Telemonitoring for Home Assisted Ventilation: A Narrative Review

Jason Ackrivo, MD, MSCE

Lauren Elman, MD

John Hansen-Flaschen, MD

Online Data Supplement.

Introduction

This Online Supplement presents several case vignettes illustrating how remote ventilator telemonitoring can identify and troubleshoot problems that may be encountered during home assisted ventilation.

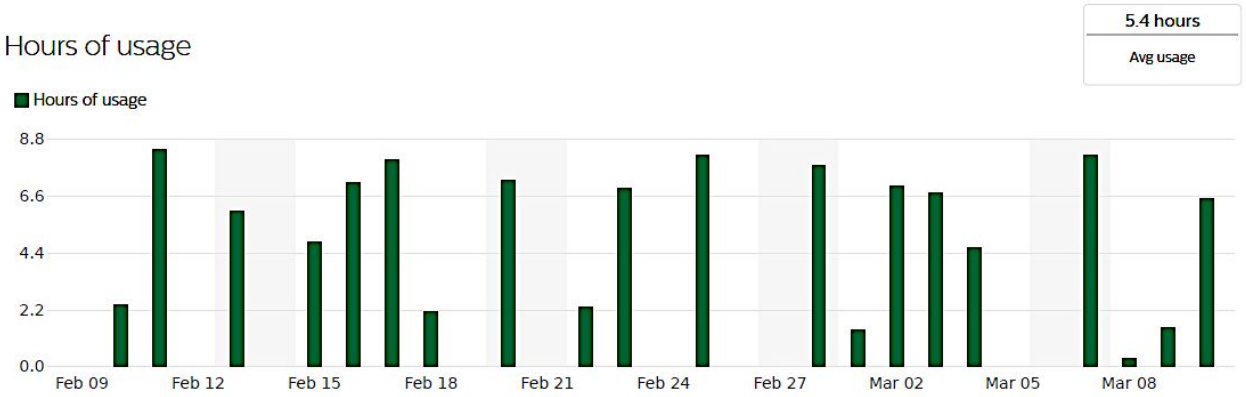
The first five vignettes selectively highlight current ventilator settings, device performance recorded by telemonitoring, problem identified, a brief analysis, and a solution. Note that several of the problems have other solutions in addition to the solution presented.

The final vignette illustrates application of overnight noninvasive carbon dioxide monitoring in the home. Philips Respironics Trilogy Evo ventilators now enable integration of transcutaneous carbon dioxide data into Care Orchestrator online data reports, thereby facilitating correlation of blood gas events with simultaneously recorded ventilator performance and physiological data.

Abbreviations

AHI	apnea-hypopnea Index
AVAPS	Average Volume-Assured Pressure Support
AVAPS-AE	Average Volume-Assured Pressure Support with Auto-adjusting Expiratory positive airway pressure
Avg	average
EEP	end expiratory pressure
EPAP	Expiratory Positive Airway Pressure
IPAP	Inspiratory Positive Airway Pressure
iVAPS	Intelligent Volume-Assured Pressure Support
L/min	liters/minute
max	maximum
min	minimum
msec	milliseconds
PIP	Peak Inspiratory Pressure
PS	Pressure Support
$PtcCO_2$	Partial pressure of carbon dioxide measured transcutaneously
RR	Respiratory Rate
SpO_2	Oxygen saturation measured by pulse oximetry
S/T or ST	spontaneous/timed
Ti	inspiratory time
Ti/Ttot	Proportion of inspiratory time to total time of inhalation plus exhalation
Vti	inhaled tidal volume
Vte	exhaled tidal volume

Figure E1. Inconsistent adherence to nocturnal assisted ventilation.



A 70-year-old man with quadriplegia caused by spinal cord injury on nocturnal non-invasive ventilation.

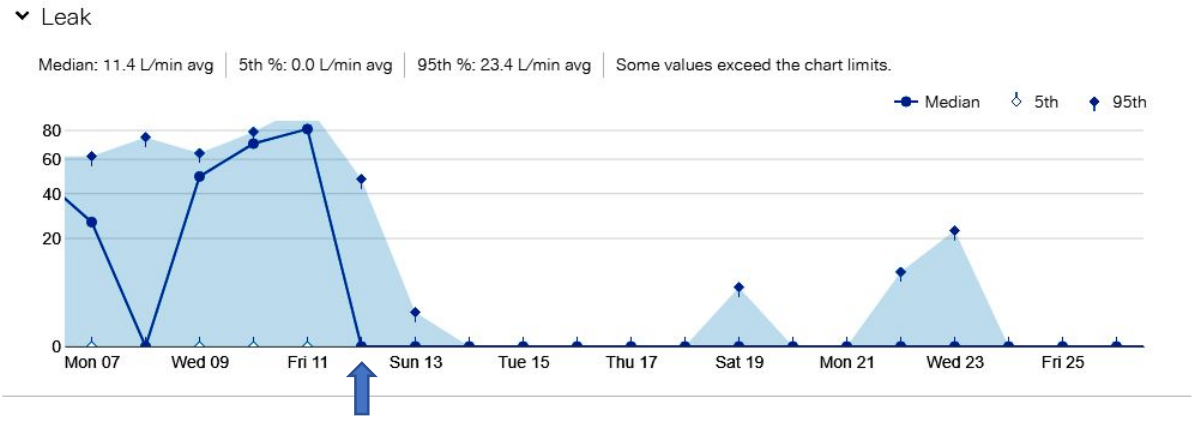
Device: Philips Respironics Trilogy ventilator. Nasal mask. Philips Respironics Care Orchestrator telemonitoring service.

Problem: Fatigue and daytime sleepiness.

Analysis: Online review of ventilator usage data indicated inconsistent use. When shown the usage graph, the patient reported that his mask often became dislodged by movement at night and he was unable to reposition it.

Solution: Adherence improved after change to a more secure oronasal mask.

Figure E2. Intermittent excessive circuit leak



A 72-year-old man with severe idiopathic kyphoscoliosis supported by nocturnal noninvasive ventilation.

Devices: ResMed Astral Ventilator. Full face mask. ResMed AirView telemonitoring service.

Problem: Frequent high leak alarms interrupting sleep.

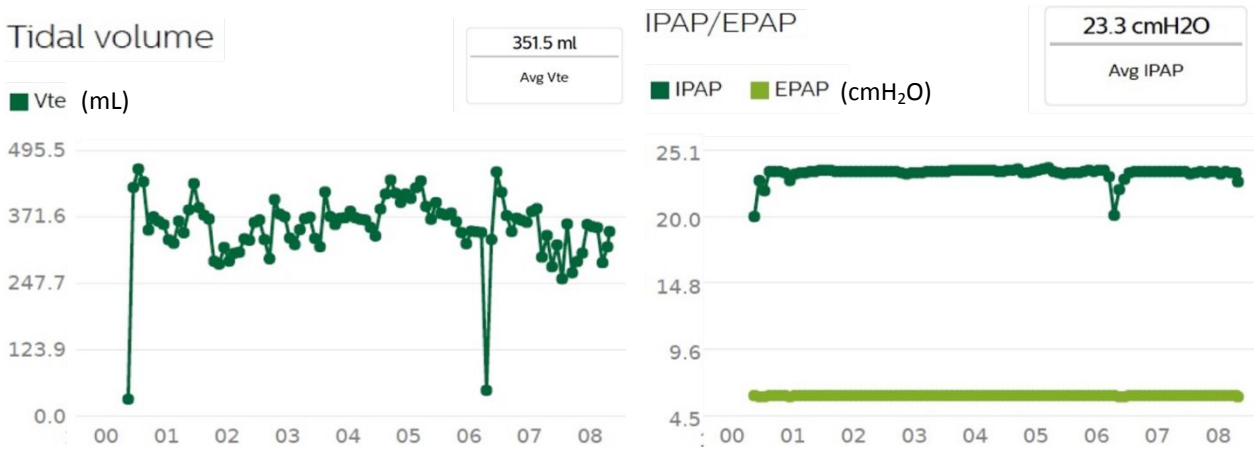
Setting: iVAPS mode, auto EPAP off. Height 63 inches; 24 breaths/min; target alveolar ventilation 7.5 L/min; EPAP 8 cmH_2O; PSmin 6 cmH_2O; PSmax 20 cmH_2O; Ti 1.0–1.6 sec; cycle 25%.

Performance (median): PIP 24.8 cmH_2O; EEP 7.9 cmH_2O; tidal volume 415 ml; 24 breaths/min; minute ventilation 9.8 L/min. Unintentional circuit leak > 60 ml/min. Note that estimated tidal volumes and minute ventilation are unreliable with this degree of circuit leak.

Analysis: The report reveals a variably excessive unintentional circuit leak while the patient slept. Either the mask fit poorly or the patient opened and retracted his jaw beneath the full-face mask while sleeping, thereby creating a leak at the chin. The patient's complaint of dry mouth while sleeping at night despite use of a humidifier suggested the latter cause. A similar pattern can occur with a nasal mask.

Solution: Addition of a chin strap greatly reduced the circuit leak (arrow) and quieted the excessive leak alarms.

Figure E3. Below target tidal volumes with IPAP "pinned" at IPAPmax



A 44-year-old woman with an unidentified chronic neuromuscular disease supported by nocturnal noninvasive ventilation.

Devices: Philips Respironics Trilogy ventilator. Full face mask. Philips Respironics Care Orchestrator telemonitoring service.

Problem: The overnight average tidal volume (351 mL) falls below target (450 ml) (7 mL/kg predicted body weight).

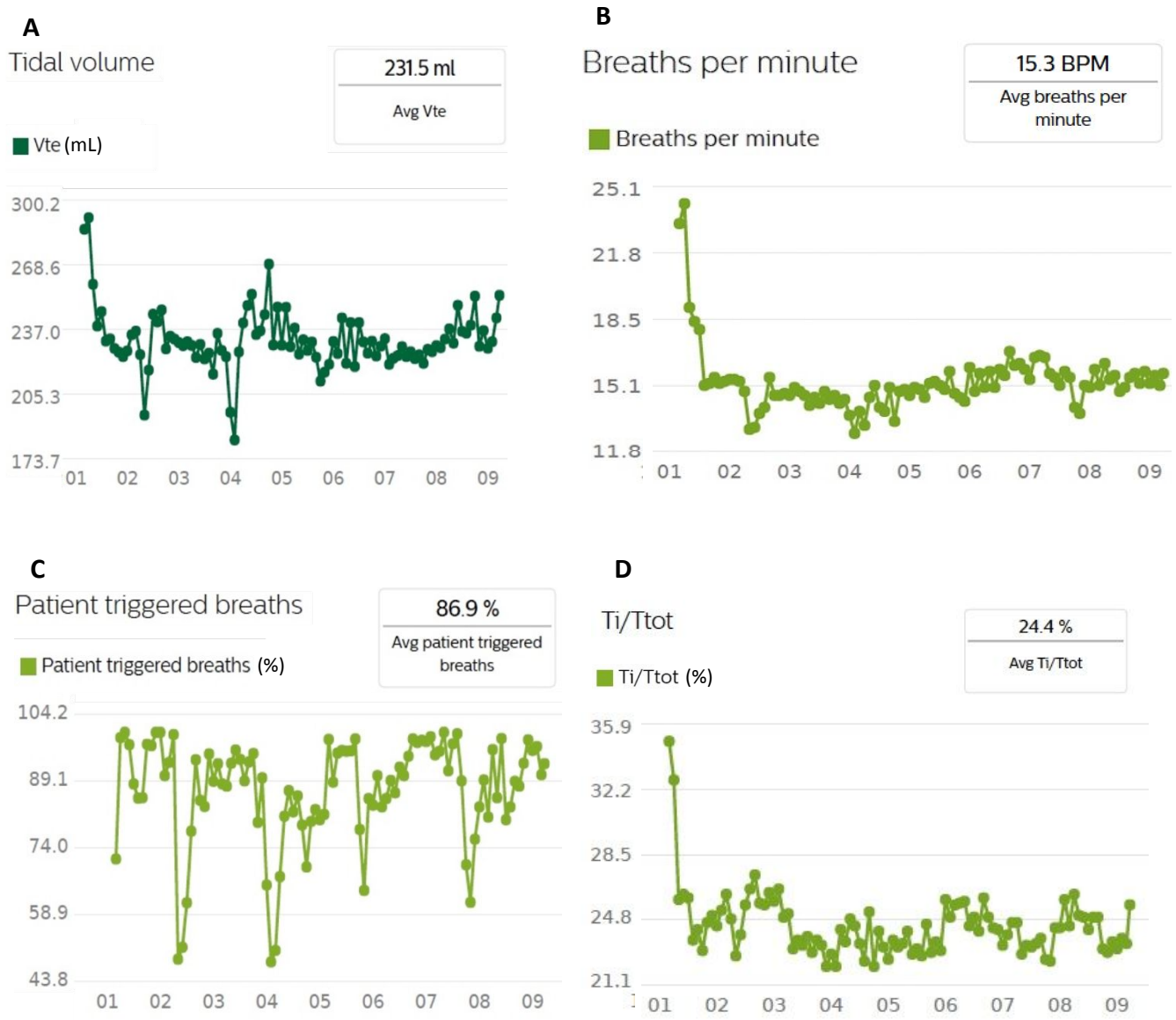
Settings: S/T mode, AVAPS on. Height 68 inches. Target tidal volume 450 mL (7 mL/kg predicted body weight); IPAPmin 12 cmH_2O, IPAPmax 24 cmH_2O; inspiratory time 1.0 sec; 14 breaths/minute; flow cycle sensitivity 20%; Flow trigger sensitivity 2 L/min; rise 3.

Performance (average): Tidal volume 351.5 mL; 14.5 breaths/minute; IPAP 23.3 cmH_2O; leak 36 L/min.

Analysis: The IPAP/EPAP panel shows that IPAP is continuously "pinned" near the IPAPmax setting (24 cmH_2O) Effectively, AVAPS was inactivated resulting in smaller than desired tidal volumes by preventing the device from increasing IPAP to achieve the targeted tidal volume.

Solution: An increase in IPAPmax to 30 cmH_2O enabled the ventilator to maintain an average tidal volume near the target tidal volume.

Figure E4. Inadequate tidal volumes in AVAPS-AE



A 50-year-old-man with advanced amyotrophic lateral sclerosis supported by noninvasive ventilation.

Devices: Philips Respironics Trilogy ventilator. Full face mask. Philips Respironics Care Orchestrator telemonitoring service.

Problem: Inadequate minute ventilation to maintain normal gas exchange at night.

Settings: AVAPS-AE mode. Height 69 inches.Target tidal volume 450 ml (7 ml/kg predicted body weight); PSmin 10 cmH_2O; PSmax 20 cmH_2O; EPAPmin 4 cmH_2O; EPAPmax 5 cmH_2O; 12 breaths/min; Ti 1.0 sec; trigger - Auto-Trak; rise 3.

Performance (average): Tidal volume 232 ml; 16 breaths/min; minute ventilation 3.6 L/min; IPAP 14 cmH_2O; EPAP 4.7 cmH_2O; patient-triggered breaths 87%; leak 35 L/min; Ti/Tot 24%.

Analysis: The patient's unacceptably low minute ventilation (3.6 L/min) reflects low tidal volumes (232 ml) relative to the target tidal volume (450 ml) (panel A) combined with a non-compensating respiratory rate (panel B). He is triggering most breaths at night (panel C). The inspiratory time is highly variable, and often <1.0 sec based on the Ti/Tot recording which shows an average value of 24% (average: 60 seconds/16 breaths/min x 0.24 = 0.9 sec) (panel D). Like S/T mode, AVAPS-AE applies the set inspiratory time only to ventilator-triggered breaths. When the patient breathes faster than the set rate, (as in this vignette), inspirations cycle when the inspiratory flow falls below the set cycle threshold. When "Auto-Trak" is applied as the Trigger setting, the Trilogy automatically adjusts the trigger and cycle sensitivity. If the patient's inspiratory flow rate falls quickly, as commonly occurs with advanced respiratory muscle weakness, the breaths cycle early, leading to short inspiratory times. Consequently, tidal volumes may fall below target even when AVAPS is active. Increasing the IPAP is unlikely to restore target tidal volumes in this situation. Instead, initial adjustments should focus on ensuring an adequate inspiratory time.

Solution: The ventilator mode was converted to PC with Ti 1.4 seconds, 15 breaths/min, flow trigger 2 L/min. The PC mode applies the set Ti to all patient-triggered as well as ventilator-triggered breaths. These revised settings increased tidal volumes to the target value, lowered the frequency of patient-triggered breaths to <20%, and normalized minute ventilation.

Figure E5. Inadequate minute ventilation caused by uncorrected progression of respiratory muscle weakness.

A 72-year-old man with amyotrophic lateral sclerosis 14 months after initiation of noninvasive ventilation. Referred for respiratory management and consideration of a tracheostomy.

Devices: Philips Respironics Trilogy ventilator. Full face mask. Philips Respironics Care Orchestrator telemonitoring service.

Problem: Inadequate ventilation as evidenced in panel A with consistently low minute ventilation and tidal volumes.

Settings (panel A before correction): S/T mode; height 69 inches; target tidal volume 470 (7 mL/kg predicted body weight); IPAP 12 cmH_2O; EPAP 4 cmH_2O; 10 breaths/minute; rise 3; Ti 0.9 seconds; trigger - Auto-Trak.

Performance: At the time of referral, average daily usage was 12 hours/day.

Analysis: At the onset of assisted ventilation 14 months prior to these recordings, ventilator settings were adjusted empirically to patient comfort. Those initial settings were never readjusted subsequently as respiratory muscle weakness progressed. At the time of consultation, IPAP and the set rate were inadequate to assure adequate tidal volume and minute ventilation.

Solution (panel B after correction): The ventilator was converted to PC mode with IPAP 22 cmH_2O; EPAP 4 cmH_2O; 20 breaths/minute; Ti 1.2 seconds; rise 3; trigger - Auto-Trak Sensitive. The resultant increase in IPAP, set respiratory rate, and consistent inspiratory time assured adequate tidal volumes and minute ventilation.

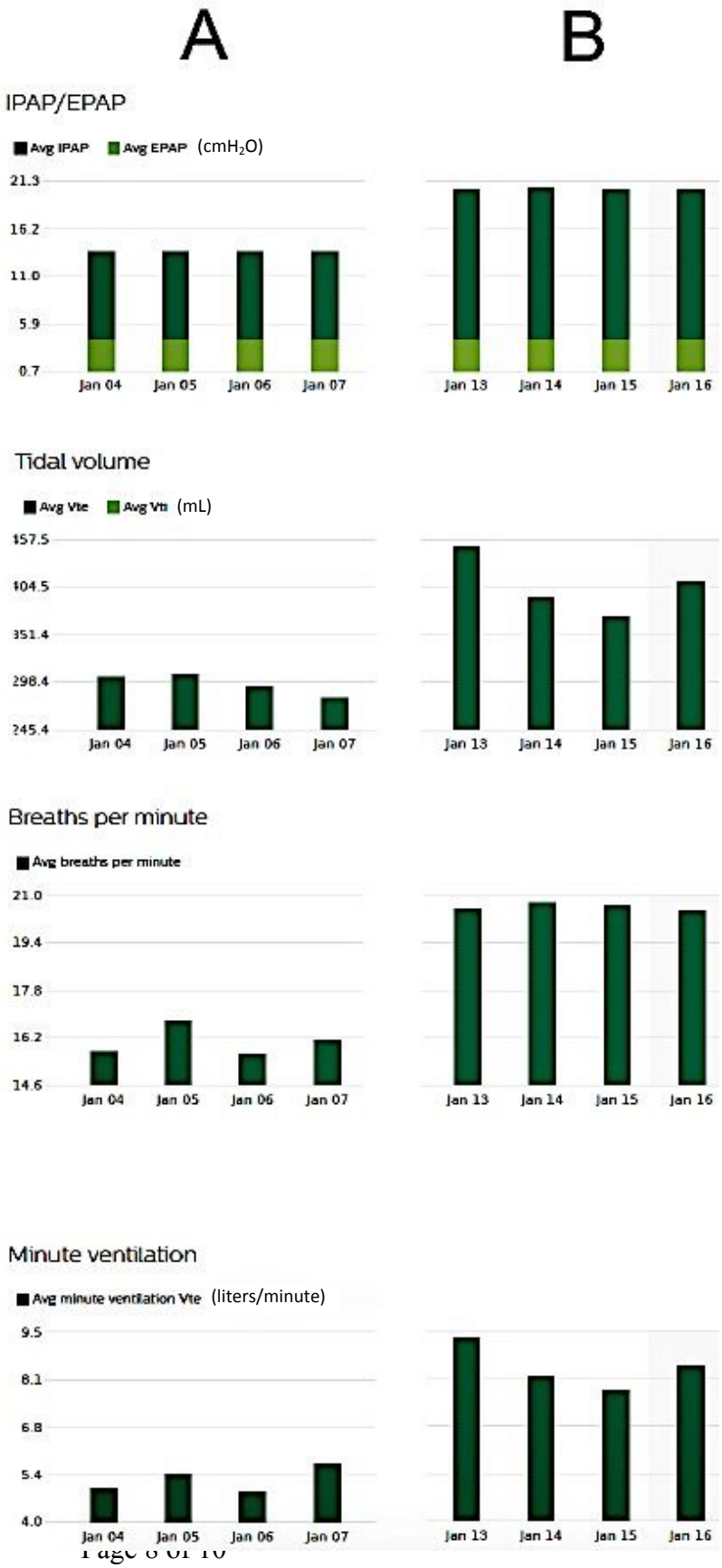
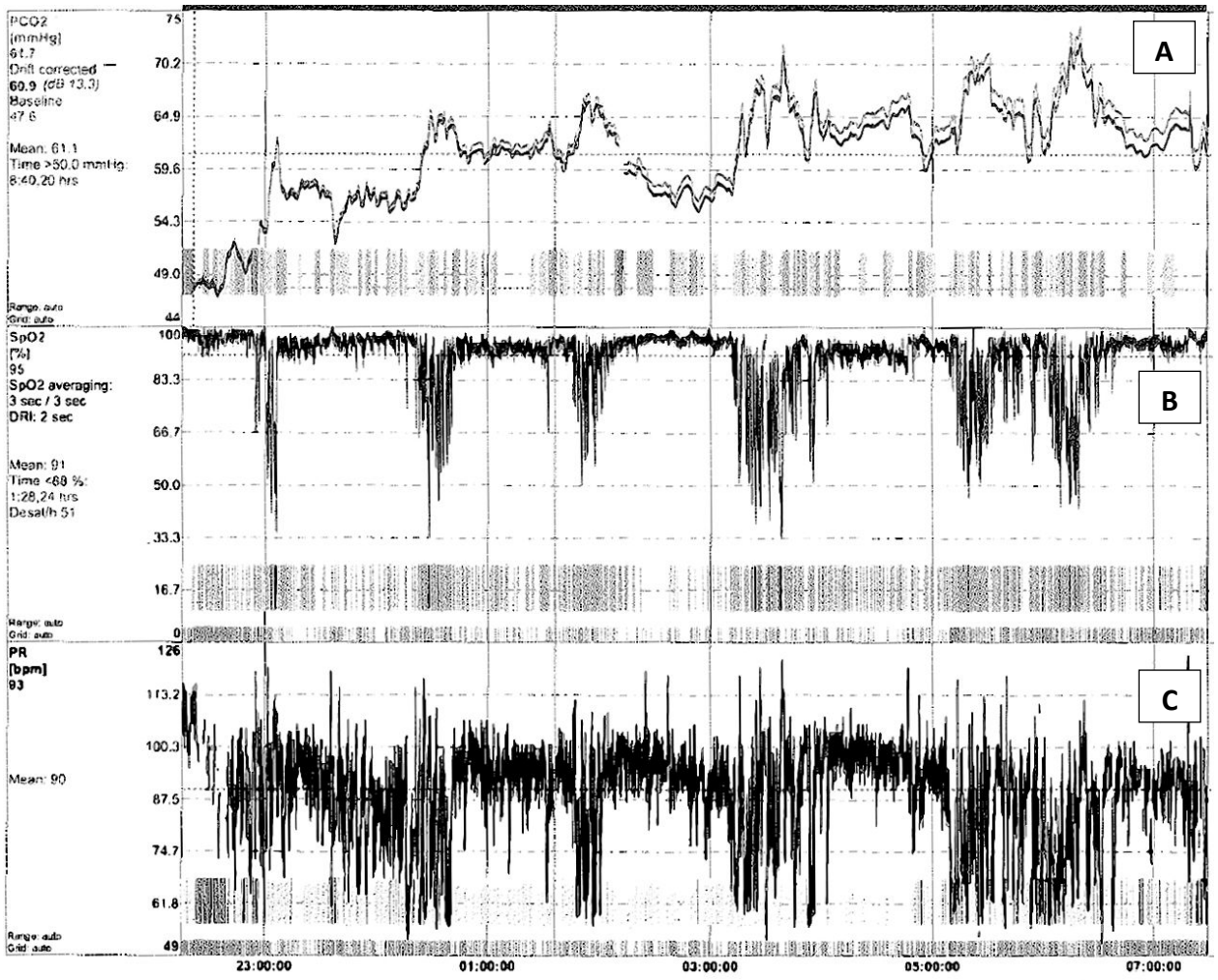


Figure E6. Episodic nocturnal hypoxemia and hypercapnia.



A 25-year-old man with Duchenne muscular dystrophy on nocturnal noninvasive ventilation.

Devices: Sentec transcutaneous V-sign monitor with simultaneous carbon dioxide (panel A), pulse oximetry (panel B), and heart rate (panel C) monitoring. The higher tracing shown in panel A recorded $PtcCO_2$ uncorrected for CO_2 drift. The lower tracing shows drift-corrected values. Philips Respironics Trilogy ventilator. Philips Respironics Care Orchestrator telemonitoring service (data not shown).

Problem: Intermittent nocturnal hypercapnia and hypoxemia.

Settings: AVAPS-AE mode. Height 64 inches. Target tidal volume 440 mL (8 ml/kg predicted body weight); PSmin 12 cmH_2O; PSmax 24 cmH_2O; EPAPmin 4 cmH_2O; EPAPmax 10 cmH_2O; 20 breaths/min; inspiratory time 1.0 sec; trigger - Auto-Trak; rise 2. The patient was breathing room air.

Performance: (average): Tidal volume 464 mL; 20 breaths/minute; IPAP 20 cmH_2O; EPAP 6 cmH_2O; patient-triggered breaths 9.3%; total circuit leak 49 L/min; Ti/Ttot 34%. $PtcCO_2$ awake 48 mmHg; mean overnight 61 mmHg; peak $PtcCO_2$ 75 mmHg; time $PtcCO_2$ >50 mmHg 8 hours 40 minutes. SpO_2 time <88% was 1 hour, 24 minutes.

Analysis: Six times overnight, $PtcCO_2$ increased while simultaneous both SpO_2 and heart rate decreased. The frequency and duration of these episodes suggest that they correspond to epochs of rapid eye movement (REM) sleep. After noting the patient's macroglossia, we suspected emergence of hypopneas and apneas during REM sleep not adequately corrected by the auto-adjusting EPAP feature of the ventilator. Supporting this interpretation, review of online Care Orchestrator ventilator performance tracings recorded the same night showed increases in EPAP with intermittent "pinning" against EPAPmax and simultaneous increases in circuit leak occurring at the same time as the recorded increases in $PtcCO_2$.

Solution: The patient declined in-lab polysomnography. Conversion to a fixed EPAP pressure of 12 mmHg largely corrected the episodes of hypercapnia and simultaneous hypoxemia.