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Utility and Outcome of Follow-Up Polysomnography in Patients With Ambulatory Noninvasive Ventilation

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ABSTRACT

Background: Noninvasive ventilation (NIV) is a cornerstone of respiratory management in patients with various chronic conditions. While a follow-up polysomnography (PSG) is recommended to optimize ventilatory support, its utility and outcome data are limited. This study aimed to describe problems identified during the follow-up PSG and subsequent ventilator setting adjustments in this population.

Methods: The follow-up titration PSGs of patients prescribed with ambulatory NIV between January 2022 and January 2024 were retrospectively reviewed. Mixed effects logistic regression models were used to identify factors associated with setting changes.

Results: Two hundred ninety-seven PSGs from 106 patients (median age 15.9 years) were included in the analysis, including 216 titration and 81 baseline studies. Fifty percent of patients were diagnosed with neuromuscular diseases. The most common code of NIV was 77.4% on BPAP-ST, followed by PC-SIMV (14.2%) and PCV mode (8.5%). 81.5% of the titration studies resulted in ventilator setting adjustments. The most common problems identified were residual respiratory events, inadequate ventilation and significant leaks. The lower home IPAP setting and higher BMI were associated with increased odds of ventilator setting adjustment, with odds ratio of 0.86 (95% CI: 0.76, 0.98; *p*-value 0.021) and 1.02 (95% CI: 1.00, 1.03; *p*-value 0.017), respectively.

Conclusion: Follow-up PSG frequently results in ventilator setting adjustments in patients with ambulatory NIV. Patients with lower IPAP setting and higher BMI are more likely to have changes in ventilator setting after PSG. The facility involving the care of ambulatory NIV patients should be familiar with the common problems found in PSGs.

1 | Introduction

Noninvasive ventilation (NIV) is a cornerstone of respiratory management in patients with various chronic conditions [1]. The effective utilization of noninvasive ventilation improves survival, symptoms, and quality of life [1–3]. Despite increasing number of experienced centers and advancing knowledge surrounding ambulatory noninvasive ventilation, several challenges persist in optimizing the use of technology [4].

One of the main challenges is the monitoring of these patients during periods of follow-up visits, especially in children [4].

Patients who are reliant on noninvasive ventilation especially those with neuromuscular disorders usually suffer from the progressive nature of underlying diseases [4, 5]. Moreover, there are changing physiological demands from a growing child and maturation of the respiratory system. The clinical symptoms often fail to indicate abnormal ventilatory patterns in this population. In addition, nocturnal oximetry alone seems inadequate to capture the abnormalities during sleep [6]. Therefore, polysomnography (PSG) is recommended for pediatric patients who need home ventilation support [7, 8]. It provides valuable information on respiratory alterations from the progression of underlying medical conditions, sleep disruptions and adequacy of the current treatment prescribed [9]. It also offers an opportunity to titrate up or wean the level of respiratory support to match a patient's demand [9].

However, the availability of facilities equipped to conduct PSG for patients using NIV, especially in pediatric population, remains limited [1, 10]. Resource allocation is essential for providing timely management, as a delay in PSG titration could lead to treatment delays, possibly adverse outcomes, and suboptimal management. Current literature supports the benefits and the utility for performing initial polysomnographic assessment in the NIV-dependent population, and evidence-based criteria have been established [4, 11, 12]. Nevertheless, the data on the utility of follow-up PSG in NIV-dependent patients are still limited, and there is no consensus regarding the appropriate interval for performing follow-up PSG [4].

To expand the understanding of the utility of follow-up PSG, outlining the findings from the standard in-laboratory PSG would be informative. In addition, data regarding identified problems and interventions during the test would be valuable for clinicians and sleep technologists to be vigilant for common abnormalities and to plan the study thoroughly. These data may also help determine necessary auxiliary channels to be employed in home sleep studies to enhance the detection of common sleep abnormalities.

Therefore, we conducted a retrospective study of patients who were using NIV and underwent follow-up PSG studies. The study primarily aimed to describe the problems identified during the follow-up PSG and subsequent ventilator setting adjustment. We also aimed to investigate factors associated with the adjustment after the follow-up PSG studies.

2 | Methods

2.1 | Design

We retrospectively reviewed medical records of in-laboratory PSG data performed at Cincinnati Children's Hospital Medical Center (CCHMC) between January 1, 2022 and January 31, 2024. Inclusion criteria were the titration PSG studies of patients age under 25 years old who had been prescribed NIV either with bilevel positive ventilation (BPAP) machine or ventilator before the identified PSG during the specified duration (index PSG). All PSGs done before the index PSG were reviewed to comprehensively include all the titration studies and to establish the numbers of titration studies previously performed and the interval between each study. The diagnostic PSGs of each patient were also reviewed if available. The most recent diagnostic PSGs before NIV prescription were included as each patient's baseline study. The studies with total sleep time less than 240 min, ventilator titration through tracheostomy and technically unsatisfactory studies were excluded from analysis. CCHMC's institutional review board exempted the requirements to obtain informed consent for this study (IRB 2024-0026).

2.2 | Scoring and Titration

The titration PSGs montage included the following recordings: electroencephalography (F3/F4, C3/C4, O1/O2), left and right electrooculograms, three chin electromyograms (chin EMGs), right/left leg EMGs, intercostal EMGs, thoracic and abdominal respiratory inductance plethysmography (RIP), pulse oximetry (Masimo, Irvine, CA), nasal thermistor, nasal pressure transducers (Pro-Tech, Murrysville, PA), nasal end-tidal carbon dioxide ($EtCO_2$) cannula, and transcutaneous CO_2 ($TcCO_2$) recording (Sentec, Lincoln, RI). Omnilab (Phillips, Murrysville, PA, USA) system was used for bilevel pressure titration. Ventilator airflow and tidal volume were measured by pneumotachograph (Phillips NM3).

The PSGs were performed according to the guidelines endorsed by the American Academy of Sleep Medicine. The definitions of respiratory events were as follows: Obstructive apnea was the reduction of airflow to less than 10% of baseline with the presence of respiratory effort and the duration of at least two respiratory cycles. Central apnea was the reduction of airflow to less than 10% of baseline without the presence of respiratory effort and the duration for at least two respiratory cycles associated with 3% oxygen desaturation or arousal. Hypopnea was the reduction of airflow to less than 70% of baseline, lasting for at least two respiratory cycles and associated with 3% oxygen desaturation or arousal. Apnea-hypopnea index (AHI) was defined as the total number of respiratory events per hour of sleep. Periodic limb movements were defined as recommended by the AASM scoring manual [13]. Obstructive AHI was defined as the total number of obstructive apnea and hypopnea per hour sleep.

All studies were performed by registered sleep technologists under supervision of board certified pediatric sleep physicians. Most patients used their own home masks for the follow-up titration study. New mask fitting trials were performed for patients who experienced issues with their current masks or who forgot to bring them. The titration study was guided by our standard sleep lab protocol. In brief, for the bilevel pressure devices, the initial inspiratory positive airway pressure (IPAP) would be 2–4 cm of water (cwp) below the home setting, depending on whether the home prescribed IPAP was more than 15 or less than 15 cwp. Of note, the rationale to start IPAP at lower pressures is that our protocol has been designed to assess all possible scenarios of patients who are currently on NIV. Although patients with neuromuscular disorder usually have progression of their conditions requiring increasing support, other patients with different conditions such as chronic lung diseases may have an improvement over time. Expiratory

positive airway pressure (EPAP) would be started at the current home setting. IPAP would be increased if there were obstructive hypopneas, snoring, respiratory arousals, EtCO2 persistently higher than 45 mmHg or increased work of breathing. The increased work of breathing was defined by the presence of findings such as "paradoxical breathing," "out-of-phase between chest and abdominal recordings," and "increased intercostal EMG activity." EPAP would be targeted to eliminate obstructive apneas. The difference between IPAP and EPAP would be kept at least 4 cwp. After obstructive respiratory events were controlled, respiratory rate would be titrated in case of failure to trigger, central events, tachypnea or total respiratory rate below age-specific physiologic limit. For noninvasive ventilator titration, the pressure control and pressures support were increased by 1 cwp for obstructive hypopneas, snoring, increased work of breathing, EtCO2 persistently higher than 45 mmHg or respiratory arousals. The PEEP was increased by 1 cwp for obstructive apneas. The ventilator rate was increased for failure to trigger or central events. For neuromuscular patients, the rate was also adjusted if the patient was tachypneic or if total rate was less than physiologic respiratory rate. In addition, patients with inadequate oxygenation would require increasing EPAP or adding supplemental oxygen. Patients with ineffective triggering would require increasing backup rate or changing trigger sensitivity or correcting leak if present.

The registered sleep technologists documented the ventilator setting changes and associated findings in the respiratory care flowsheet for later review. Registered sleep technologists scored the PSGs and board-certified pediatric sleep physicians reviewed all PSGs for final interpretation and recommendation. During the study, the settings were adjusted according to our sleep lab protocol, which required real-time recognition of respiratory events such as apnea, hypopnea and flow limitation by sleep technicians. However, those changes would not be implemented until sleep physicians reviewed the study and provided recommendations. Sleep physicians reviewed the study based on respiratory events and other ventilator related issues as described below.

The problems identified during the PSGs were defined as follows:

- **Residual respiratory events;** respiratory events or flow limitations found on the current home setting leading to setting adjustments which were recommended or implemented after sleep physicians reviewed the study based on PSG data such as AHI and obstructive AHI or subtle findings such as increased work of breathing or flow limitation. The cut-off values for AHI or obstructive AHI to define residual respiratory events depended on several factors including the amount of sleep time and whether REM and/or supine position were noted on that setting.
- **Inadequate oxygenation;** peripheral oxygen saturation (SpO_2) persistently below 93% or physician-specified threshold on the previous home setting leading to settings adjustment or additional oxygen supplementation.
- **Inadequate ventilation;** $EtCO_2$ persistently higher than 45 mmHg (for neuromuscular patients) or physician-specified threshold, after titrated to previous home setting leading to settings adjustment. Of note, in our sleep center, most patients on NIV have neuromuscular disorders, our goal is to maintain CO_2 between 35 and 45 mmHg. Therefore, $CO_2 > 45$ mmHg is used as a cut-off to define inadequate ventilation and the need for sleep technicians to make adjustment in NIV settings.
- **Significant leak;** significant leak leading to mask adjustments or changes or application of chin strap.
- **Tachypnea;** persistent sleep respiratory rate> 20 per minute or age-specified threshold leading to settings adjustment. For ages-specific target respiratory rates for NIV titration, our sleep lab protocol used the following parameters: age 8–12 years old; 14–18/min, and age > 12 years old; 12–16/min.
- **Ineffective triggering;** ineffective or failure triggering ventilator by patient's effort identified in a PSG.
- **Periodic limb movements during sleep (PLMS)**; the presence of periodic limb movements index ≥ 5/hour in patients < 18 years old or ≥ 15/h in patients ≥ 18 years old at the time of PSG.

2.3 | Collected Data

Demographic data, anthropometric measurements, and clinical diagnoses of each patient were extracted from electronic medical records. The primary diagnoses leading to home ventilation use were grouped as pulmonary (e.g., cystic fibrosis), neuromuscular disease (NMD) (e.g., Duchenne muscular dystrophy, spinal muscular atrophy), neurologic (e.g., congenital central hypoventilation, Chiari malformation, brain tumors), genetics (e.g., Down syndrome, other chromosomal abnormalities), and others. Sleep and respiratory parameters obtained from PSG (total sleep time, sleep architecture, AHI, obstructive AHI, SpO_2, $EtCO_2$) and problems identified during each PSG were reviewed and collected. Ventilator settings prescribed by physicians after reviewing each titration study were also compared with the home ventilator settings before conducting the sleep study to assess changes in home ventilator setting. The presence of setting adjustment was defined as any changes in IPAP, EPAP, backup respiratory rate or set respiratory rate and inspiratory time.

2.4 | Statistical Analysis

Baseline demographic data were presented in count and percentage for categorical variables and median with interquartile range for continuous variables. A comparison of data between patients with and without ventilator setting changes was done using a mixed effects logistic regression model with a patient-specific random intercept. Significant factors associated with setting changes were depicted from mixed effects multivariable logistic regression model. All statistical analyses were conducted using SAS (Version 9.4; Cary, North Carolina, USA). Statistical significance was determined if the *p*-value was less than 0.05.

3 | Results

The process of PSG studies review is depicted as a flow chart in Figure 1. Two hundred ninety-seven PSGs (216 titration studies,

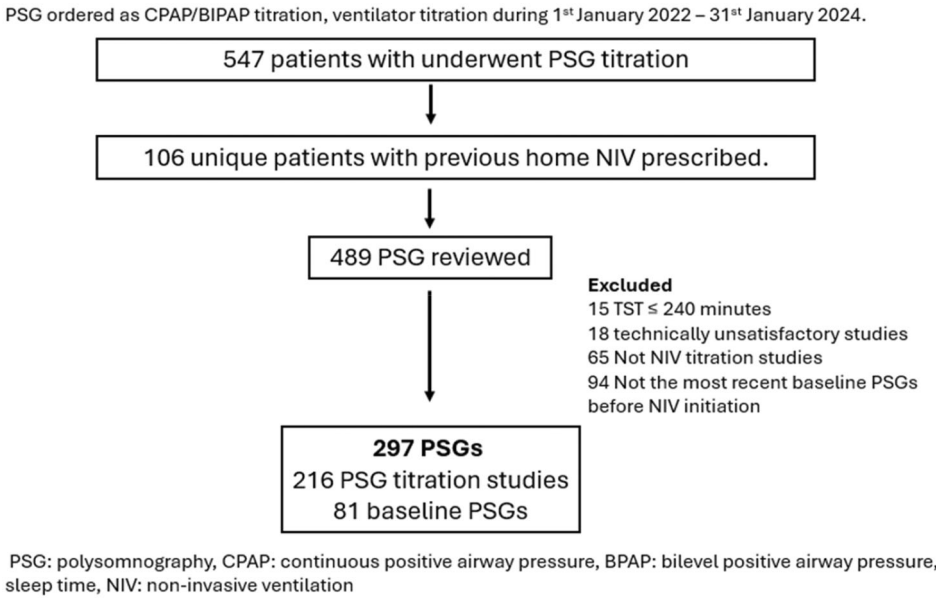

FIGURE 1 | Flow chart of included and excluded sleep studies. BPAP, Bilevel positive airway pressure; CPAP, continuous positive airway pressure; NIV, noninvasive ventilation; PSG, polysomnography; TST, total sleep time.

81 baseline studies) of 106 patients were included in the analysis. The demographic, clinical and PSG data of patients are presented in Table 1. The median age of patients was 15.9 years and 65% of patients were male. For primary diagnosis, the most common diagnosis was neuromuscular disorder (50%), followed by genetic disease (24.5%) and neurologic disorder (17%). Initiation of NIV was based on physician decisions and depended on several factors including results of sleep study, underlying conditions and worsening of clinical status. For mode of ventilation, the most common mode of ventilation was BiPAP-ST (77.2%), followed by PC-SIMV (14.2%) and PAC (8.5%).

Of the 216 titration PSG studies, 176/216 (81.5%) resulted in the adjustment of ventilator settings. The characteristics of patients whose PSG titration studies resulted in ventilator adjustment and no adjustment were compared and presented in Table 2. Patients with lower IPAP before the titration study were more likely to have ventilator setting adjustment (median IPAP 14 [IQR 12, 18] cwp vs. 16 cwp [14,19.5], $p = 0.021$). Ventilator settings adjustments by BMI are shown in a supplemental table. 88/174 (50.6%) were classified as overweight or obese by BMI at the time of PSG. Further analysis of patients based on BMI showed that patients who were overweight (BMI 85%–94.99%) and obese (BMI percentage > 95%) had higher proportion of patients requiring IPAP and EPAP increases after PSGs (Supporting Information: Table S1).

The problems identified during PSGs are depicted in Figure 2. The three most common problems identified were residual respiratory events (72.1%), inadequate ventilation (27.4%) and significant leak (21.4%). Other problems identified included significant periodic limb movements during sleep (18.6%), inadequate oxygenation (14.9%), ineffective triggering (14.9%) and tachypnea (13.5%). Of note, a significant number of studies (18.6%) showed significant periodic limb movements during sleep.

A summary of ventilator setting changes is presented in Table 3. The most common setting adjustment was an increase in IPAP (58.6%) with a median increase of 2 cwp [IQR: 2,4], followed by an increase in EPAP (30.2%) with a median increase of 1 cwp [1, 2] and an increase in ventilator rate with a median increase 2/min [2, 4]. Four of the studies (1.9%) resulted in mode changes: two with a change from BPAP-ST to PAC, one with a change from PC-SIMV to PAC and one with a change from BPAP-ST to BPAP-S. New mask fitting trials were done in 94/216 (43.7%), and a chinstrap was applied in 23/216 (10.7%) of the studies. Of note, the number of patients who decided to use the new interfaces after trials were not recorded.

A generalized linear mixed model controlled with age at the time of sleep studies, BMI percentile, home IPAP setting, home EPAP setting and interval from the previous PSG titration was performed. The odd ratios of each variable are presented in Table 4. Lower home IPAP setting and higher BMI percentile were significantly associated with increased odds of ventilator setting adjustments, with odd ratios (95% CI) of 0.86 (0.76, 0.98) and 1.02 (1.00, 1.03) respectively.

4 | Discussion

The main finding of our study is that most of the follow-up in-laboratory PSGs titration (81.5%) in patients with ambulatory NIV resulted in changes in ventilator settings. The most common problems identified were residual respiratory events, inadequate ventilation and significant leak. Further analysis found that patients with lower home IPAP setting and higher BMI percentile had increased odds of ventilator setting adjustment, with IPAP being the primary issue.

The utility of sleep studies in evaluating the level of ventilation support has been examined in a few previous studies. A previous report by Tan et al. found 66% of patients underwent sleep studies resulted in a change in level of respiratory support [14]. In this study, PSGs were conducted in a pediatric ward, one-thirds were full PSGs and two-thirds of the studies were

TABLE 1 | Demographic, clinical and PSG data of patients ($n = 106$).

Demographic	
Age (years)	15.9 [10.5, 19.4]
Male	69 (65.1%)
Weight (kg)	48.9 [36.2, 65.9]
Weight percentile	34.8 [4.6, 93.3]
BMI (kg/m^2)	23.6 [19.5, 29.2]
BMI percentile	86.4 [49.0, 97.0]
Primary diagnoses	
Neuromuscular diseases	53 (50.0%)
Genetic diseases	26 (24.5%)
Neurological diseases	18 (17.0%)
Pulmonary diseases	5 (4.7%)
Others	4 (3.8%)
Baseline diagnostic PSG	
oAHI (events/hour)	6.9 [3.5, 16.2]
Average SpO_2 REM (%)	96.0 [95.0, 97.2]
Average SpO_2 NREM (%)	96.1 [95.0, 97.2]
Average $EtCO_2$ (mmHg)	42.5 [39.9, 45.9]
Maximum $EtCO_2$ (mmHg)	50.2 [46.0, 54.0]
$ETCO_2 \geq 45$ (%TST)	6.7 [0.1, 65.0]
$ETCO_2 \geq 50$ (%TST)	0 [0, 3.5]
Mode of noninvasive ventilation	
BIPAP-ST	82 (77.4%)
PC-SIMV	15 (14.2%)
PAC	9 (8.5%)
Setting before titration	
IPAP (cwp)	15.0 [13.0, 18.0]
EPAP (cwp)	6.0 [5.0, 8.0]
Backup rate (times/min)	14.0 [12.0, 16.0]
Inspiratory time (seconds)	1.0 [1.0. 1.2]
Sleep architecture during titration PSG	
Total sleep time (min)	396.5 [346.8, 443.0]
Sleep efficiency (%)	83.8 [75.9, 90.3]
NREM 1 (%)	3.1 [1.9, 5.1]
NREM 2 (%)	50.9 [43.8, 58.1]
NREM 3 (%)	24.7 [19.9, 31.0]
REM (%)	10.5 [14.8, 23.5]
PLMI (per hour)	0 [0, 6.475]

Note: Continuous variables were presented as median [IQR]. Data presented as median [IQR], or number (percent).
Abbreviations: BIPAP-ST, bilevel positive airway pressure-spontaneous timed; BMI, body mass index; cwp, centimeter of water; EPAP, expiratory positive airway pressure; EtCO2, end-tidal CO2; IPAP, inspiratory positive airway pressure; IQR, interquartile range; NREM, non-rapid eye movement; oAHI, obstructive apnea-hypopnea index; PAC, pressure-assisted controlled; PC-SIMV, pressure-controlled-synchronized intermittent mechanical ventilation; PLMI, periodic limb movement index; PLMI, periodic limb; PSG, polysomnography; REM, rapid eye movement; SpO2, peripheral saturation of oxygen.

monitored by limited channels cardiorespiratory polygraph. However, in our study, all studies were full PSGs and were attended to by experienced sleep technicians. The other studies done by Al-Saleh et al. and Widger et al. indicated that 73% and 65% of patients had changes in respiratory support settings, respectively [15, 16]. These two studies utilized full PSGs similar to our sleep study.

Our study has a relatively higher percentage of alteration in ventilator support following titration PSGs (81.5%) which might be explained by two main factors. First, we included only in-laboratory PSGs titration studies, which could demonstrate a wider range of abnormalities such as ineffective triggering, and inadequate ventilation in various stages of sleep. Hence, more frequent adjustments may be warranted. Second, while other studies included some patients on CPAP, we exclusively studied patients on bilevel ventilation support or full ventilator support, who might be prone to changes in ventilation support. Additionally, half of the patients in our cohort were affected by neuromuscular diseases and are likely to have a progression of muscle weakness, which impacts their demand for respiratory support. In fact, Al-Saleh et al. reported that bilevel ventilation and neuromuscular diseases were the predictors of a change in respiratory support [15]. This emphasizes the high need for NIV optimization in these groups.

The most common problems identified in our study were residual respiratory events, inadequate ventilation and significant leak. These events were occasionally subtle and require specific polysomnographic channels with good signal quality for detection, so this might raise a concern about the utility of unattended home monitoring. The other benefit of attended PSG is the ability to make changes in real-time when abnormalities were identified. While Crescimanno et al. [17] demonstrated a promising success rate and patient preference for home PSG in neuromuscular patients, they did not report the number of patients who needed intervention after the nocturnal PSG, and the number of scorable respiratory events in this study was low. Another study by Caldarelli et al. demonstrated that unintentional leaks and respiratory events were common problems identified by polygraphs in stable NIV children. However, the utility of the polygraphs as home monitoring is still uncertain, as the polygraphs in this particular study were performed in the hospital setting [18]. The number of abnormal studies was even lower in patients who had only oximetry and CO_2 monitoring. A study of home overnight monitoring with oximetry and transcutaneous CO_2 ($TcCO_2$) found that only 12% of ambulatory NIV patients had abnormal gas exchange, despite the stringent criteria applied ($SpO_2 \leq 90\%$ or $TcCO_2$ of $\geq 2\%$ TST were considered abnormal) [19]. Integrating the data from device's built-in software might assist identifying patients who need an intervention [20]. Telemonitoring using built-in software and various external monitors showed promising results in terms of adherence monitoring, reducing hospital visits and cost; nevertheless, several issues involving long-term effectiveness, service resources, medicolegal, safety and reimbursement are still unaddressed [21].

Interestingly, we found that lower home IPAP setting was associated with an increased likelihood of ventilator setting

TABLE 2 | Comparison of the characteristics of patients whose PSG titration had resulted in adjustment and no adjustment of NIV settings.

Demographic	Adjustment ($n = 176$)	No adjustment ($n = 40$)	p-value
Age (years)	13.1 [8.1, 17.3]	11.0 [8.6, 17.9]	0.701
Male			
Primary diagnoses			
Neuromuscular diseases	89 (50.6%)	17 (42.5%)	0.382
Genetic diseases	43 (24.4%)	12 (30.0%)	0.479
Neurological diseases	32 (18.2%)	8 (20.0%)	0.828
Pulmonary diseases	6 (3.4%)	1 (2.5%)	0.761
Others	6 (3.4%)	2 (5%)	0.628
Mode of noninvasive ventilation			
BIPAP-ST	150 (85.7%)	31 (77.5%)	0.419
PC-SIMV	18 (10.3%)	7 (17.5%)	
PAC	7 (4%)	2 (5%)	
Reason to perform PSG			
Interval check	75 (42.6%)	23 (57.5%)	0.198
Titration	58 (33.0%)	8 (20.0%)	
Worsening symptoms	43 (24.4%)	9 (22.5%)	
Numbers of titration	2.0 (1.0, 3.0)	2.0 (2.0, 3.0)	0.064
Interval from previous PSG (days)	701.0 [385.0, 1253.0]	530.5 [378.0, 1187.0]	0.417
Setting before titration			
IPAP (cmH_2O)	14.0 [12.0, 18.0]	16.0 [14.0, 19.5]	0.021*
EPAP (cmH_2O)	6.0 [5.0, 8.0]	5.5 [5.0, 8.0]	0.796
Backup rate (times/min)	14.0 [10.0, 16.0]	14.0 [12.0, 20.0]	0.152
Inspiratory time (seconds)	1.0 [0.9, 1.0]	1.0 [1.0, 1.2]	0.364

Note: Data presented as median [IQR], or number (percent).
Abbreviations: BIPAP-ST, bilevel positive airway pressure-spontaneous timed; EPAP, expiratory positive airway pressure; IPAP, inspiratory positive airway pressure; IQR, interquartile range; PAC, pressure assisted controlled; PC-SIMV, pressure controlled-synchronized intermittent mechanical ventilation.
*The p-values are generated from generalized linear mixed model (GLMM) considering repeated binary responses, the value < 0.05 indicates a statistical difference between two groups.

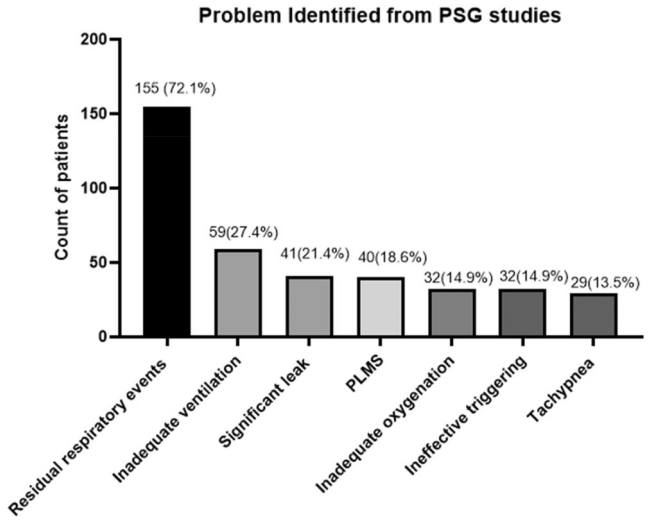

FIGURE 2 | Problems identified from PSG titration studies.

adjustment in our cohort. There are various studies suggest that higher IPAP might be needed in patients with chronic hypoventilation. In a physiologic study, higher IPAP was significantly associated with less work of diaphragm [22]. A small post-hoc analysis of neuromuscular patients found that those who had higher level of pressure support were associated with lower mean nocturnal CO_2 value [23]. However, there are several precautions in patients with neuromuscular diseases as too high IPAP may increase leak, glottic closure and sleep disturbance [24]. Therefore, patients with lower IPAP might need more frequent monitoring and precise adjustment guided by PSG, especially when the lung function declines to a certain range or diurnal hypoventilation occurs.

Higher BMI percentile is also associated with a higher chance of ventilator setting adjustment. This may be due to a higher risk of obstructive sleep apnea in this group of patients [24]. In contrast, two previous reports did not demonstrate the association between body weight and change in respiratory support, which might be due to the difference in the population studied [14, 15]. Our study specifically examined patients requiring bilevel ventilation, who may be particularly susceptible to weight-related issues impacting their ventilation. Consequently, these patients demonstrate the stronger association between BMI and setting adjustments. Tracking changes of body weight in NIV-dependent patients with BMI might be helpful to identify patients who will need ventilation optimization.

TABLE 3 | Summary of NIV setting changes.

	Number (%)	Median change [IQR]
IPAP		
Increase	126 (58.6%)	+2 [2, 4]
Decrease	30 (14.0%)	−2 [−3, −1]
No change	59 (27.4%)	
Absolute change		2 [0, 3]
EPAP		
Increase	65 (30.2%)	+1 [1, 2]
Decrease	19 (8.8%)	−2 [−3, −1]
No change	131 (60.9%)	
Absolute change		0 [0,1]
Backup rate		
Increase	61 (28.7%)	+2 [2, 4]
Decrease	25 (11.8%)	−2 [−4, −2]
No change	126 (59.4%)	
Absolute change		0 [0, 2]
Inspiratory time		
Increase	9 (22.5%)	+0.1 [0.1, 0.2]
Decrease	1 (2.5%)	−0.3 [−0.3, −0.3]
No change	30 (75.0%)	
Absolute change		0 [0,0.05]

Note: Data presented as median [IQR], or number (percent). Absolute change: summary of overall change made after the titration studies.
Abbreviations: EPAP, expiratory positive airway pressure; IPAP, inspiratory positive airway pressure; IQR, interquartile range; NIV, Noninvasive ventilation.

TABLE 4 | Odd ratio estimates with 95% confidence interval (CI) of each variable effect on setting changes from mixed effects multivariable logistic regression model.

Factors	Odd ratio [95% CI]	*p*-value
Age at the sleep studies	0.98 (0.88, 1.09)]	0.719
BMI percentile	**1.02 (1.00, 1.03)**	**0.017***
Home IPAP setting	**0.86 (0.76, 0.98)**	**0.021***
Home EPAP setting	0.99 (0.75, 1.22)	0.711
Interval from previous PSG titration	1.00 (0.99, 1.00)	0.681

Abbreviations: BMI, body mass index; EPAP, expiratory positive airway pressure; IPAP, inspiratory positive airway pressure; PSG, polysomnography.

Our study has several limitations. First, we do not have clinical outcome data regarding symptoms and adherence after adjustment. Although we observed relatively small alterations in ventilator settings in our population, these small increases might be sufficient to improve a symptom score [16]. Second, we could not establish the optimal interval of follow-up PSG titration. Our data suggested that patients needing adjustments had slightly longer intervals between PSGs, although this difference was not statistically significant. In addition, we did not have an interval between NIV initiation and PSG. Third, the data on device download, daytime CO_2 data and nocturnal oximetry were not collected. Therefore, we could not eliminate the possibility of empirical adjustments based on symptoms, device downloads, blood gas analysis, or nocturnal oximetry results. Fourth, all the PSG titrations were done in a high-volume sleep center with specific expertise in patients with NIV. Some issues and challenges found in smaller or newly established sleep laboratory units might not apply. Finally, a certain parameter such as i-time is not specifically outlined in our sleep lab protocols. Although sleep physicians may change this parameter based on sleep study findings, the lack of explicit instruction to change i-time could lead to relatively low percentage of i-time changes. In addition, the definition of respiratory-related findings and inadequate ventilation was based on our sleep lab protocol, which might differ from others.

5 | Conclusion

Overall, our study shows that follow-up PSGs in patients with ambulatory NIV frequently identify problems that lead to ventilator setting adjustments. Patients with lower home ventilator IPAP setting and higher BMI are more likely to require ventilator setting changes after titration PSGs. The sleep facility should be well equipped with personnel familiar with the respiratory events associated with NIV use, CO_2 PSG monitoring and its interpretation. If PSG is not feasible, a system that could synchronize oximetry and CO_2 data, respiratory flow patterns and leak, such as built-in ventilator software combined with auxiliary monitors, might be necessary to capture common events adequately [25]. Future prospective trials should focus on the clinical outcome of patients who underwent follow-up titration PSGs.

Author Contributions

Athiwat Tripipitsiriwat: conceptualization, data curation, methodology, visualization, writing – original draft, writing – review and editing. **Prakarn Tovichien:** data curation, writing – original draft, writing – review and editing. **Neepa Gurbani:** conceptualization, writing – review and editing, methodology, writing – original draft. **Md M. Hossain:** writing – original draft, formal analysis. **Narong Simakajornboon:** conceptualization, methodology, supervision, writing – review and editing, writing – original draft.

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Ethics Statement

Cincinnati Children's Hospital Medical Center's institutional review board oversighted and approved the study (IRB 2024-0026).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

1. J. P. Praud, "Long-Term Non-Invasive Ventilation in Children: Current Use, Indications, and Contraindications," *Frontiers in Pediatrics* 8 (2020): 584334.

2. D. W. Sheehan, D. J. Birnkrant, J. O. Benditt, et al., "Respiratory Management of the Patient With Duchenne Muscular Dystrophy," *Pediatrics* 142, no. Suppl 2 (2018): S62–S71.

3. H. K. Young, A. Lowe, D. A. Fitzgerald, et al., "Outcome of Noninvasive Ventilation in Children With Neuromuscular Disease," *Neurology* 68, no. 3 (2007): 198–201.

4. B. Fauroux, F. Abel, A. Amaddeo, et al., "ERS Statement on Paediatric Long-Term Noninvasive Respiratory Support," *European Respiratory Journal* 59, no. 6 (2022): 2101404.

5. H. Sawnani, P. S. Horn, B. Wong, et al., "Comparison of Pulmonary Function Decline in Steroid-Treated and Steroid-Naïve Patients With Duchenne Muscular Dystrophy," *Journal of Pediatrics* 210 (2019): 194–200 e2.

6. A. Amaddeo, V. Caldarelli, M. Fernandez-Bolanos, et al., "Polygraphic Respiratory Events During Sleep in Children Treated With Home Continuous Positive Airway Pressure: Description and Clinical Consequences," *Sleep Medicine* 16, no. 1 (2015): 107–112.

7. R. N. Aurora, R. S. Zak, A. Karippot, et al., "Practice Parameters for the Respiratory Indications for Polysomnography in Children," *Sleep* 34, no. 3 (2011): 379–388.

8. A. Côté, "Section 4: Home Monitoring and Follow-Up of Home-Ventilated Children," *Canadian Journal of Respiratory, supplement, Critical Care, and Sleep Medicine* 2, no. sup1 (2018): 23–31.

9. N. Gurbani, D. Benscoter, C. Torres-Silva, G. Huang, M. M. Hossain, and N. Simakajornboon, "Utility of Polysomnography for Management of Chronic Invasive Mechanical Ventilation in Children," *Pediatric Pulmonology* 57, no. 2 (2022): 560–566.

10. R. Amin, S. Al-Saleh, and I. Narang, "Domiciliary Noninvasive Positive Airway Pressure Therapy in Children," *Pediatric Pulmonology* 51, no. 4 (2016): 335–348.

11. A. Khan, L. Frazer-Green, R. Amin, et al., "Respiratory Management of Patients With Neuromuscular Weakness," *Chest* 164, no. 2 (2023): 394–413.

12. N. Gurbani, J. E. Pascoe, S. Katz, and H. Sawnani, "Sleep Disordered Breathing: Assessment and Therapy in the Age of Emerging Neuromuscular Therapies," *Pediatric Pulmonology* 56, no. 4 (2021): 700–709.

13. R. B. Berry, R. Brooks, C. Gamaldo, et al., "AASM Scoring Manual Updates for 2017 (Version 2.4)," *Journal of Clinical Sleep Medicine* 13, no. 05 (2017): 665–666.

14. E. Tan, G. M. Nixon, and E. A. Edwards, "Sleep Studies Frequently Lead to Changes in Respiratory Support in Children," *Journal of Paediatrics and Child Health* 43, no. 7–8 (2007): 560–563.

15. S. Al-Saleh, P. Sayal, D. Stephens, et al., "Factors Associated With Changes in Invasive and Noninvasive Positive Airway Pressure Therapy Settings During Pediatric Polysomnograms," *Journal of Clinical Sleep Medicine* 13, no. 2 (2017): 183–188.

16. J. A. Widger, M. J. Davey, and G. M. Nixon, "Sleep Studies in Children on Long-Term Non-Invasive Respiratory Support," *Sleep and Breathing* 18, no. 4 (2014): 885–889.

17. G. Crescimanno, F. Greco, and O. Marrone, "Monitoring Noninvasive Ventilation in Neuromuscular Patients: Feasibility of Unattended Home Polysomnography and Reliability of Sleep Diaries," *Sleep Medicine* 15, no. 3 (2014): 336–341.

18. V. Caldarelli, J. C. Borel, S. Khirani, et al., "Polygraphic Respiratory Events During Sleep With Noninvasive Ventilation in Children: Description, Prevalence, and Clinical Consequences," *Intensive Care Medicine* 39, no. 4 (2013): 739–746.

19. L. Griffon, S. Touil, A. Frapin, et al., "Home Overnight Gas Exchange for Long-Term Noninvasive Ventilation in Children," *Respiratory Care* 65, no. 12 (2020): 1815–1822.

20. M. Georges, C. Rabec, E. Monin, et al., "Monitoring of Noninvasive Ventilation: Comparative Analysis of Different Strategies," *Respiratory Research* 21, no. 1 (2020): 324.

21. J. Ackrivo, L. Elman, and J. Hansen-Flaschen, "Telemonitoring for Home-Assisted Ventilation: A Narrative Review," *Annals of the American Thoracic Society* 18, no. 11 (2021): 1761–1772.

22. J. Lukácsovits, A. Carlucci, N. Hill, et al., "Physiological Changes During Low- and High-Intensity Noninvasive Ventilation," *European Respiratory Journal* 39, no. 4 (2012): 869–875.

23. A. Léotard, M. Delorme, S. Hartley, et al., "Non-Invasive Ventilation in Neuromuscular Diseases: Should We Use Higher Levels of Ventilatory Support?," *Sleep and Breathing* 27, no. 2 (2023): 673–677.

24. L. S. Aboussouan, "Sleep-Disordered Breathing in Neuromuscular Disease," *American Journal of Respiratory and Critical Care Medicine* 191, no. 9 (2015): 979–989.

25. J.-P. Janssens, C. Cantero, P. Pasquina, M. Georges, and C. Rabec, "Monitoring Long Term Noninvasive Ventilation: Benefits, Caveats and Perspectives," *Frontiers in Medicine* 9 (2022): 874523, https://doi.org/10.3389/fmed.2022.874523.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.