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Feasibility of split night polysomnography in children to diagnose and treat sleep related breathing disorders

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ABSTRACT

Study objectives: The gold standard test for diagnosis of sleep related breathing disorders (SRBD) in children is diagnostic polysomnography (PSG). This is often followed by a titration PSG to identify optimal non-invasive ventilation (NIV) pressures. Access to pediatric PSG is limited, resulting in delays to diagnosis and initiation of treatment. Split-night PSGs (snPSG) combine a diagnostic and titration PSG into a single night study. Although described in adults, the pediatric literature on this topic is sparse. The objective of this study was to describe a large cohort of children who utilized snPSG to diagnose SRBD and initiate NIV.

Methods: This multi-center study analyzed clinical and PSG data from children with SRBD who had initiated NIV following a snPSG. Data from diagnostic and titration portions of the snPSG were analyzed separately.

Results: The study included 165 children who initiated NIV following a snPSG. The majority of children (61.8%) were initiated on NIV for upper airway obstruction. The population included children with medical complexity, including those with central nervous system disorders (17.0%), musculoskeletal/neuromuscular disorders (12.1%), and cardiac disorders (1.2%). Moderate to severe SRBD was present in 87.2% of children with a median apnea-hypopnea index (AHI) of 16.6 events/hour (IQR: 8.2, 38.2). The median AHI was reduced on treatment to 7.6 events/hour (IQR: 3.3, 17.1), with fewer subjects meeting criteria for severe SRBD.

Conclusions: snPSG is technically feasible in children, facilitating the diagnosis of SRBD and initiation of NIV, even in those with high medical complexity.

Statements

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1. Introduction

Sleep Related Breathing Disorders (SRBD), including obstructive

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Abbreviations

- AHI Apnea Hypopnea Index
- BPAP Bi-level Positive Airway Pressure
- CPAP Continuous Positive Airway Pressure
- NIV Non-invasive Ventilation
- OSA Obstructive Sleep Apnea
- PSG Polysomnography
- REM Rapid-Eye Movement
- SRBD Sleep Related Breathing Disorder
- SE Sleep Efficiency
- SL: Sleep Latency
- snPSG Split-night Polysomnography
- SpO_2 Oxygen Saturation
- TST Total Sleep Time

sleep apnea (OSA), are common in children, as OSA alone has an estimated prevalence of 5.7% [1]. OSA contributes to childhood morbidity, including impaired cognition and executive function, behavioural challenges, cardio-metabolic dysfunction, and reduced quality of life [2]. History, questionnaires, physical exam, and overnight oximetry lack sensitivity and specificity for identifying SRBD in children [1,3–6]. As a result, in-laboratory overnight polysomnography (PSG) is the gold standard for diagnosis of SRBD in children. PSG not only facilitates diagnosis of SRBD, but also can assess the immediate effects of non-invasive ventilation (NIV), including both continuous positive airway pressure (CPAP) and bi-level positive airway pressure (BPAP) on respiratory function and gas exchange [7].

PSG is resource intensive with respect to time, staff, and physical resources. While available PSG resources have remained the same in Canada, demand for pediatric PSGs has increased due to several factors, including the increase in childhood obesity [8], increased survival of medically complex children requiring long-term NIV support, and overall increased awareness of SRBD in pediatric subjects [9,10]. As a result, access may be limited, and wait times for pediatric PSG in Canada can be lengthy [9,11]. Other methods of assessing sleep, such as home studies, are not currently recommended in the pediatric population [12].

Split-night PSG (snPSG) combines a diagnostic and titration PSG into a single study. Typically, in the first half of the study, the diagnostic portion assesses the presence and severity of SRBD. If present, initiation and titration of NIV is performed during the second half of the study. This approach has been shown to be a viable option to increase laboratory capacity and reduce wait times in adults [13–15]. Results suggest that snPSG is effective at diagnosing OSA in adults and can be used to successfully titrate CPAP [16–19]. Although a prior study had demonstrated the reliability of a 4 h diagnostic PSG to diagnose SRBD in infants, this has not been demonstrated in older children [20]. Routine use of snPSG in children is not yet established. Despite a paucity of scientific literature, centers do in fact utilize pediatric snPSGs [21].

This study aims to describe the clinical characteristics and snPSG parameters in a large cohort of children who were diagnosed with SRBDs during snPSG and were initiated on long-term NIV within the same snPSG.

2. Methodology

2.1. Study design

This study used data from a larger multi-center retrospective longitudinal cohort study that aimed to review the clinical presentation, comorbidities, ventilator requirements and long term outcomes for children treated with NIV in Alberta, Canada during the period 2005–2014 [10]. Demographic and clinical characteristic of the subjects, PSG data, and technology related parameters were obtained from medical charts and sleep laboratory records at the time of data collection. This study was approved by the Research Ethics Boards at the University of Alberta and the University of Calgary (Pro00045803).

2.2. Subjects

Subjects were identified through NIV patient lists from the two pediatric tertiary care centers in the province of Alberta: the Stollery Children's Hospital in Edmonton, and the Alberta Children's Hospital in Calgary. The inclusion criteria for this study comprised children aged 0–18 years who were started on long-term NIV for any SRBD following a snPSG between May 2010 and December 2014. NIV was not routinely introduced prior to the snPSG. Subjects were excluded if the total sleep time (TST) was less than 60 min in either the diagnostic or titration portion of the snPSG, or if two or more of the following parameters were missing from the PSG report: total sleep time (TST), sleep efficiency (SE) or sleep latency (SL).

2.3. PSG protocols

PSG was initiated after standard set up as outlined in the American Academy of Sleep Medicine (AASM) scoring manual, including electroencephalograms, electro-oculograms, chin electromyogram, bilateral leg electromyogram, oronasal thermal flow, nasal pressure, snore signal, thoracoabdominal belts, and pulse oximetry [22]. Transcutaneous and end-tidal carbon dioxide (CO2) values were measured during the diagnostic portion, with transcutaneous carbon dioxide monitored during the titration portion of the study. NIV device flow was monitored during the titration portion of the study.

The decision to employ snPSG was made based on the findings on the first (diagnostic) half of the PSG study, performed without NIV. Laboratory protocols at both centers permitted initiating NIV if the AHI was estimated to be > 10 events/hour on a diagnostic PSG, though physicians could elect to initiate NIV at a lower AHI based on the clinical context of the subject which may include gas exchange abnormalities, and/or airflow limitation not meeting scoring criteria, and may have occurred irrespective of the AHI. A period of REM sleep prior to initiating NIV was not required under the sleep laboratory protocols. CPAP was initiated in the presence of airway obstruction, and pressures were increased to eliminate obstructive events. BPAP was initiated if airway obstruction or hypoventilation did not improve with CPAP, for central sleep apnea, or when requested by the ordering physician based on the subject's medical condition.

All PSG data were scored using pediatric scoring criteria from the most up to date AASM scoring manual at the time of the PSG [22]. SRBD was defined as a total AHI >1.5 events/hour, and included both central sleep apnea and obstructive sleep apnea. The secondary use of data already collated in a database did not allow for central and obstructive indices to be separated. Extrapolating from previously published literature, SRBD severity was categorized as follows: AHI <1.5 was considered normal; AHI 1.5 to <5.0 was considered mild; AHI 5.0 to <10.0 was considered moderate; AHI 10.0 and greater was considered severe [23–27].

2.4. Primary and secondary outcomes

The primary aim of the study was to describe a large cohort of

subjects who had initiated on long-term NIV following snPSG. Demographic information, primary diagnoses, comorbidities, and surgeries performed prior to NIV initiation were collected as previously described [10]. The primary condition that led to the need for NIV was grouped into broad categories, including central nervous system, upper airway, cardiac, pulmonary, and musculoskeletal/neuromuscular disorders [10].

Specific PSG parameters that were collected included: TST, SL, sleep efficiency (SE), AHI, mean and minimum pulse oxygen saturation (SpO_2), and the presence of hypoventilation. Hypoventilation was defined as a CO2 level greater than 50 mmHg for at least 25% of the TST using either transcutaneous or end-tidal monitoring [22].

Adherence data were available for a small subgroup of subjects via electronic download from the NIV device. This follow up was determined by the treating team, and occurred between 6 and 12 months after NIV initiation. This included nightly hours of NIV use (nights used), and percent of days with NIV use >4 h in a 30-day period.

2.5. Data management and statistical analysis

Data from the diagnostic and titration portions of the snPSGs were reported separately, and confidence interval (CI) for median of within patient difference (Wilcoxon Signed Rank based) is provided. Analysis was performed using R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/. Data are summarized as median and interquartile range for numerical variables and as frequency and percentage for categorical variables.

3. Results

A total of 168 children underwent a snPSG during the study period. Three (3) subjects were excluded given a reduced TST in either the diagnostic or titration portion of the study. This study therefore included 165 children who initiated on long-term NIV following snPSG. The population was predominantly male and had the median age at snPSG was 7.16 (1.6, 13.0) years. The majority of included subjects were initiated on NIV due to upper airway obstruction, with over 60% of subjects not having undergone adenotonsillar surgery prior to initiating NIV (Table 1).

The TST and SE were lower on the titration portion of the snPSG when compared to the diagnostic portion (Table 2). SL was similar between the diagnostic and titration portion of the snPSG. Subjects spent proportionally more time in Stage N1, N2, and REM sleep in the titration portion of the snPSG, while stage N3 was more predominant during the diagnostic portion of the snPSG (Table 2).

Oxygen levels were significantly higher during the titration portion of the snPSG, with less time spent with an SpO2 below 90%. Transcutaneous CO2 levels did not significantly change during the titration portion of the snPSG, though fewer subjects met criteria for hypoventilation (Table 2).

The majority of subjects (87.2%) had moderate to severe SRBD on the diagnostic portion of the snPSG, with a median AHI of 16.6 events/hour (IQR: 8.2, 38.2) (Table 2, Fig. 1). Compared to the diagnostic portion of the snPSG, more patients normalized their AHI while on NIV during the titration portion of the snPSG (13.3% vs 2.4%). Fewer subjects had moderate to severe SRBD on the titration portion of the study (63.0%), with a median AHI of 7.6 events/hour (IQR: 3.3, 17.1) (Table 2, Fig. 2). Change in classification of SRBD severity, from diagnostic to titration portions of the snPSG, is shown in Table 3. Of the 55 subjects who continued to meet criteria for severe SRBD on both diagnostic and titration portions of the snPSG, the mean AHI was reduced from 61.4 (SD 51.3) to 28 (SD 16.3), while mean SpO2 or TcCO2 levels did not significantly change with NIV.

Table 1
Demographic and clinical characteristics.

Number	165
Sex – no. (%)	
Male	114 (69.1%)
Female	51 (30.9%)
Age[a] – yrs	7.16 (1.6,13.0)
<1 yrs[b]	27 (6.5%)
1 yr to < 5 yrs[b]	41 (25.0%)
5 yrs to < 12 yrs[b]	46 (28.0%)
12 yrs or greater[b]	50 (30.5%)
Primary Disease[c] – no. (%)	
Upper Airway	102 (61.8%)
CNS	28 (17.0%)
MSK	10 (12.1%)
Pulmonary	11 (6.7%)
Cardiac	2 (1.2%)
Adenotonsillar Surgery – no. (%)	
None	98 (61.3%)
Adenotonsillectomy	42 (26.2%)
Adenoidectomy	17 (10.6%)
Tonsillectomy	3 (1.9%)
Other Surgeries – no. (%)	
Cardiac	16 (9.7%)
G-tube	16 (9.7%)
Neurosurgery	13 (7.9%)
Airway[d]	14 (8.5%)
Tracheostomy	4 (2.4%)

[a] Median (IQR)).
[b] Number (%).
[c] Category based on medical condition leading to NIV initiation.
[d] Airway surgeries include orthognathic, supraglottoplasty, dental, cleft repair, and excludes surgery of the tonsils and adenoids.

Following snPSG, CPAP was recommended in 123 children (76.9%) and BPAP in 26 children (16.2%). The specific type of NIV recommended was not available for the remaining 16 children.

Download data regarding adherence to NIV was available for 58 subjects at the 6–12 month outpatient follow up visit. Within child average usage of NIV (hours per night) had a median of 5.0 h/night (IQR: 3.00, 8.00). NIV was used for more than 4 h on 67.1% of days (IQR: 33.2, 90.0).

4. Discussion

Through our description of this cohort of children who initiated long-term NIV subsequent to snPSG, this study demonstrates the feasibility of snPSG. The use of snPSG has several potential benefits of snPSG in this population. First, moderate to severe SRBD can be diagnosed on snPSG, despite the reduced diagnostic time. Given that the severity of SRBD is often worse in REM sleep, and that REM stage sleep increases as the night progresses, it is unlikely that we have over diagnosed the severity of SRBD in this population. The ability to characterize SRBD as moderate to severe in the first half of the snPSG thereby allows initiation of NIV more rapidly, as it can be started in the latter half of the snPSG.

Secondly, we observed a clinically similar sleep latency and sleep efficiency between the diagnostic and titration portion of the snPSG. This suggests that while a child may wake for the initiation of NIV, they are able to re-initiate sleep, indicating that not all children react poorly to initiation of NIV midway throughout the snPSG. While our cohort only included those who tolerated snPSG, these results are encouraging that snPSG can be performed in children without substantial disruption in sleep quality.

Finally, the majority of subjects in our study had improvement in their AHI, oxygen saturation, and ventilation with NIV treatment,

Table 2
Sleep architecture, respiratory findings, and SRBD severity during snPSG.

	Diagnostic portion of snPSG[a]	Titration portion of snPSG[a]	Within Patient Difference (median)	95% Confidence Intervals[b]
Sleep Times and Latency				
TST (min)	208.5 (158.0, 280.2)	174.5 (105.0, 237.5)	36.55	11.70, 60.65
SL (min)	10.8 (4.3, 21.4)	5.5 (1.3, 18.3)	1.75	−1.35, 4.50
SE (%)	85.5 (77.3, 92.0)	80.5% (71.2, 89.9)	2.90	0.15, 5.50
Sleep Stage Distribution				
N1 - %	4.4 (2.8, 7.4)	6.2 (3.4, 10.4)	−1.80	−2.80, −0.85
N2 - %	43.3 (36.1, 51.2)	51.2 (39.6, 61.5)	−6.55	−9.40, −3.65
N3 - %	34.7 (26.1, 44.9)	18.9 (9.0, 27.2)	17.85	14.80, 20.80
REM - %	12.0 (7.8, 19.0)	22.3 (16.2, 28.4)	−9.80	−11.70, −7.85
Respiratory Findings				
Mean SpO_2 - %	94.1 (92.2, 95.4)	95.3 (94.1, 96.4)	−1.45	−1.75, −1.20
Minimum SpO_2 - %	84.3 (78.0, 88.6)	88.5 (85.6, 91.5)	−4.70	−5.70, −3.85
% of TST with SpO_2 <90%	1.3 (0.1, 15.1)	0.1 (0.0, 1.5)	5.90	3.50, 9.60
Mean ETCO2 – mmHg	44.7 (41.8, 47.3)	N/A	N/A	N/A
Mean TCCO2 – mmHg	44.6 (41.6, 47.6)	43.4 (39.9, 47.0)	1.50	0.90, 2.10
Hypoventilation – n (%)	45 (28.1%)	21 (13.2%)		
SRBD Severity[b]				
Normal – n (%)	4 (2.4%)	22 (13.3%)		
Mild – n (%)	17 (10.3%)	39 (23.6%)		
Moderate – n (%)	36 (21.8%)	40 (24.2%)		
Severe – n (%)	108 (65.4%)	64 (38.8%)		

[a] Median (IQR).
[b] 95% Confidence Interval for the median of the difference.

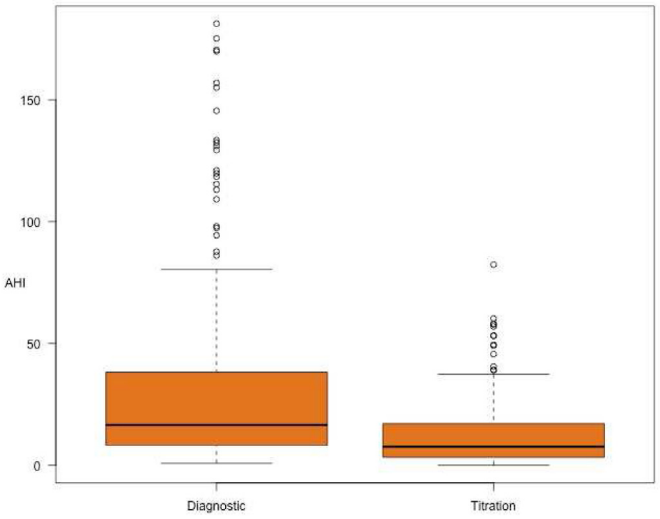

Fig. 1. Apnea-hypopnea index during diagnostic and titration portions of the split night polysomnograms.

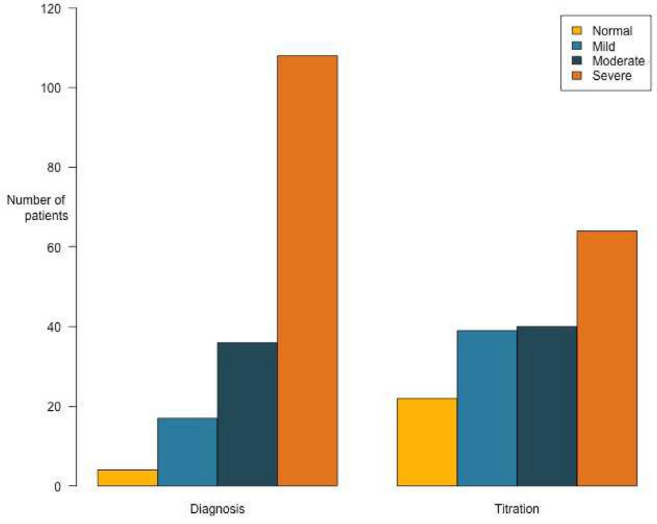

Fig. 2. Distribution of severity of sleep related breathing disorder based on apnea-hypopnea index during the diagnostic and titration portions of the split night polysomnogram.

suggesting that despite the reduced titration time, snPSG can still achieve improved respiratory function. The improvements in SRBD severity and AHI are in keeping with other published literature in children with OSA in which individual diagnostic and therapeutic PSG were used [25,28,29]. We do note that NIV was initiated in several subjects with an AHI below 10 events/hour. This may be due to challenges in estimating the AHI in real time, though other reasons could include initiation of NIV secondary to hypoxemia, hypoventilation, other clinical factors, or instructions from the ordering physician.

Within the adult population, long term adherence to NIV has not been shown to be affected if the subject initiated following a snPSG, though this has not been studied in children [16,30]. We had limited long-term adherence data in our cohort, though the median usage is consistent with other published pediatric literature with published adherence rates between 33 and 98% [31–36]. While our population is limited to those with adherence data, and was selected from a cohort who were using NIV at home, our data implies that initiation of NIV following a snPSG does not necessarily reduce long-term adherence.

Table 3
Change in OSA severity from diagnostic to titration portions of snPSG.

		Titration			
		Normal	Mild	Moderate	Severe
Diagnostic	Normal	1	2	1	0
	Mild	6	6	4	1
	Moderate	8	10	10	8
	Severe	7	21	25	55

snPSGs have become a common practice in adults, and account for the majority of sleep evaluations in the US [14]. The AHI from the truncated PSGs in the adult population has been found to have high correlation with full night studies, particularly when the

diagnostic portion is at least 3 h in length, and when designed to evaluate for severe sleep apnea [18,19,37,38]. In situations where a diagnosis of severe OSA is established during the first half of a PSG, it is unlikely that additional diagnostic data will be forthcoming during the latter half of the study. Initiation of NIV midway through the study may provide the clinician with additional information regarding the patient's response to NIV, and can provide useful data as to starting pressures for initiation of home NIV. This is particularly important for adherence, as large pressure differences between empirically trialed NIV pressure and the prescribed NIV pressure from a PSG has been shown to be associated with lower NIV usage [39].

These benefits have been realized in adult populations, with the ability to successfully titrate CPAP to optimal pressures shown to be unaffected by the shortened studies, and no difference in long-term adherence to CPAP when compared to full night PSGs [16,30,40]. Given these findings, snPSG has been included in the AASM clinical practice guidelines as the suggested diagnostic test for most adults with suspected OSA [41]. The same recommendation does not exist for pediatrics, despite the use of snPSG clinically. With this study, we have demonstrated that snPSG is feasible in a pediatric population and would encourage further research aimed at closing the gap between adult and pediatric evidence. Similar to adult subjects, snPSG may not be the preferred test for a number of subjects. This may include those with developmental delays or sensory processing disorders, who would benefit from acclimatization to NIV, while other subjects with complex cardiorespiratory physiology may benefit from a longer titration study.

This study was designed as a “proof of concept” and does not attempt to show non-inferiority nor superiority to the use of traditional full night diagnostic and subsequent titration PSGs and hence presents limited statistical testing. The limitations of this study include its retrospective in nature, and only included children who had used NIV for $\geq$3 months. Subjects who were not able to initiate NIV on the night of the snPSG were not labeled as undergoing a snPSG, and were therefore not included. This study was conducted on patients with a high degree of medical complexity, and did not collect data on specific patient specific factors such as the rationale for not proceeding with surgical interventions prior to NIV initiation, nor did it collect data on other potential factors associated with tolerability of a snPSG [10]. Therefore, the generalization of these results to specific populations is limited. Finally, adherence data were missing from a number of patient charts, which affects the generalizability of these results.

5. Conclusion

This study provides evidence that snPSGs provide sufficient time to establish a diagnosis of a SRBD and can allow for NIV initiation and titration. The subjects identified in this study tolerated the initiation of NIV and had improvements in the severity of the SRBD, suggesting that improvement in SRBD severity can be achieved within the time available. Finally, when a subgroup of subjects was compared to published literature, our study showed that NIV adherence is similar to what has been reported, suggesting that long-term adherence is not reduced by NIV initiation following a snPSG. Further research is needed to characterize which children are best suited for this modality, the ability to reach “ideal” NIV pressures, the effects on long term adherence, and whether snPSG could be utilized to improve access to pediatric sleep laboratories around the world.

CRediT authorship contribution statement

Christopher A. Gerdung: Conceptualization, Methodology, Data curation, Writing – original draft. **Maria L. Castro-Codesal:** Investigation, Methodology, Writing – review & editing, Supervision. **Alberto Nettel-Aguirre:** Methodology, Formal analysis, Data curation, Writing – review & editing. **Karen Kam:** Writing – review & editing. **Patrick J. Hanly:** Writing – review & editing. **Joanna E. MacLean:** Investigation, Methodology, Writing – review & editing. **Glenda N. Bendiak:** Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision, Project administration.

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