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Management of sleep-disordered breathing in three spinal cord injury rehabilitation centres around the world: a mixed-methods study

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STUDY DESIGN: Mixed-methods observational study.
OBJECTIVE: To describe the sleep-disordered breathing (SDB) management models of three spinal cord injury (SCI) rehabilitation centres that are screening, diagnosing and treating uncomplicated SDB, and to determine their common elements.
SETTING: Three specialist SCI rehabilitation centres.
METHODS: Data collection at each site included direct observations and interviews with lead clinical staff and an audit of SDB-related clinical practice in 2019. Detailed descriptions of the models of care, including process maps, were developed. A theory-based analysis of the common elements of the three care models was undertaken.
RESULTS: At each centre a multidisciplinary team, consisting of medical, allied health and/or nursing staff, provided a comprehensive SDB management service that included screening, diagnosis and treatment. Inpatients with SCI were assessed for SDB with overnight oximetry and/or polygraphy. Further assessment of patient symptoms, respiratory function, and hypercapnia supported the diagnostic process. Treatment with positive airway pressure was initiated on the ward. Having a collaborative, skilled team with strong leadership and adequate resources were the key, common enablers to providing the service.
CONCLUSION: It is feasible for multi-disciplinary SCI rehabilitation teams to independently diagnose and treat uncomplicated SDB without referral to specialist sleep services provided they are adequately resourced with equipment and skilled staff. Similar models of care could substantially improve access to SDB treatment for people with SCI. Further research is required to determine the non-inferiority of these alternatives to specialist care.

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INTRODUCTION

Sleep disordered breathing (SDB) is highly prevalent and poorly recognized in people with spinal cord injury (SCI). A recent systematic review and meta-analysis estimated the prevalence of at least mild, moderate and severe SDB in high SCI (tetraplegia) to be 83%, 59% and 36%, respectively [1]. This is up to nine times higher than general population estimates [2]. SDB is associated with substantial neurocognitive impairment and reduced quality of life in people with tetraplegia [3, 4]. Despite this, SDB is under-diagnosed and under-treated, with surveys suggesting that less than 25% of people with SCI are investigated for the disorder [5, 6].

Qualitative research has identified that the usual management pathway for people with SCI and symptoms of SDB involves referral from SCI rehabilitation physician or general practitioner to a specialist sleep/respiratory physician for further investigation and treatment [1]. However this pathway can present significant access barriers to people with SCI. SCI rehabilitation physicians have reported difficulty accessing specialist sleep management models due to their locations and high demand [7]. Furthermore, people living with SCI have indicated that sleep laboratories are poorly designed for people with disability, and overnight sleep studies are disruptive to their daily routines [8].

Poor access to specialist sleep services for management of obstructive sleep apneoa is a recognised problem in the general population [9, 10]. In response, clinical trials have consistently demonstrated that ambulatory models of diagnosis and treatment are not inferior to laboratory-based care [9]. Three randomised controlled trials have investigated whether alternative health professionals, such as general practitioners and nurses, can be trained to provide safe and effective care for uncomplicated obstructive sleep apnea in the general population. All demonstrated non-inferior outcomes in the alternative group when compared to sleep specialist care [11–13]. As yet, there have been no clinical trials investigating alternatives to specialist sleep services for people with SCI; a population with a unique profile of health complications and disability.

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SDB is usually diagnosed using a combination of the clinical presentation and an objective sleep study. Different types of sleep studies range in complexity from an overnight, in-laboratory polysomnography (PSG; Level I), to overnight pulse oximetry (Level IV) [14]. All identify SDB by estimating the number the number of respiratory events per hour of sleep. Further information on the types of sleep studies, their signals and metrics, have been summarised in the Online Supplement. While PSG has been recommended for SDB diagnosis in SCI [15], ambulatory devices are increasingly being used in the clinical setting [7]. Two recent studies have investigated the use of Level III and IV sleep studies to detect SDB in SCI. One modified and validated use of a questionnaire followed by overnight oximetry for detecting moderate to severe SDB in chronic tetraplegia [16]. The other assessed and confirmed the feasibility of polygraphy and transcutaneous CO_2 monitoring ($TcCO_2$) to detect SDB in chronic SCI [17].

Our previous qualitative research identified three SCI rehabilitation centres that routinely screen, diagnose and treat uncomplicated SDB in people with tetraplegia, without consultation from specialist sleep services [7]. Their models of care were developed in response to poor access to specialist sleep services. The three centres were the Swiss Paraplegic Centre (SPZ, Switzerland); Stan Cassidy Centre for Rehabilitation (SCCR, Canada); and Heliomare Rehabilitation Centre (HRC, The Netherlands).

Expanding the scope of SDB management in SCI rehabilitation centres could lower barriers to diagnosis and treatment. The aim of this study was to describe the SDB management models in three SCI rehabilitation centres managing non-complicated SDB without sleep specialist involvement, and to determine their common elements.

METHODS

This study employed an observational, mixed methods design, with theory-informed analysis of qualitative and quantitative data. The lead clinical staff from each SCI centre were co-investigators of this study. Ethics approval was obtained from the local institutional review boards of the three hospitals.

Data collection

Qualitative data. In 2019 the lead author (MG) spent one week at each SCI rehabilitation centre to observe and interview lead clinical staff and to document the SDB management practices. Observations and interviews were informal and conducted on-site. Detailed field notes describing the processes for screening, diagnosing, and treating SDB were taken. Online Supplement Table 2 lists the qualitative information collected.

Quantitative data. Each site retrospectively collected clinical data on any person admitted to the rehabilitation centre for a new SCI who was screened for SDB during 2019. Data included demographic information, screening and diagnosis information (e.g. test dates and results) and treatment information (e.g. treatment prescription and usage). See Online Supplement Table 3. In accordance with the local ethics approvals, two sites provided de-identified, individual patient clinical data for analysis, and one site provided aggregated data.

Data analysis

Data were analysed and reported in three stages. Stage 1 constituted detailed written descriptions of the setting, personnel, equipment, and key processes of each SDB service. Process maps representing the management pathways were also developed. Descriptive analysis of the clinical data enabled service indicators (i.e. proportion of patients screened for SDB) to be estimated.

In Stage 2, similarities in the clinical pathways of each service were identified. The common processes were summarised as a narrative synthesis and a process map.

In stage 3, common enablers of the unique services were identified by thematically analysing qualitative field data. These were mapped to the domains of the Theoretical Domains Framework (TDF). The TDF is a set of 12 validated domains that are commonly used in implementation research to understand the determinants of clinical behaviours [18].

RESULTS

Stage 1: Detailed description of each service

Table 1 summarises the key components and processes at each centre. The written descriptions and process maps for each service are provided in the Online Supplement.

Clinical indicators are summarised in Table 2. Briefly, between 44 and 63% of new SCI admissions were screened with objective tests; mostly within two months of their injury and within a month of their rehabilitation admission. The 4% oxygen desaturation index (ODI) was greater than 15 in approximately 50% of screened patients. Between 17 and 45% of screened patients were commenced on PAP, and of these, 64–100% were discharged using the device.

Stage 2: The common processes and pathways

Staffing. All three SCI centres had a small, highly skilled team dedicated to providing screening, diagnosis and treatment of SDB and other respiratory issues. At each centre the team was led by a rehabilitation doctor and supported by one or more nurses/respiratory therapists, who performed most of the screening, diagnostic testing, and treatment initiation under the supervision of the doctor. Collaboration and communication were important features of each service, with regular ward rounds and/or team meetings.

Screening and diagnosis. Figure 1 describes the common inpatient pathway. Routine testing for all SCI inpatient admissions meeting "at risk" criteria included overnight oximetry and/or polygraphy, and bedside spirometry. Assessment for hypercapnia was conducted at SPZ and HRC with transcutaneous CO_2 or a morning blood capillary CO_2. Oximetry was usually followed by polygraphy for those with a positive result. Whilst the definition of "at risk" patients varied between sites, all included patients with new tetraplegic SCI.

All data were reviewed by the team to decide whether treatment for SDB was indicated. Raw traces from the oximetry, polygraphy and $TcCO_2$ were reviewed alongside the automated analysis. Decisions about treatment were made collaboratively by the doctor and nurse/therapist and based on test results, and the patient's symptoms and views. A diagnosis of SDB was usually made if the overnight oximetry/polygraphy results showed more than 15–20 respiratory events per hour. More than 10 and less than 15–20 events per hour was considered a "grey zone", requiring careful consideration of other factors, such as severity of symptoms and patient characteristics.

Treatment. Initiation and titration of PAP therapy was undertaken on the rehabilitation ward by the team. Bi-level PAP was the "default" therapy at SCCR; CPAP was predominantly used at HRC; and SPZ appeared to use both equally. Bi-level PAP was initiated at SPZ and HRC if there was evidence or risk factors for hypoventilation (e.g. $TcCO_2 > 45$ mmHg, FVC < 70% predicted). At each centre the team would discuss the initial prescription. The nurses/respiratory therapists would fit the mask and trial the PAP device during the day. Patients would commence night-time use with a low pressure, which was gradually increased as the patient became accustomed to the therapy. All three teams closely monitored and reviewed the patient's progress and troubleshooted problems as required. When the patient was comfortable and able to sleep with the device for more than four hours, the sleep study (oximetry OR polygraphy $\pm TcCO_2$) was repeated with PAP treatment to assess treatment effectiveness. If the sleep study demonstrated less than 5–10 respiratory events/hour, the patient continued to use the device on the ward and was reviewed by the team as required. More than 5–10 respiratory events/hour with PAP led to further review, adjustment and assessment of the treatment.

Additional support. Managing SDB in patients with pre-existing lung disease was considered by each of the teams to be outside

Table 1. Summary of SDB models of care.

	SPZ	HRC	SCCR
Hospital and SCI unit	190 bed SCI hospital In 2019 there were 1249 SCI admissions (143 new SCI admissions)	100 bed general rehabilitation hospital with up to 40 specialist SCI beds. In 2019 there were 130 SCI admissions (76 new SCI admissions)	18 bed neuro-rehabilitation hospital with approx. 10 specialist SCI beds. In 2019 there were 32 SCI admissions (18 new SCI admissions)
SDB team	"Respicare team" (all respiratory management) Rehabilitation consultant (0.2 EFT respicare) 3 respiratory nurses (combined EFT = 2.8)	"Respicare team" (all respiratory management) Rehabilitation consultant (~2 hours/week for SCI) 3 respiratory nurses (combined EFT = 1.0; 0.4EFT for SCI)	SCI respiratory service: Rehabilitation consultant (~3 hours/week) 1 respiratory therapist (~0.3EFT for SCI respiratory service) (Vendor respiratory therapist also involved)
Screening- patients	All inpatients with tetraplegia plus paraplegia if signs and symptoms	All new SCI admissions T12 or higher Others (new SCI lower than T12, or readmissions) if signs and symptoms reported by patient/family/ward staff	All new SCI admissions. SCI readmissions if signs and symptoms or never been screened.
Screening- routine tests	Overnight oximetry with $TcCO_2$ monitoring Bedside spirometry or body plethysmography (Ward staff)	Assessment of symptoms Overnight oximetry Bedside spirometry (Respicare nurse)	Assessment of symptoms Bedside spirometry MIP/MEP/SNIP Peak cough flow Overnight oximetry OR polygraphy (Ward RT/ward nurses/vendor RT)
Subsequent diagnostic tests	Assessment of symptoms Overnight polygraphy *(Respicare team)*	Overnight polygraphy Overnight $TcCO_2$ monitoring OR Blood capillary CO_2 (morning) *(Respicare team)*	NA
Diagnostic thresholds	RDI or ODI > 20 = SDB RDI or ODI of 10–20 + symptoms = SDB	RDI or ODI > 15 = SDB RDI or ODI of 10–15 + symptoms = SDB	RDI or ODI > 20 = SDB RDI or ODI of 10–20 + symptoms = SDB
Treatment	Usually commenced on CPAP, then bilevel-PAP if CPAP not tolerated. Bi-PAP if high tetraplegia, low lung volumes and/or $TcCO_2$ > 50 mmHg) (Respicare team)	Usually commenced on CPAP Bilevel-PAP if evidence of hypoventilation ($TcCO_2$ > 45 mmHg) (Respicare team)	Usually commenced on bilevel-PAP (Rehab physician/ward RT in consultation with vendor RT)
Review	Oximetry and $TcCO_2$ with PAP when patient sleeping well with device. If ODI > 5, continue to adjust and reassess. (Respicare team)	Oximetry with PAP when patient sleeping well with device. If ODI > 10, continue to adjust and reassess. (Respicare team)	Oximetry with PAP when patient sleeping well with device. If ODI > 5, continue to adjust and reassess. (Ward RT/vendor RT/rehab physician)
Follow-up	Discharge and outpatient clinics (3, 6, 12 months and annually thereafter) (Respicare team)	Discharge and outpatient clinics (3, 6, 12 months and annually thereafter) (Respicare team)	Discharge and outpatient review (2–3 times in first year and annually thereafter) (Rehabilitation physician)

SPZ Swiss Paraplegic Centre, *HRC* Heliomare Rehabilitation Centre, *SCCR* Stan Cassidy Centre for Rehabilitation, *SCI* Spinal Cord Injury, *EFT* Equivalent Full Time, *TcCO2* Transcutaneous CO_2, *RT* Respiratory therapist, *MIP* Maximum inspiratory pressure, *MEP* Maximum expiratory pressure, *SNIP* Maximal sniff nasal inspiratory pressure, *RDI* Respiratory Disturbance Index, *ODI* Oxygen Desaturation Index, *SDB* Sleep Disordered Breathing, *CPAP* Continuous Positive Airway Pressure, *PAP* Positive Airway Pressure.

their scope of practice and these patients were referred to local respiratory physicians. When hypoventilation requiring bi-level PAP was identified at HRC, support from a local respiratory service was usually sought.

Equipment. At each centre, equipment for diagnosis and treatment was owned by the hospital and/or loaned by local companies. Following discharge, the PAP device was usually purchased or loaned by the insurer.

Stage 3: The common enablers of the SDB care models

Six common enablers of the SDB services were identified and mapped to nine domains of the TDF (Fig. 2):

Multidisciplinary, collaborative teams. Each service had a small, highly collaborative team that met weekly to discuss the patients in the SDB service. The clinical opinions of each team member were valued and considered. *(TDF Domain: Social Influences; Environmental context and resources)*

Strong leadership. Each team was headed by an effective, enthusiastic leader who had initiated and established the SDB service. *(TDF Domain: Social/Professional Role and Identity)*

Adequate resources. The services were well resourced with adequate staff and equipment to support the clinical workload. (*TDF Domain: Environmental context and resources)*

Highly skilled, confident clinicians. The teams were highly skilled, experienced, and confident in managing respiratory issues in SCI. (*TDF Domains: Skills, Knowledge, Beliefs about capabilities)*

Routine processes and clear pathways. Clinical processes and clear referral pathways were embedded into usual clinical care (*TDF Domain: Memory, attention and decision processes)*

Belief in their service. Team members were strongly motivated and inspired by their service. They believed the service resulted in positive outcomes for their patients with SCI. (*TDF Domains*: *Optimism; Beliefs about consequences)*

Table 2. Summary of SDB services provided to new SCI admissions in 2019.

Indicator	SPZ	HRC	SCCR
N new SCI admissions in 2019			
• Total	143	76	18
• Tetraplegia	80	30	9
• Paraplegia	63	46	9
N screened for SDB (% of new admissions)			
• Total (*n*, %)	63 (44%)	48 (63%)	11 (61%)
• Tetraplegia	31 (39%)	30 (100%)	6 (67%)
• Paraplegia	32 (51%)	18 (39%)	5 (56%)
Demographic information (of those screened)			
Age, Mean (SD)	60.3 (14.6)	59.6 (15.0)	54.1 (15.7)
Sex (*n*, % male)	47 (75%)	26 (54%)	9 (82%)
Traumatic injury, *n* (%)	42 (67%)	26 (54%)	9 (82%)
Tetraplegia, *n* (%)	31 (49%)	30 (63%)	6 (55%)
Complete SCI (AIS A), *n* (%)	19 (30%)	5 (10%)	4 (36%)
Days from injury/diagnosis to objective screening, Median (IQR)	45 (30–91)	27 (21–38)	58 (47–71)
Days from hospital admission to objective screening, Median (IQR)	26 (13–73)	1 (0–6)	11 (7–42)
Screening results			
Oximetry			
N with oximetry (% of screened)	59 (94%)	42(88%)	9 (9%)
4% ODI, Mean (SD)	19.1 (22.6)	24.4 (19.8)	23.2 (19.8)
4% ODI > 5, *n* (%)	42 (71%)	40 (95%)	7 (78%)
4% ODI > 15, *n* (%)	26 (44%)	24 (57%)	5 (56%)
Polygraphy			
N with polygraphy (% of screened)	35 (56%)	15 (33%)	0
RDI, Mean (SD)	31.4 (20.9)	32.1 (25.3)	NA
RDI > 10, *n* (%)	28 (80%)	10 (67%)	NA
RDI > 15, *n* (%)	26 (74%)	8 (53%)	NA
Hypercapnia assessement			
N with $TcCO_2$ (% of screened)	55 (87%)	3 (6%)	0
$TcCO_2$ mmHg, Mean (SD)	39.3 (6.2)	44.7 (6.8)	NA
$TcCOo_2$ > 50 mmHg, *n* (%)	3 (6%)	1 (33%)	NA
N with capillary blood gas (% of screened)	--	12 (25%)	NA
$PaCO_2$ mmHg, Mean (SD)	--	38.6 (3.5)	NA
$PaCO_2$ > 45 mmHg, *n* (%)	--	0 (0%)	NA
Spirometry			
N with bedside spirometry, (% of screened)	29 (46%)	40 (83%)	7 (64%)
Spirometry results:			
• FEV_1 L, Mean (SD)	2.0 (0.7)	2.0 (0.7)	2.1 (0.9)
• FVC L, Mean (SD)	2.5 (1.0)	2.6 (1.0)	2.7 (1.1)
• PEF L/min, Mean (SD)	285.9 (130.3)	266.7 (101.4)	207.2 (64.6)
Treatment results			
N commenced PAP, (% of screened)	28 (44%)	8 (17%)	5 (45%)
Type of PAP offered, *n* (%)			
• CPAP	20 (71%)	7 (88%)	1 (20%)
• BiPAP	7 (25%)	1 (13%)	4 (80%)
• Other	1 (4%)		
N adherent with PAP (% of those prescribed treatment)[a]	8 (29%)	8 (100%)	4 (80%)
N discharged with PAP (% of those prescribed treatment)	18 (64%)	6 (75%)	5 (100%)
N discharged with PAP (% of screened)	18 (29%)	6 (13%)	5 (45%)

SPZ Swiss Paraplegic Centre, *HRC* Heliomare Rehabilitation Centre, *SCCR* Stan Cassidy Centre for Rehabilitation, *SCI* Spinal Cord Injury, *SD* Standard deviation, *IQR* Interquartile range, *AIS* American Spinal Cord Association Impairment Scale, $TcCO_2$ Transcutaneous CO_2, *RDI* Respiratory Disturbance Index, *ODI* Oxygen Desaturation Index, $PaCO_2$ Partial Pressure of Oxygen, FEV_1 Forced Expiratory Volume in 1 second, *FVC* Functional Vital Capacity, *PEF* Peak Expiratory Flow, *L* Litres, *CPAP* Continuous Positive Airway Pressure, *PAP* Positive Airway Pressure.

[a]measured at SPZ as device download showing average nightly usage of >4 hours per night; measured subjectively at HRC and SCCR.

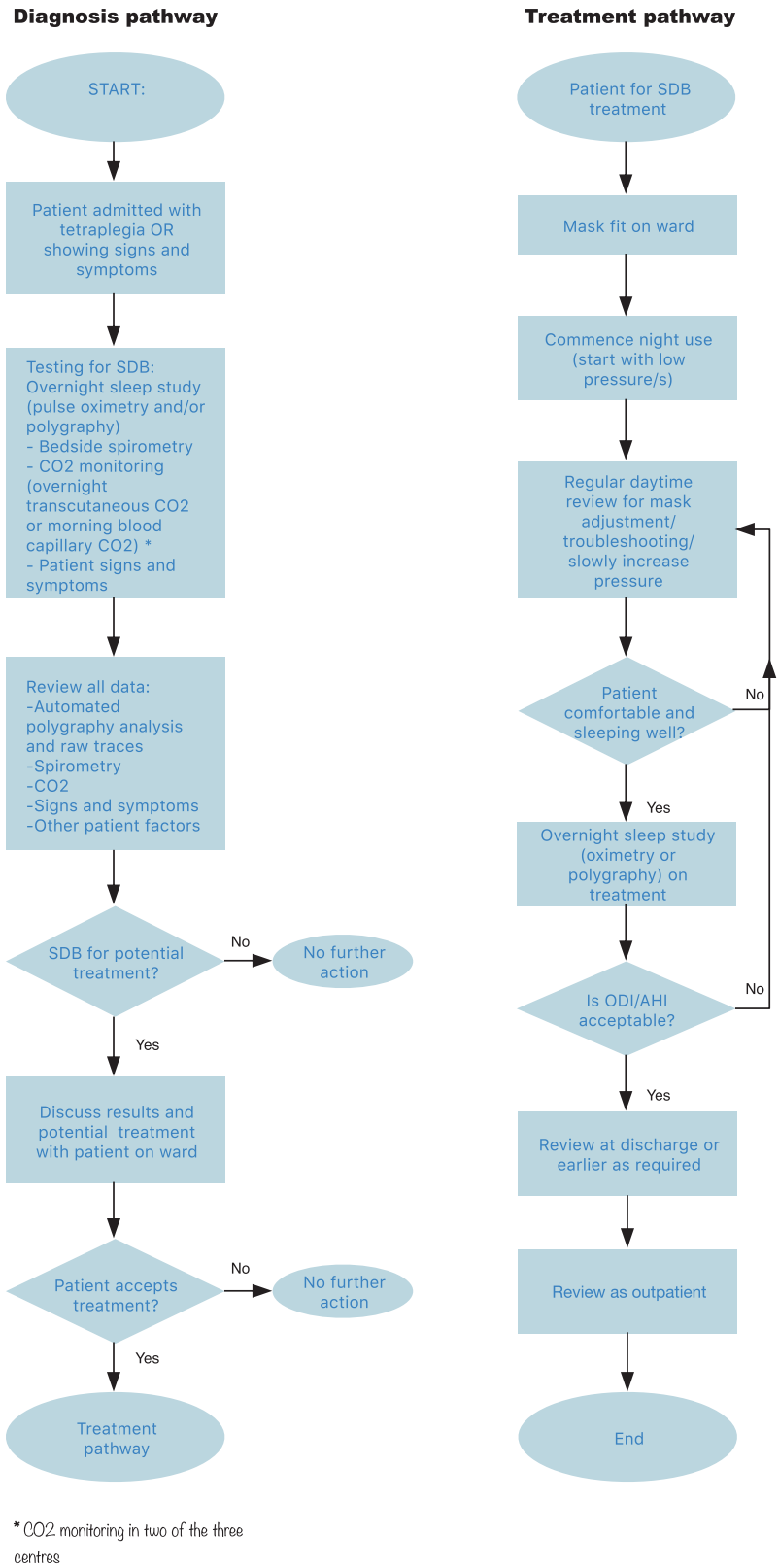

Fig. 1 Common SDB management pathway. Level 1: Common sleep-disordered breathing (SDB) management pathway. Level 2: Diagnosis pathway and treatment pathway. ODI oxygen desaturation index, AHI apnea hypopnea index.

DISCUSSION

The SDB management models at the three SCI rehabilitation centres were remarkably similar. At the core of each service was a well-established multi-disciplinary team of SCI clinicians who were skilled in the management of SDB. Each team was led by a rehabilitation physician with nurses or respiratory therapists who executed most

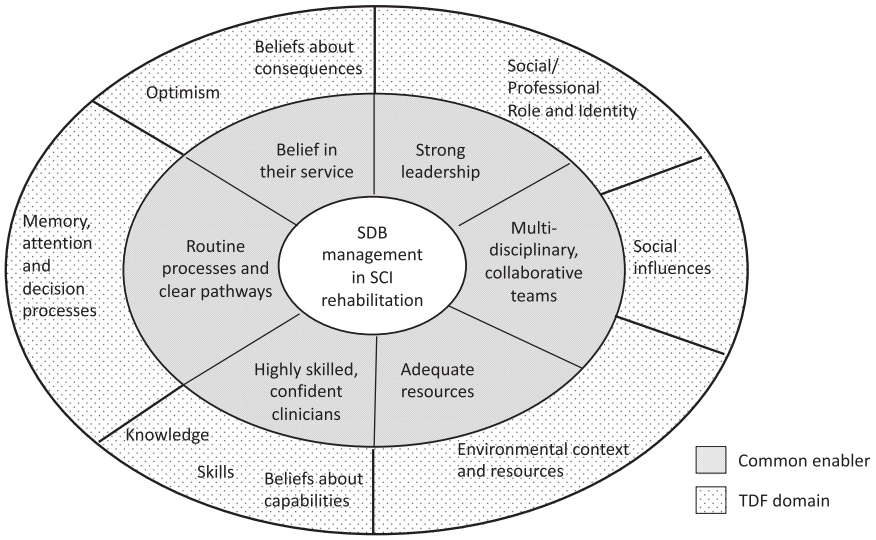

Fig. 2 Enablers to managing SDB within a SCI rehabilitation centre, and the corresponding TDF domains. Level 1: Enablers to managing sleep-disordered breathing (SDB) within a spinal cord injury (SCI) rehabilitation centre. Level 2: Enablers and the corresponding domains of the Theoretical Domains Framework (TDF).

of the procedures. The teams were small, collaborative, and their processes were well-defined and embedded into usual care.

Pulse oximeters (level IV sleep studies) and/or polygraphy devices (level III sleep studies) were used to assess likelihood of SDB by measuring the frequency of respiratory events during sleep. Greater than 15–20 events per hour from either of these devices would usually diagnose SDB in these three centres, while a result of between 10 and 20 required further consideration of symptoms and other patient characteristics. Our group has previously developed and validated a four-item questionnaire followed by overnight oximetry to detect moderate to severe SDB. Greater than 13 events/hour, with a 95% CI of 10–22, was identified in our study as the optimal threshold for diagnosis. We suggested that the confidence interval range of 10–22 events per hour could be considered a "grey zone", whereby clinicians could proceed to treatment or not based on other test results, symptoms and patient characteristics [16]. This is essentially what these three services have been practicing clinically. Over 80% of people with tetraplegia have SDB [1]. As such, we argue that the risk of incorrectly detecting SDB from applying thresholds that have been developed to detect at least moderate disease is low.

Hypoventilation is a rare but clinically important complication of high SCI, which results in retention of CO_2 (hypercapnia) and can result in hypercapnic (Type 2) respiratory failure. While the population prevalence is unknown, hypercapnia in high SCI appears to be low. In our multicentre trial of CPAP for SDB in tetraplegia, only eight of 1,810 patients (0.44%) screened for inclusion were excluded based on daytime hypercapnia. Ideally, hypoventilation is assessed with an arterial blood gas, however this is invasive and typically impractical in a rehabilitation setting [19]. Nocturnal $TcCO_2$ is a commonly used alterative to assessing hypercapnia, and while $TcCO_2$ may effectively detect overnight change in arterial CO_2 (suggesting nocturnal hypoventilation), absolute $TcCO_2$ correlates variably well with arterial $PaCO_2$, thus affecting absolute accuracy [20]. End-tidal CO_2 assessments closely approximate $PaCO_2$ if an end-alveolar plateau is reliably detected [21]. Unfortunately, lower lung volumes, as observed in SCI, can affect end-tidal CO_2 accuracy and no prospective validation of end-tidal CO_2 has been published in SCI. As such, it remains unclear how to best assess hypoventilation in SCI using ambulatory techniques.

Notwithstanding this, the risk of hypoventilation was assessed by each team. Lung volumes were measured with bedside spirometry, and in two of the three services, hypercapnia was assessed with overnight $TcCO_2$ or a morning blood capillary test, alongside oximetry/polygraphy. These two teams examined the raw $TcCO_2$ data, and a CO_2 result that was believed not to represent uncontrolled electrode drift that exceeded 50 mmHg would alert the team to probable hypercapnia. Using these definitions, hypercapnia was identified in six (SPZ) and seven (HRC) percent of tested patients. Hypercapnia was not objectively assessed at SCCR because most patients were commenced on bi-level PAP, the usual treatment for hypoventilation, which was believed to minimize any ongoing hypoventilation risk.

Treatment with PAP was commenced on the ward by the team. In all three centres, the procedures for device set-up, titration, adjustment and review were similar. Patients were commenced with low, fixed pressures which were slowly increased as tolerance and comfort improved. Type of PAP that was usually prescribed did vary between services, with SCCR almost always prescribing bi-level PAP. Bi-level PAP was usually only prescribed in HRC and SPZ when hypoventilation was identified or suspected clinically. These differences appeared to be the result of cultural differences between centres and may also be related to differences in funding models for equipment. Bi-level PAP is often easier to fund in Canada than CPAP, which is not the case in Europe.

This project has described three similar models for managing SDB within a SCI rehabilitation centre. The models described in this study were developed locally, each in response to a local problem and in the context of a unique setting. We do not presume that this "in-house" model is the most effective method for managing SDB in SCI, nor that it is suitable to every SCI rehabilitation centre. Our previous research has identified other models for managing SDB within the SCI rehabilitation setting. We interviewed 20 doctors from 20 rehabilitation centres in seven countries and classified three as predominantly diagnosing and treating SDB in inpatients and outpatients (the subjects of this study). A further six were practicing some elements of SDB diagnosis and treatment independently, with reliance on sleep specialists for various aspects of the care. Eleven of the 20 doctors predominantly referred all suspected SDB to sleep specialist services for diagnosis and treatment; a model that was fitting for some and problematic for others [7].

Successful implementation of evidence-based care models requires local adaptations and targeted behaviour change strategies [22]. We believe that many SCI rehabilitation centres could improve access to effective SDB treatment by adapting their service to include routine screening for SDB, followed by ambulatory testing and treatment with PAP. Careful consideration of the parameters in which the rehabilitation clinicians can safely operate without a respiratory specialist, as has been undertaken by these three services, would be required.

The six common enablers to SDB service provision identified in this study could be considered the "key ingredients" and used to guide any local implementation effort in a naïve centre. Strategies that build a collaborative team with strong leadership, improve clinical skills and confidence, embed practices and pathways, and ensure adequate resourcing will be essential to the success of any new service. Our mapping of these enablers to the domains of the TDF will facilitate future implementation research. Theory-based frameworks such as the Behaviour Change Wheel and Behaviour Change Techniques Taxonomy are designed to guide behaviour change strategies by targeting the known determinants of behaviours; both frameworks have been mapped to the TDF [23].

We have established the feasibility of independently managing non-complicated SDB within the SCI rehabilitation setting. We hypothesise that this model of care is not inferior to that provided by a specialist sleep centre. A multi-centre randomised control trial comparing the two models of care would be required to test this hypothesis. Before this, research assessing the feasibility of implementing the model in a naïve SCI rehabilitation centre should be undertaken.

Study limitations

This study described three innovative models of managing SDB within a SCI rehabilitation environment. We did not assess the safety or effectiveness of the care models. These services were developed over time by passionate and skilled clinicians. Whether similar models of care can be adapted and implemented in other SCI units is yet to be determined. There were differences between sites in how the clinical data were collected and as such, any comparisons between centres should be made cautiously. This study focussed primarily on the inpatient management of SDB, with only a brief description of their outpatient services.

CONCLUSION

People living with SCI are under-diagnosed and under-treated for SDB, a highly prevalent and detrimental complication of SCI. Our findings have demonstrated that is feasible for multi-disciplinary SCI rehabilitation teams to independently diagnose and treat uncomplicated SDB without external referral for specialist sleep services. Adequate resourcing and skilled, motivated teams were key enablers of the "in-house" services. Similar models could be adapted by other SCI rehabilitation centres to improve access to treatment. Whether patient outcomes from this unique model are not inferior to the usual sleep specialist model warrants further investigation.

DATA AVAILABILITY

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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AUTHOR CONTRIBUTIONS

MG was responsible for designing the study, data collection and analysis, interpreting results, and writing the manuscript. DFO, CMO, MEB, GM, BD, BLK, HL were responsible for obtaining ethical approval and data collection at their sites. They all contributed to the interpretation of the results and manuscript preparation. DJB contributed to study design, interpretation of the results and manuscript preparation.

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COMPETING INTERESTS

The authors declare no competing interests.

ETHICS APPROVAL

Ethics approval was obtained from: • Horizon Health Network Research Ethics Board, New Brunswick, Canada (2020–2856). • Ethics Committee for Northwestern and Central Switzerland, Basil, Switzerland (2020–00180). • Medical ethics review committee, Amsterdam UMC, The Netherlands (2020.176). We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers/animals were followed during the course of this research.

ADDITIONAL INFORMATION

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