TECHNICAL REPORT

Sleep Apnea in Spinal Cord Injury: A Systematic Review

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SYNOPSIS
Context: Spinal cord injury commonly results in neuromuscular weakness that impacts respiratory function. This would be expected to be associated with an increased likelihood of sleep disordered breathing.
Objective: 1. Understand the incidence and prevalence of sleep disordered breathing in spinal cord injury. 2. Understand the relationship between injury and patient characteristics and the incidence of sleep disordered breathing in spinal cord injury. 3. Distinguish between obstructive sleep apnea and central sleep apnea incidence in spinal cord injury. 4. Clarify the relationship between sleep disordered breathing and stroke, myocardial infarction, metabolic dysfunction, injuries, autonomic dysreflexia and spasticity incidence in persons with spinal cord injury. 5. Understand treatment tolerance and outcome in persons with spinal cord injury and sleep disordered breathing.
Methods: Extensive database search including PubMed, Cochrane Library, CINAHL and Web of Science.
Results: Given the current literature limitations, sleep disordered breathing as currently defined is high in patients with spinal cord injury, approaching 60% in motor complete persons with tetraplegia. Central apnea is more common in patients with tetraplegia than in patients with paraplegia.
Conclusion: Early formal sleep study in patients with acute complete tetraplegia is recommended. In patients with incomplete tetraplegia and with paraplegia, the incidence of sleep disordered breathing is significantly higher than the general population. With the lack of correlation between symptoms and SDB, formal study would be reasonable. There is insufficient evidence in the literature on the impact of treatment on morbidity, mortality and quality of life.

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Traumatic spinal cord injury (SCI) results in 12,000 new cases in the United States yearly, with an estimated population of 270,000 persons in the United States living with traumatic spinal cord injury (1). In addition, the number of persons with non-traumatic causes of spinal cord injury have been increasing with an aging population and advanced medical care such that the number of persons in the United States living with spinal cord injury from any cause is approaching or exceeding one half million persons.

In persons with traumatic SCI, more than one half sustain an injury in the cervical level (1). The potential for significant neuromuscular respiratory dysfunction is great as spinal cord injury affecting the diaphragm, abdominal and intercostal muscles is present. For this reason, pulmonary morbidity is great.

Indeed, respiratory dysfunction is the number one cause of death in persons who survive acute traumatic spinal cord injury (2, 3).

Neuromuscular respiratory weakness would be expected to have an impact on obstructive sleep apnea. With weakness of muscles of inspiration, weakness of muscles of exhalation, and decreased flow rates, one would think that obstruction of the upper airway would be more likely to result in failure of effective airflow during sleep. In addition, patients with upper cervical spinal cord injury who are able to wean from the ventilator might be vulnerable to central sleep apnea due to relative inefficiency of ascending and descending pathways of the upper cervical spinal cord.

Sleep disordered breathing (SDB) in the able bodied population has a robust literature indicating the prevalence of the problem and the health and psychosocial risk factors associated with it. Currently, the known prevalence is 4% of the male and 2% of the female population. Risk factors for sleep apnea include obesity and increased neck circumference (4). The relationship between sleep apnea and the incidence of myocardial infarction (5, 6), stroke (7, 8) and metabolic dysfunction (9-12) have been well established in the able bodied population.

Specific issues related to SDB in SCI include what is the incidence and prevalence and what are associated factors that are related to the presence of SDB in patients with SCI. It would be important in persons with SCI to be able to differentiate between obstructive and central sleep apnea and to understand the incidence of each compared to the general population. Knowing this is critical as the treatment of these two problems would be different. The obstructive component can be treated with CPAP alone, while central sleep apnea would require a back-up rate, and sleep-related hypoventilation would require a pressure differential between inspiration and expiration (BiPAP), and possibly a back-up rate as well. It would be valuable to evaluate if the factors associated with SDB in the general population are the same in patients with SCI. It would be valuable to know if factors that are common or specific to spinal cord injury, for example the presence of co-existent traumatic brain injury, sleep position, and medication use such as opioid medication, baclofen, and benzodiazepines, affects SDB in SCI. It would be valuable to know if symptom questionnaires are valid in the SCI patients. It is important to know if SDB is associated with medical morbidity as it is in the general population, including risks of stroke, myocardial infarction, metabolic dysfunction, and accidents. It would also be important to know if SDB is associated with other common secondary conditions after spinal cord injury, including spasticity and autonomic dysreflexia. Given the relationship between sleep apnea and sympathetic nerve activity, the association been SDB in SCI and autonomic dysreflexia would be important to understand (13, 14). It would also be useful to know how CPAP titration differs in patients with spinal cord injury and if the rate of compliance is different from the general population of patients with SDB. The outcomes of effective SDB treatment in SCI is important, including resolution of the symptoms of SDB, resolution of the sleep study abnormalities during treatment and the impact on health and psychosocial variables over the lifespan. The positive impact of treatment on mortality, as is seen in amyotrophic lateral sclerosis (15) and other neuromuscular disorders (16), would be important to know.

METHODS

An extensive search of published peer-reviewed studies published from 1980 to 2013 was conducted in the following databases: PubMed, Cochrane Library, CINAHL, and Web of Science. Searches were performed using the appropriate subject heading terms and keywords for spinal cord injuries, sleep apnea, sleep disordered breathing, hypoventilation, respiratory insufficiency, and polysomnography. Complete search strategies for the databases, including all the search terms used, are given in Table 1. The ending date for the searches was March 15, 2013.

The spinal cord injury term was defined as penetrating and non-penetrating injuries to the spinal cord resulting from traumatic external forces. Sleep apnea syndromes were defined as disorders characterized by multiple cessations of respirations during sleep that induce partial arousals and interfere with the maintenance of sleep. Sleep apnea syndromes are divided into central, obstructive, and mixed central-obstructive types. Hypoventilation was defined as a reduction in the amount of air entering the pulmonary alveoli. Respiratory insufficiency was defined as failure to adequately provide oxygen to cells of the body and to remove excess carbon dioxide from them.

In all 703 articles were identified using this method.

A final review of the literature was performed in November, 2014 prior to the completion of the text. In addition, the references for the articles that were chosen for inclusion were reviewed to identify other literature on the topic that was not previously identified.

Of these, 13 were included. They were limited to articles with clinical series of patients with the best studies either representing a larger sample, a cohort sample, or a consecutive patients' sample.

The articles were organized in a table format based on date of publication, separating out the three studies related to treatment outcome (Table 2).

RESULTS

EVALUATION

Berlowitz used an inpatient sleep study methodology in a prospective cohort study of thirty new cervical SCI patients. Patient evaluation was with full polysomnograms (EEG, air flow, O_2 saturations, chest wall motion, and diaphragm surface EMG). Hypopneas were defined as greater than 50% reduction in chest wall motion or less than 50% reduction with cortical arousal on EEG or O_2 desaturations of greater than 3% (17). Chest wall compliance is less of an issue in patients with acute SCI compared to chronic SCI in testing chest wall motion. However, there was no differentiation if the drop in chest wall motion was obstructive or central in nature.

Sankari used an inpatient sleep study methodology evaluating 26 patients who were greater than 6 months post-injury who were willing to complete an evaluation with spirometry measurements, O_2 levels, EEG, submental EMG, nasal airflow, pharyngeal pressure, end tidal CO_2, and upper airway resistance. The study used the American Academy of Sleep Medicine criteria scoring the study twice; once using the 2007 criteria of hypopnea with greater than or equal to a 30% reduction of nasal airflow for at least 10 seconds, associated with at least a 4% desaturation from pre-event baseline and once using the 2012 criteria of hypopnea of with at least a 30% reduction of nasal airflow for at least 10 seconds, associated with at least a 3% desaturation from pre-event baseline or arousal. The study defined sleep disordered breathing as an apnea-hypopnea index (AHI) of at least 5 per hour and a central sleep disorder with more than 5 episodes an hour (18).

Leduc evaluated a 41 member prospective outpatient cohort and did full home unsupervised polysomnography including EEG. Their criteria included symptoms (daytime sleepiness or two or more of recurrent awakening, choking or gasping during sleep, unrefreshing sleep, daytime fatigue, or impaired concentration) with an AHI >= 5 per hour. Hypopneas were defined as greater than or equal to 50% reduction in air flow or less than 50% with a greater than 3% decrease in O_2 saturation (19).

McEvoy used a home study including EEG, EOG, sub-mental EMG, nasal airflow, body movement, respiratory movement and SPO_2 in their study of 40 patients greater than 6 months after their spinal cord injury who still lived in the state of South Australia, with nearly 55% excluded because they no longer fit the inclusion criteria (8%), no longer lived in the area (9%), had exclusion criteria (2%), did not reply (29%) or were unwilling to participate (7%). There was no significant difference between the sample group and the full cohort with regard to age, years since injury, and sex distribution. Hypopneas were defined as a reduction in airflow of 50% or more from baseline, lasting 10 seconds or more (20).

Klefbeck evaluated 33 of 37 consecutive patients with tetraplegia who returned to clinic for a routine annual examination over a six year period of time. This study used in hospital investigation testing SPO_2 as well as body and respiratory movement. Criteria for sleep apnea included at least 5 episodes of at least a 4% drop in oxygen saturation per hour and greater than 45% periodic respiration time out of the total sleeping time (21).

Stockhammer used a hospital based study of nasal thermistor, SPO_2, and chest wall motion to study a random sample of 50 patients with tetraplegia at least 6 months after injury. A criterion for SDB was an apnea-hypopnea index of at least 15 and an apnea index of at least 5 (22). Short evaluated 22 ”consecutive” patients over the age of 40 who were at least 3 months post-injury with cervical or thoracic SCI. The patients were evaluated in a hospital setting and included EEG, EMG, EOG, rib and abdominal movement, and O_2 saturations, with SDB being defined as a drop of at least 4% in oxygen saturations at least 15 times per hour (23).

INCIDENCE and PREVALENCE

Assessing incidence and prevalence varies for many important reasons. Study populations vary with regard to age, time since injury and neurological level, and these are characterized in detail in the results section. The type and location of sleep study use varies, as noted in the previous section. One might assume that analysis in the patient’s own home setting is most ideal, given the patient’s care needs and potential need for attendant care at night, although there is currently no literature differentiating home and sleep lab results. The criteria used to identify sleep disordered breathing vary with studies and is spelled out in the results and in the previous section. Commonly the standards set are consistent with American Academy of Sleep Medicine (AASM) diagnostic criteria (2007 or 2012 version) as the accepted guideline. That said, the standard AASM criteria based on polysomnogram standards were not designed with respiratory muscle paralysis and hypoventilation in mind, and there is no consideration of how the presence of SCI and respiratory muscle weakness may affect the validity of AASM criteria in any of the reviewed articles. Inattention to this problem could have caused some studies to overestimate the already high prevalence of OSA, while at the same time leaving hypoventilation underestimated and potentially under-treated. Also relevant to this point is that continuous monitoring of pCO_2 was not done in any of these studies. Symptoms suggesting sleep disordered breathing would be fairly standard in the general population, but it is questionable how this would apply to an SCI population where skin care and bladder care at night time often make interrupted sleep commonplace.

A study using a prospective cohort of patients with cervical spinal cord injury using a cut off of AHI > 10 noted a diagnosis of obstructive sleep apnea in 14/19 or 74% of patients with tetraplegia who were studied in their six week inpatient rehabilitation program post-acute injury (24). Using the same criteria, the same authors reported in a cross sectional study of 78 patients an incidence of 91% in acute complete tetraplegia and an incidence of 56% in patients with acute incomplete tetraplegia. There was no relationship between the neurological level and AHI (25). In a study of 26 spinal cord injured patients, 15 cervical and 11 thoracic, showed an AHI >=5 in 77% with an incidence of 89% cervical and 50% thoracic (18). Twenty two consecutive patients presenting with spinal cord injury older than 40 years old and with time since injury greater than 3 months showed that 12 had an AHI >= 5 and 6 had an AHI >= 15. Two patients had central apnea in REM stage. In this small sample, there was no relationship between AHI and age, AIS level, time since injury, BMI, head circumference, or spirometry measures (23). Leduc completed at home sleep studies in 41 patients with spinal cord injury with 23 (56%) with AHI >= 5 and 22 of these patients had symptoms of daytime sleepiness. There was a relationship between AHI and daytime sleepiness, BMI and neck circumference. There was no relationship to neurological level, time since spinal cord injury, or medications such as opiates and benzodiazepines (19)

A regional cohort of 40 patients with C8 and above level spinal cord injury, AIS A, B or C, was studied at least six months post-injury with a home sleep study. Eleven (27.5%) had an RDI >= 15 while 16/19 had a REM sleep RDI >= 15 (20). A randomly selected population of 50 patients with spinal cord injury, 23 C3-5 and 27 C6-8 with 40 patients ASIA A or B was studied using a hospital sleep study process. AHI >=15 was noted in 31 (62%) with 24 (48%) with an AI >=5. Sixteen patients had obstructive sleep apnea, six were mixed and 2 had central apnea. AHI was related to age, male sex and BMI (22). An inception cohort of 30 patients noted that the incidence of obstructive sleep apnea after acute spinal cord injury was at or slightly above 60% and stabilized over the 52 week evaluation, although only 13/30 subjects completed the 52 week evaluation. The study consisted of 9 patients C4 ASIA A, 10 at C5 ASIA A, 6 incomplete tetraplegia, and the rest C6-T1 ASIA A (17). A study of 33 of 37 consecutive patients with C4-T1 ASIA A-D with 3 C4, 12C5, 9 C6, 5C7, 1C8 and 2T1 was completed. Using the criteria of ODI>6, five met the criteria for sleep disordered breathing. There was a relationship between ODI and ASIA motor score in patients with complete injuries only. There was no relationship to BMI, although all patients had a BMI <30 (21). Central sleep disordered breathing was noted in a small sample (16 patients with 6 tetraplegia) and was noted to be more common in cervical spinal cord injury than thoracic spinal cord injury, with incidences of 63% and 13%, respectively (26).

SYMPTOMS

The study of Leduc used symptoms of SDB including daytime sleepiness, or 2 or more of the following "not better explained by other factors": recurrent awakening, choking/gasping during sleep, unrefreshing sleep, daytime fatigue, impaired concentration. They noted no relationship between patient symptoms and AHI. They did note that obstructive sleep apnea was related to daytime sleepiness, BMI greater than 30 kg/m^2, neck circumference and greater than 3 awakenings at night (19). The McEvoy study of patients with tetraplegia noted a relationship between SDB and systolic blood pressure, diastolic blood pressure, and neck circumference (20). Stockhammer noted a relationship between SDB and increased age, male sex, and BMI in his population with tetraplegia. The Berlowitz studies noted a relationship between Multivariate Apnea Prediction Index, measuring sleep apnea risk pre-injury, and sleep study results post-injury. In their study, ten percent of subjects likely had sleep apnea pre-injury and all had AHI greater than 35 post-injury. AHI correlated with neck and abdominal circumferences and benzodiazepine use; six of seven patients had non-statistically different decreases in AHI after stopping benzodiazepine use (22). Sankari used the Epworth Sleepiness Scale (ESS), Pittsburgh Sleep Quality Index, Berlin Questionnaire (BQ) and Fatigue Severity Scale (FSS) in their study of 15 cervical and 11 thoracic SCI patients. Although ESS showed scores of greater than 10 indicating excessive daytime sleepiness in 59%, FSS showed scores of greater than 20 indicating daytime fatigue in 96% and BQ indicated high risk of SDB in 46%, ESS was the only score that was an independent predictor of AHI. Interestingly, there was no difference in the questionnaire scores between patients with cervical and thoracic SCI even though their relative incidence of SDB was different (18).

TREATMENT

In a postal survey, 40 out of 72 patients treated by a Veterans Administration Hospital service for spinal cord injury and SDB replied for evaluation. Patients averaged 4.2 years post-injury with 37 of 40 with tetraplegia. CPAP was tried by 32 (80%) and used by 63% of these for 6.5 nights per week and 6.9 hours per night. Of the 17 not being treated, 12 of the 13 who were offered CPAP tried it with 67% citing inability to fall asleep on CPAP, 42% citing mask discomfort, and 33% citing claustrophobia as the reasons to discontinue use. ESS and Sleep Apnea Quality of Life Index were not different comparing the treatment and non-treated patients, indicating that symptomatic improvement may not be an expected result of treatment, just as symptoms have been shown to be poor predictors of sleep apnea in the first place (27).

A retrospective study of 25 patients with tetraplegia and 219 control patients, all with obstructive sleep apnea, was completed by which all were evaluated on the result of CPAP treatment. No correlation was identified between AHI and effective CPAP or between BMI and effective CPAP in the tetraplegia group. The control group had higher BMI and required higher CPAP pressure to control obstructive sleep apnea (28).

In a prospective cohort study of 19 cervical spinal cord injury patients where AHI greater than 10 during a diagnostic overnight sleep study was used as a criteria for SDB, 14/19 (74%) met this criteria. Auto-titration CPAP was initiated with intensive clinical support. A physiotherapist spent approximately three hours per night for three to four nights in the first week of implementation with the patient. Approximately one hour daily was spent troubleshooting equipment and to debrief the participant. Seven or 50% were adherent for 3 months. Patients who tolerated CPAP were older, had higher BMI, were sleepier and had more severe OSA (24).

OUTCOME

There are many issues related to SDB outcome that have not been substantiated in the current literature. Although we do know that vital capacity changes over the lifetime of persons with spinal cord injury, there is not available literature to indicate the impact of these changes on the incidence or severity of sleep disordered breathing.

In spite of the literature on the incidence and prevalence of SDB in SCI, there is a lack of literature showing the impact of treatment on this disorder. There is some literature on patient compliance but no similar literature indicating the impact of treatment on respiratory parameters that were used to make the diagnosis. Therefore, there is a lack of information that indicates that the parameters which have triggered treatment have been altered by treatment.

In addition, there is a lack of literature that indicates the downstream impact of treatment on patients with spinal cord injury. Sleep apnea in able bodied adults is associated with daytime hypertension, stroke, heart disease, impaired glucose tolerance and insulin resistance, and accidents related to daytime sleepiness. These associations, and associations with other SCI complications such as pneumonia, respiratory insufficiency and autonomic dysreflexia, have not been established in the spinal cord injured population. In addition, the impact of treatment on these associated factors or on psychosocial outcomes such as depression, quality of life, and employment have not been adequately studied.

DISCUSSION

There were only two articles that used a cohort series in that all patients in a region or all patients presenting within a given time frame were included in the study. The series samples were relatively small, making it more difficult to extrapolate the results to the larger populations of patients with spinal cord injury.

The incidence of SDB after SCI is high. This is not surprising in a population of patients with neuromuscular weakness of muscles of inspiration and expiration. This is especially true in patients with complete tetraplegia, where an incidence of approximately 60% seems well established using currently established criteria for able bodied patients. Whether such criteria are reasonable in patients with spinal cord injury are reasonable to question, and would require further research to explore the impact of treatment on these indices and on the use of other measures of respiratory function such as continuous CO_2 monitoring.

OSA is best documented as the most common form of sleep-disordered breathing, although some studies have indicated an appreciable prevalence of CSA as well. While sleep-related hypoventilation at least partly attributed to respiratory muscle weakness undoubtedly occurs, it is not yet clear how respiratory muscle weakness impacts the reliability of polysomnograms in the diagnosis of sleep-disordered breathing. Likewise, it is not clear how respiratory muscle weakness impacts the development or severity of OSA or CSA.

It is also well established that the development of sleep disordered breathing after spinal cord injury occurs early. This is not surprising, as one would expect that the impact of neurological dysfunction is related to the higher incidence of sleep disordered breathing in this population. This is supported by the evidence that in patients with complete injury, one study demonstrated a relationship between ASIA motor score and AHI. Studies that grouped patients who are complete and incomplete did not appreciate this relationship. This is not surprising as C2 and C3 level incomplete injuries would be grouped with patients with lower cervical injuries.

CONCLUSION

Based on these findings, it is clear that in patients with complete tetraplegia, early formal sleep study is important. In patients with incomplete tetraplegia and paraplegia, the incidence is not as high. However, given the poor relationship between daytime sleepiness evaluations and AHI, it would be reasonable to consider baseline testing in all patients.

Given the current limitations in the literature, the standard evaluation of sleep apnea in patients with spinal cord injury is not clear. Although it makes inherent sense to complete the evaluation in the patient's home setting, no study compares these evaluation techniques with more standard in hospital sleep lab methods.

Given the limitations of the current literature, there is much still to learn about the relationship between spinal cord injury and sleep disordered breathing. The areas where a knowledge gap exists include the best method to evaluate, the best criteria to use to direct treatment, the best criteria to use to identify effective treatment, and the downstream impact of effective treatment on morbidity, mortality, and quality of life outcomes.

Table 1: Search Terms and Measures by Database

Database	Search Strategy
PubMed	(Spinal Cord Injuries[mh] OR "Spinal cord injury" OR "spinal cord injuries" OR "spinal cord injured" OR "spinal injury" OR "spinal injuries" OR "cervical spine injury" OR "cervical spine injuries" OR "CS injury") AND (Sleep Apnea Syndromes[mh] OR Hypoventilation[mh] OR Respiratory Insufficiency[mh] OR Polysomnography[mh] OR "sleep apnea" OR "sleep apneas" OR "Sleep Disordered Breathing" OR "Sleep Hypopneas" OR "sleep hypopnea" OR hypoventilation OR Hypoventilations OR "Respiratory Insufficiency" OR "Respiratory Failure" OR "Respiratory Depression" OR "Ventilatory Depression" OR Polysomnography OR Polysomnographies OR "sleep monitoring" OR Somnography OR Somnographies OR "sleep studies" OR "sleep study") Filters activated: English
Cochrane Library	The ID line # is followed by a corresponding search strategy: #1—MeSH descriptor: [Spinal Cord Injuries] explode all trees #2—("Spinal cord injury" or "spinal cord injuries" or "spinal cord injured" or "spinal injury" or "spinal injuries" or "cervical spine injury" or "cervical spine injuries" or "CS injury") #3—MeSH descriptor: [Sleep Apnea Syndromes] explode all trees #4—MeSH descriptor: [Hypoventilation] explode all trees #5—MeSH descriptor: [Respiratory Insufficiency] explode all trees #6—MeSH descriptor: [Polysomnography] explode all trees #7—("sleep apnea" or "sleep apneas" or "Sleep Disordered Breathing" or "Sleep Hypopneas" or "sleep hypopnea" or hypoventilation or Hypoventilations or "Respiratory Insufficiency" or "Respiratory Failure" or "Respiratory Depression" or "Ventilatory Depression" or Polysomnography or Polysomnographies or "sleep monitoring" or Somnography or Somnographies or "sleep studies" or "sleep study") #8—#1 or #2 #9—#3 or #4 or #5 or #6 or #7 #10—#8 and #9
CINAHL	(MH "Spinal Cord Injuries+" OR MH "Spinal Cord Injury Nursing" OR TX "Central Cord Syndrome" OR TX "Spinal Cord Compression" OR TX "Spinal cord injury" OR TX "spinal cord injuries" OR TX "spinal cord injured" OR TX "spinal injury" OR TX "spinal injuries" OR TX "cervical spine injury" OR TX "cervical spine injuries" OR TX "CS injury") AND (MH "Sleep Apnea Syndromes+" OR MH "Hypoventilation+" OR MH "Respiratory Failure+" OR MH "Polysomnography" OR TX "sleep apnea" OR TX "sleep apneas" OR TX "Sleep Disordered Breathing" OR TX "Sleep Hypopneas" OR TX "sleep hypopnea" OR TX hypoventilation OR TX Hypoventilations OR TX "Respiratory Insufficiency" OR TX "Respiratory Failure" OR TX "Respiratory Depression" OR TX "Ventilatory Depression" OR TX Polysomnography OR TX Polysomnographies OR TX "sleep monitoring" OR TX Somnography OR TX Somnographies OR TX "sleep studies" OR TX "sleep study") Limiters - English Language; Exclude MEDLINE records

Database	Search Strategy
Web of Science	Topic=("Spinal cord injury" OR "spinal cord injuries" OR "spinal cord injured" OR "spinal injury" OR "spinal injuries" OR "cervical spine injury" OR "cervical spine injuries" OR "CS injury") AND Topic=("sleep apnea" OR "sleep apneas" OR "Sleep Disordered Breathing" OR "Sleep Hypopneas" OR "sleep hypopnea" OR hypoventilation OR Hypoventilations OR "Respiratory Insufficiency" OR "Respiratory Failure" OR "Respiratory Depression" OR "Ventilatory Depression" OR Polysomnography OR Polysomnographies OR "sleep monitoring" OR Somnography OR Somnographies OR "sleep studies" OR "sleep study") Timespan=1970-01-01 - 2013-03-14. Databases=SCI-EXPANDED, SSCI, A&HCI, CPCI-S.

Table 2: Articles With Clinical Series of Patients With the Best Studies—Representing a Larger Sample, a Cohort Sample, or a Consecutive Patients' Sample

Author	Patient selection	Patients	Study parameters	Definition of SDB	Outcome	Correlates
Short (1992)	Consecutive series	22, greater than 40 > 3 mo post injury	EEG, EMG, EOS Trunk strain gauges O2 sats	O2 > 4% drop from preceding 10 minute average	55% AHI > 5 27% AHI > 15 2 central apnea	No relationship to age, time since injury, obesity, spirometry
McEvoy (1995)	Regional cohort	44, C8 and above, ASIA A, B, C >6 mo post injury	Home sleep study EEG, EOG, submental EMG, body movement, nasal air flow, respiratory movement, SPO2	Hypopnea=10 second of >50% airflow drop from baseline	30% AI >=5 27.5% AHI >= 15	AHI related to systolic bp, diastolic bp, neck circumference, supine position
Klefbeck (1998)	Consecutive series	33 C4-T1 ASIA A-D 3 C4, 12 C5, 9 C6, 5 C7, 1 C9, 2T1	Hospital sleep lab O2, body movement	O2 > 4% drop	15% met criteria	Related to ASIA level in ASIA A group only
Stockhammer (2002)	Random selection	50, C3-C8 23 C3-5, 27 C6-8 40 ASIA A-B	Hospital sleep lab O2, nasal thermistor, chest wall motion	Hypopnea 50-90% drop airflow for 10 sec Apnea > 90% drop for 10 sec	48% AI >= 5 62% AHI >=15	AHI related to age, male sex, BMI.
Berlowitz (2005)	Inception cohort	30, 13 finished 52 week evaluation C4 9, C5 10, C6 2, C7 1, C8 1 ASIA 1-B 20%	Hospital sleep lab EEG, submental and diaphragm EMG, EOG, ECG, nasal thermistor, plethysmography, SP 02	Hypopnea defined as 50% reduced airflow or <50% airflow and >3% O2 drop Apnea defined as no airflow	60% AHI >=5 by 2 weeks, then stable	

Author	Patient selection	Patients	Study parameters	Definition of SDB	Outcome	Correlates
LeDuc (2007)	Prospective cohort	41 outpatients	Home unsupervised polygrams	Symptoms plus AHI Hypopnea 50% reduction in airflow or >3% drop O2	56% AHI >= 5	No relationship of symptoms to AHI OSA related to daytime sleepiness, BMI greater than 30 kg/m2, neck circumference and greater than 3 awakenings at night
Berlowitz (2012)	Cross sectional	78, tetraplegia	Hospital sleep lab EEG, submental and diaphragm EMG, EOG, ECG, nasal thermistor, plethysmography, SP 02	AHI > 10	91% complete with SDB 56% incomplete	No relationship between AHI and ASIA level
Sankari (2014 J Appl Physiol)	Case Control	16 SCI (6 cervical) and 16 control	Non-invasive hyperventilation to induce apnea, CO2 trial to abolish central apnea Polysomnogram	AHI > 5	Central SDB 63% cervical, 13% thoracic CO2 reserve narrower in cervical, best in controls.	

Author	Patient selection	Patients	Study parameters	Definition of SDB	Outcome	Correlates
Sankari (2014 JCSM)	Consecutive Series	26, 15 cervical	Hospital sleep study Polysomnogram: EEG, submental EMG, nasal air flow, pharyngeal pressure, ETCO2, upper airway resistance Epworth, Pittsburgh, Berlin, Fatigue severity	AHI > 5 Central AI > 5	PSQ 10.3, ESS 10.4 Fatigue 96%, daytime sleepiness 59%, Berlin high risk 46%. AHI >5 77%, 89% cervical, 50% thoracic. Central AI 33% cervical, 13% thoracic.	
TREATMENT						
Burns (2005)	Postal survey	40 of 72 being treated for SDB			CPAP tried by 80%, used by 63%. Reasons: 67% unable to fall asleep, 42% discomfort, 33% claustrophobia	No difference in symptoms between users and non-users
Berkowitz (2009)	Prospective cohort	74% of 19 with SCI and AHI >10	Auto-titration CPAP with PT support for 3-4 nights			Patients who tolerated CPAP were older, had higher BMI, were sleepier and had more severe OSA
Leguen (2012)	Retrospective Case Control	25 SCI, 219 controls with OSA				No relationship between effective use and BMI or AHI

Key Words: spinal cord injuries, sleep apnea, sleep disordered breathing, polysomnography

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