, France), have been developed and compared with standard RIP for detection of apneas. Sensitivity ranged from 98–100%, and specificity ranged from 70–75%, with a significant number of RIP-determined central apneas scored as obstructive apneas by PneaVoX.⁸⁴

Respiratory

The AASM defines an obstructive apnea as a decrease in oronasal airflow by 90% or more, and a hypopneic event is defined as a decrease in oronasal airflow by $\geq 50\%$ in the presence of ongoing respiratory effort for two respiratory cycles.³⁴ Given that the reduction in oronasal airflow is central to the definitions of both apneas and hypopneas, airflow measurement devices could potentially be used during HSAT. The principal limitation of nasal pressure transducers is the discomfort experienced by the patient over the course of the night. The Flow Wizard® (DiagnoseIT, Sydney, Australia) is a single-channel nasal airflow pressure transducer to screen for OSA. The accuracy of the Flow Wizard increased from 84% in adult patients with AHI >5 to 96% in patients with AHI >30 . On average, the AHI determined by the Flow Wizard was 6.2 events/hour lower than the standard PSG.⁸⁵ The ApneaLink™ Plus (ResMed, San Diego, CA, USA) also measures airflow in addition to oximetry, respiratory effort, and heart rate. In a study of obese adolescents with mild, moderate, and severe OSA, the sensitivity associated with the use of ApneaLink Plus ranged from 85–100%, and specificity ranged from 46–90%.⁸⁶ Using logistic regression to model home airflow recordings combined with oximetry had an accuracy of 86.3%, a positive predictive value of 88.4%, and an area under receiver operator characteristic curve of 0.95, demonstrating an excellent overall predictive capability.⁸⁷

Conclusions

Although fixed anesthesia protocols may be able to mitigate the perioperative risk associated with OSA,⁸⁸ preoperative risk stratification is necessary for safely performing tonsillectomy and adenoidectomy. The challenges of cost and accessibility warrant continued investigation into alternatives to a PSG. The AASM maintains a position that there is insufficient data to support the current use of HSAT in children. The validation of HSAT in children is limited by the perceived need to achieve results identical to a PSG. Using the AHI as the sole metric for determining resolution of OSA following tonsillectomy and adenoidectomy also precludes the widespread implementation of HSAT in children. That said, PSG is a test of cardiopulmonary variation during sleep and does not predict morbidity in every instance.^{30,89} Clinical parameters are poor predictors of OSA severity, yet a majority of children undergo surgery without a PSG. Furthermore, no outcome-related differences have been

found in these children relative to those who obtain pre-treatment screening or diagnosis with PSG.²⁶ Many of the technologies mentioned in this review unfortunately do not achieve accuracies, sensitivities, or specificities that can be considered equivalent to those of PSG. Additionally, HSAT is unsuitable for the diagnosis of pediatric sleep disorders, such as central sleep apnea, periodic limb movement disorder, and parasomnias, which require video recording and therefore a full PSG.

Currently, HSAT-based testing is the diagnostic standard for adults with OSA. The transition from in-lab PSG to HSAT in the adult population required substantial research into feasibility and cost effectiveness, which could not be replicated in children. The number of children requiring diagnostic evaluation for OSA is also likely to increase with the rising burden of obesity. In an effort to refine healthcare delivery and to contain the costs associated with the screening process, this is a domain that merits further research. □

Article highlights

- Pediatric obstructive sleep apnea has a prevalence of 5%; it is diagnosed by overnight polysomnography and treated with tonsillectomy and adenoidectomy
- Preoperative risk stratification is important to recognize children at risk of perioperative adverse events
- Preoperative polysomnography for all children is not feasible due to the high cost and inadequate number of certified sleep centers
- Home sleep apnea testing is used to diagnose obstructive sleep apnea in adults, but is not approved for use in children due to a lack of data for validation
- A number of sensors and technologies have been developed for data collection in SCOPER domains (Sleep, Cardiovascular, Oximetry, Position, Effort, and Respiratory)
- Further research into these potential screening strategies is warranted to reduce costs associated with diagnosing obstructive sleep apnea, and to improve perioperative safety in these children

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