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ORIGINAL RESEARCH

# Simplified Approach to Diagnosing Sleep-Disordered Breathing and Nocturnal Hypercapnia in Individuals With Spinal Cord Injury

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**Abstract**

**Objective:** To evaluate a strategy of home-based testing to diagnose sleep-disordered breathing and nocturnal hypercapnia in individuals with spinal cord injury (SCI).

**Design:** Case series.

**Setting:** Referral center.

**Participants:** Adults with C1-T6 SCI (N=81). Individuals were eligible if ≥18 years old, with SCI of ≥3 months' duration, living within 100 miles of the study site, and not meeting exclusion criteria. Of the 161 individuals recruited from the SCI Model System database who were not enrolled, reasons were not interested in participating, change of location, prior positive pressure ventilation use, or medical contraindication. Ten individuals did not complete the study.

**Interventions:** Performance of an unsupervised home sleep apnea test combined with transcutaneous partial pressure of carbon dioxide/oxygen saturation by pulse oximetry monitoring.

**Main Outcome Measures:** Prevalence of sleep-disordered breathing and nocturnal hypercapnia. Clinical and physiological variables were examined to determine which, if any, correlate with the severity of sleep-disordered breathing.

**Results:** Obstructive sleep apnea (OSA) was found in 81.3% of individuals, central sleep apnea (CSA) was found in 23.8%, and nonspecific hypopnea events, where respiratory effort was too uncertain to classify, were present in 35%. Nonspecific hypopnea events correlated strongly with CSA but weakly with OSA, suggesting that conventional sleep apnea test scoring may underestimate central/neuromuscular hypopneas. Nocturnal hypercapnia was present in 28% and oxygen desaturation in 18.3%. Neck circumference was the primary predictor for OSA, whereas baclofen use and obstructive apnea/hypopnea index weakly predicted CSA. Awake transcutaneous partial pressure of carbon dioxide and CSA were only marginally associated with nocturnal hypercapnia.

**Conclusions:** Unsupervised home sleep apnea testing with transcutaneous capnography effectively identifies sleep-disordered breathing and nocturnal hypercapnia in individuals with SCI.

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Individuals with spinal cord injury (SCI) commonly have sleep-disordered breathing, particularly obstructive sleep apnea (OSA).[1-4] Individuals with SCI may also experience central sleep apnea (CSA) or nocturnal hypoventilation due to reduced ventilatory drive during sleep and/or respiratory muscle paralysis.[5] In the general population, OSA is associated with impaired cognitive function and increased risk of myocardial infarction, stroke, congestive heart failure, and the "metabolic syndrome."[6-12] Poor sleep quality is common in SCI, but we know little about its consequences.[13,14] Furthermore, it is not known whether nocturnal hypercapnia in SCI confers the same risks as OSA, although nocturnal hypercapnia portends progression of respiratory failure

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in several neuromuscular disorders.[15] Obesity, cardiovascular morbidity, and diabetes are common in SCI, raising the possibility that unrecognized sleep-disordered breathing contributes to these comorbidities.[16-19]

Polysomnography (PSG) reliably diagnoses sleep apnea, but partial pressure of carbon dioxide ($Pco_2$) measurements are not routine, so nocturnal hypercapnia may go undetected. Studies performed in sleep laboratories have shown that 40% to 60% of individuals with SCI have OSA.[1-4] Individuals with SCI often forgo facility-based PSG because of barriers such as inadequate wheelchair accessibility and accommodations for caregivers. It is probable that sleep-disordered breathing is underrecognized in individuals with SCI, thereby denying them appropriate treatment with continuous or bilevel positive pressure ventilation (PPV). Recent technological advances enable us to collect valid data from home-based studies, circumventing the logistical obstacles associated with facility-based PSG. The potential advantages of home-based testing include improved convenience/acceptance by individuals and families as well as reduced cost. The purpose of this study was to determine whether sleep-disordered breathing and nocturnal hypercapnia could be diagnosed reliably and efficiently by home-based testing in individuals with SCI. In addition, we sought to determine whether clinical factors could reliably predict the severity of sleep-disordered breathing.

## Methods

Permission was provided by the Institutional Review Board of the University of Michigan (project no. HUM00051504). The study was performed between March 1, 2012 and November 15, 2014. Eligibility was determined by reviewing the University of Michigan SCI Model System database, which includes approximately 90% of individuals with SCI in the region. Individuals were eligible if ≥18 years old, with C1-T6 SCI (all American Spinal Injury Association grades of motor impairment) of ≥3 months' duration, and lived within 100 miles of the study site. Exclusion criteria included inability to provide informed consent, comorbid condition that limited life expectancy to ≤1 year, active duty military personnel, ventilator dependence, and established diagnosis of sleep-disordered breathing, or prior use of noninvasive PPV, except during hospitalization ≥3 months before enrollment. Among those not enrolled, 61.7% were not interested in participating, 5.7% had moved beyond the maximum distance to the study site, 14.2% were ineligible because of prior PPV use or presence of a tracheostomy tube, and 9.2% for other medical reasons. After an observation phase of 4 months to establish stability, the clinical assessment, home sleep apnea test (HSAT), and transcutaneous partial pressure of carbon dioxide/oxygen saturation by pulse oximetry (tc-$Pco_2$/$Spo_2$) monitoring were performed. Weight, height, waist circumference, neck circumference, and body mass index were measured, and medical records were reviewed.[20,21] Spirometry was performed with MedGraphics Ultima spirometers[a] in the seated position according to the American Thoracic Society guidelines.[22] Motor level and completeness of SCI were determined according to the International Standards for the Neurological Classification of Spinal Cord Injury.[23]

*List of abbreviations:*

| | |
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| **CSA** | **central sleep apnea** |
| **FVC** | **forced vital capacity** |
| **HSAT** | **home sleep apnea test** |
| **O-AHI** | **obstructive apnea/hypopnea index** |
| **OSA** | **obstructive sleep apnea** |
| **$Pco_2$** | **partial pressure of carbon dioxide** |
| **PPV** | **positive pressure ventilation** |
| **PSG** | **polysomnography** |
| **SCI** | **spinal cord injury** |
| **$Spo_2$** | **oxygen saturation by pulse oximetry** |
| **tc-$Pco_2$** | **transcutaneous partial pressure of carbon dioxide** |

HSATs were performed with the Stardust II (Type III) portable system,[b] which includes a nasal airflow sensor, a single thoracoabdominal piezoelectric belt to measure respiratory effort, and a pulse oximeter.[24] At the individual's home, the study coordinator placed the sensors and provided instructions regarding sensor placement in case they were dislodged during the study. After overnight tc-$Pco_2$ monitoring, data were downloaded to the manufacturer's software and the automated analysis was reviewed and rescored manually by a physician board–certified in sleep medicine (H.M.S.). The results were scored according to the 2007 American Academy of Sleep Medicine guidelines.[25] In addition, an alternate scoring strategy was developed. As in the American Academy of Sleep Medicine guidelines,[25] apneas were defined as ≥10-second periods of absent nasal airflow and hypopneas as ≥10 seconds of ≥50% reductions in airflow, relative to the preevent baseline. Events were classified as obstructive only if they were associated with stable or increasing respiratory effort, as determined by the amplitude of chest/abdominal movement; it criterion is now concordant with the 2015 American Academy of Sleep Medicine scoring manual.[26] The obstructive apnea/hypopnea index (O-AHI) is expressed as the number of obstructive events (apneas and hypopneas) per hour of recording time. If the period of reduced airflow was associated with decreasing chest/abdominal movement, it was interpreted as a nonspecific hypopnea event and excluded from the O-AHI. Events where baseline airflow was insufficient to measure a 50% reduction were classified as nonspecific hypopnea events. Furthermore, a reduction in $Spo_2$ was not used to score an obstructive event. An O-AHI of ≥5 events/h was chosen as the threshold for diagnosing OSA.

The study coordinator calibrated the SenTec Digital Monitor[c] immediately preceding each study. Monitoring of tc-$Pco_2$/$Spo_2$ was performed continuously through the individual's normal sleep period. Previous studies[27,28] support the accuracy of this device compared to arterial $Pco_2$ measurements. For this study, hypercapnia was defined as a tc-$Pco_2$ of ≥50mmHg for ≥5% of the recording time and oxygen desaturation was defined as $Spo_2$ of ≤88% for ≥5% of the recording time.

### Statistical analysis

The distribution of continuous outcome variables was inspected using histograms. The O-AHI, CSA event, nonspecific hypopnea event, and percentage of monitoring time with tc-$Pco_2$≥50mmHg were found to be strongly skewed before and after covariate adjustment and were log-transformed before the analysis. Covariate effects for regression models with log-transformed dependent variables have a multiplicative interpretation and are reported as such. Marginal correlations were assessed using Pearson correlation coefficients. The Student *t* test was used for comparing group means. To develop predictive models, we identified a set of hypothesis-driven candidate predictor variables for each outcome