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Assistive technology to enable sleep function in patients with acquired brain injury: Issues and opportunities

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Abstract

Introduction: Sleep disorders in patients with acquired brain injury are highly burdensome and associated with disability. An assistive technology framework emphasises the need to develop and apply a broad range of devices, strategies, and practices to ameliorate disabilities. We aimed to summarise scientific evidence regarding the utility of assistive technology in managing sleep disorders in patients with various causes of acquired brain injury.

Method: We retrieved articles before January 2016, through database searches of Medline, Embase, PsycINFO, CINAHL, and various bibliographies. The person–environment–occupation framework was used to analyse complex data pertaining to technology application and utility.

Results: We found 21 studies that described seven assistive technologies (continuous positive airway pressure, adaptive servo ventilator, nasotracheal suction mechanical ventilation, positioning devices, cognitive behavioural therapy, light therapy, and acupuncture) utilised in patients with acquired brain injury to manage sleep disorders.

Conclusion: Assistive technologies demonstrated effectiveness in alleviating and/or managing sleep disorders after acquired brain injury. Adherence to using the technology is limited by the level of injury-induced cognitive and physical impairment, technological regime, and environmental support. Development of user-friendly sleep-assistive technologies that take into consideration functional limitations and practice guidelines on structural communication between the occupational therapist, patient, and caregiver may facilitate patients' self-determination in managing sleep disorders.

Keywords

Brain injury, sleep disorder, disability, assistive technology, occupational therapy, plan of care

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Introduction

An acquired brain injury (ABI) is 'an injury to the brain that occurred after birth and is not hereditary, congenital or degenerative' (Brain Injury Association of America, 2009). Stroke, traumatic brain injury (TBI), tumours, and toxic exposures are the most common causes of ABI affecting sleep (Rubiano et al., 2015). This occurs through various pathomechanisms including, but not limited to, trauma to the brain circuits responsible for sleep–wake regulation, respiratory failure in sleep, psychosocial distress, and secondary autonomic dysfunction resulting in an inability to fall asleep and maintain uninterrupted sleep (Mollayeva et al., 2013; Taylor et al., 2016). Moreover, established associations exist between the presence of sleep disorder and increased risk of injury to the brain, emphasising the growing need to address sleep dysfunction among patients with ABI at the early stages post-injury (Diaz and Sempere, 2004; Karimi et al., 2015).

Most recently, the World Health Organization (WHO) published a consensus on the impact of sleep disorders on body functions (such as sleep, energy, and drive), body structures (brain, respiratory organs), activities and participation (focusing attention, driving, handling stress, and other psychological demands, following the daily routine), and environment (immediate family, health services, systems, policies, and health professionals) (Gradinger et al., 2011). The consensus statement also

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highlights the role of enabling factors in modifying impaired structure and function, particularly with assistive technologies being considered as enabling factors within the WHO's International Classification of Functioning, Disability, and Health (ICF) (WHO, 2001). Assistive technologies are not mentioned explicitly in relation to enabling sleep function (WHO, 2001), though the definition of an assistive technology as 'any item, piece of equipment or product system whether acquired commercially, modified or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities' suggests their potential ability to enable sleep function (Assistive Technology Act, 2004: 118 STAT. 1710).

A person's aptitude for using assistive technologies may be compromised by physical, cognitive, and affective states, as well as occupational competence, his or her social environment, and financial situation (Cook et al., 2009). ABI of any cause and severity is frequently associated with impairments in one or more functions, including physical function (such as ambulation, vision, hearing, balance), cognition (such as speech and language processing, memory, attention, concentration, and reasoning), and complex psychosocial functioning (such as anger management, impulsivity, social withdrawal, poverty). Scientific literature on assistive technology in general, and on sleep-assistive technology in particular, that takes into account these various aspects relevant to patients with ABI, is sparse. Understanding all facets of application of sleep-assistive technology in ABI might guide in the selection of most appropriate existing technologies and developing new ones. Similarly, categorising issues and opportunities of sleep-assistive technologies in the context of ABI might help in developing the interventions necessary to deal with sleep disorders so that patients with brain injury can obtain optimal therapeutic gains. Consequently, it is essential that information regarding sleep-related applications of assistive technology in patients with ABI be comprehensively reviewed, to inform more rigorous and ethical clinical decision-making. We undertook a review of the literature on sleep-assistive technologies to accomplish the following purposes: (a) to identify types of assistive technology applied to manage sleep disorders in patients with any cause of ABI; (b) to examine scientific evidence regarding their efficacy; and (c) to categorise benefits and limitations in the application of sleep-assistive technologies for patients with ABI.

In the search for the most optimal structure for our review, we realised that a conceptual framework reflecting different ideas within a concept of utility of sleep-assistive technology in patients with ABI is desirable. Hence, we employed the person–environment–occupation (PEO) model (Law et al., 1996), which centres on the theory of complex dynamic relationships between people, occupations, and environments. The structure of this model provided us with a context for examining the topic and served as a guide in the systematic study of a precisely defined relationship between various aspects relevant to the utility of sleep-assistive technology in patients with ABI. We envisioned that by describing the PEO model here, we could support occupational therapists to apply their unique perspective on dealing with sleep dysfunction in patients with ABI, thereby developing and broadening the therapeutic process with the goal of improving quality of life in their patients.

Method

Data sources

We searched Medline, Embase, CENTRAL, and PsychINFO using the search terms 'exp sleep*' or 'sleep disorders' or 'exp fatigue', along with 'exp brain injuries', 'craniocerebral trauma', 'concuss', 'head injuries, penetrating', 'intracranial haemorrhage, traumatic', 'exp stroke', 'ABI or TBI or mTBI' or 'exp cerebrovascular disorders'. The appropriate truncations were included. The databases were searched up to 18 January 2016, specifically Embase (from 1974); Medline (from 1946); PsycINFO (from 1806); and Central (from 1980). Furthermore, publications identified from bibliographies of identified articles and reviews were considered eligible. We emphasised prospective studies, and nonrandomised and randomised trials that applied assistive technology to manage impaired sleep function and any specific sleep disorder in adult (>18 years old) patients with any cause of ABI (TBI, tumours, blood clots, strokes, toxic exposures, infections, metabolic disorders, neurotoxic poisoning, and asphyxia). For a complete search strategy for each database, kindly refer to (http://journals.sagepub.com/doi/suppl/10.1177/0308022616688017).

Study selection

The search procedure yielded 3794 abstracts (Figure 1). The title and abstract of the papers were scanned by two reviewers (AB and TM) to determine whether they fit the inclusion criteria. Peer-reviewed, English language studies were included if they focused on an assistive technology or product system that was used to manage sleep disorders and associated signs (daytime sleepiness) in patients with ABI. Studies that focused on a different but concurrent topic in sleep disorder (such as depression or chronic fatigue) were excluded. Case reports, paediatric studies, dissertations, and articles with no primary data were excluded.

Data extraction

After screening the titles and abstracts, 50 full-text articles were considered relevant and were downloaded for full review (Figure 1). After reading the full text of the articles selected in the first stage, 29 articles were excluded because they did not meet inclusion criteria. Differences in opinion were resolved by discussion between reviewers, or by seeking advice from the third researcher (AC). The reasons for exclusion are listed in

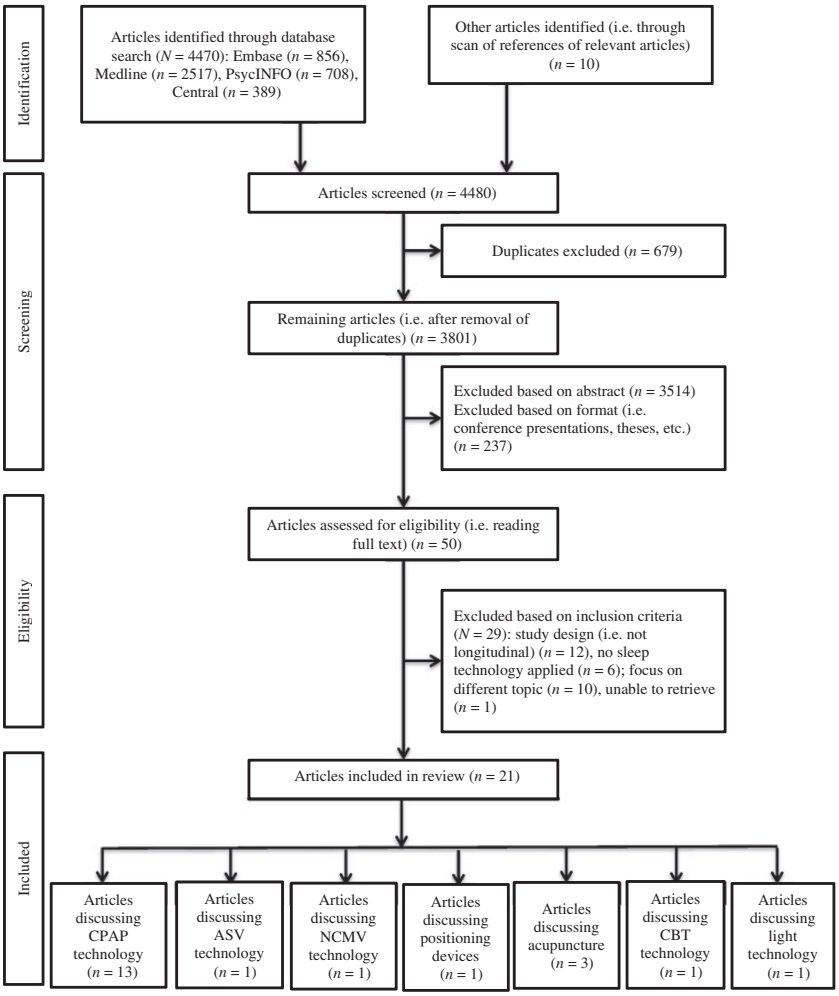

Figure 1. Flow chart documenting the process of article selection for review. Embase (1974–18 January 2016); Medline (1946–18 January 2016); PsycINFO (1806–wk2 2016); CENTRAL (1980–18 April 2016).
CPAP: continuous positive airway pressure; CBT: cognitive behavioural therapy; ASV: adaptive servo ventilator; NVMV: nasotracheal suction mechanical ventilation

(http://journals.sagepub.com/doi/suppl/10.1177/0308022616688017).

The remaining 21 articles were selected for data synthesis (Bassetti et al., 2006; Bravata et al., 2010, 2011; Brill et al., 2014; Broadley et al., 2007; Brown et al., 2013; Castriotta et al., 2009; Gasa et al., 2013; Hsu et al., 2006; Jiang et al., 2015; Kim et al., 2004; Lee et al., 2009; Minnerup et al., 2011; Ouellet and Morin, 2007; Palombini and Guilleminault, 2006; Ryan et al., 2011; Sandberg et al., 2001; Sinclair et al., 2013; Svatikova et al., 2011; Wessendorf et al., 2001; Zollman et al., 2012).

Data synthesis

Selected articles were appraised and categorised on the basis of the category of sleep disorder (American Association of Sleep Medicine, 2005) and the type of assistive technology (Cook et al., 2009). The information abstracted from the articles included study details (author names, publication year, country), study characteristics (setting, design, sample size), participant characteristics (mean age, sex, definition of ABI), intervention type, the category of sleep disorder and variables used to assess it, and characteristics of the assistive technology (usage, efficacy, limitations of the technology, adherence). We followed Elsevier's Evidence for Primary Research Questions (Elsevier, 2016) criteria to assign the level of evidence to each study (http://journals.sagepub.com/doi/suppl/10.1177/0308022616688017).

Results

Table 1 summarises the sleep-assistive technologies by category and type. Table 2 describes the study design, sample size and characteristics, outcome measures, and the key findings of the reviewed studies. Sample size varied from 10 (Sinclair et al., 2013) to 1047 (Gasa et al., 2013) patients with any cause of ABI. Primary outcomes were generally limited to measures of effectiveness in alleviating sleep-related breathing disorder (SRBD) or other sleep-related pathognominics (such as insomnia or daytime sleepiness). Seven assistive technologies used to improve sleep function were identified: (1) continuous positive airway pressure (CPAP); (2) acupuncture; (3) cognitive behavioural

Table 1. Summary of sleep-assistive technology used in stroke and traumatic brain injury.

Assistive sleep technology/ frequency of application	Type of disability	Category	Type	Proposed mechanism to enable sleep function
Acupuncture/1	Cognitive/physical impairment/ brain lesion	Soft[a]	Tool[c]	Stimulates specific points on or under the skin, prompting the neurohumeral system to release hormones and neuropeptides; modulates the limbic–paralimbic–neocortical network
Adaptive servo-ventilation (ASV)/1	Physical disability/brain lesion	Hard[b]	Tool	Provides ventilatory support to treat all forms of central sleep apnoea, mixed apnoea, and periodic breathing in sleep
Blue light/1	Cognitive/physical impairment/ brain lesion	Hard	Appliance[d]	Resets the human circadian rhythm; shifts the phase of internal clock if applied at appropriate time
Cognitive behavioural therapy (CBT)/2	Cognitive/physical impairment/ brain lesion	Soft	Tool	Works to solve problems and change unhelpful thinking and behaviour
Continuous positive airway pressure (CPAP)/10	Physical disability/brain lesion	Hard	Tool	Increases air pressure in patient's throat to maintain airway patency in sleep
Nasotracheal suction mechanical ventilation (NSMV)/1	Physical disability/brain lesion	Hard	Tool	Keeps the airway unobstructed in sleep; prevents secretion retention
Positional therapy/1	Physical disability/brain lesion	Hard	Appliance	Prevents sleep in supine position, reducing severity of apnoea (in supine position, gravity tends to pull the tongue backwards and narrow the airway in sleep)

[a]Soft technology requires the human areas of decision-making, strategies, training, concept formation, and service delivery.
[b]Hard technology refers to readily available components that can be purchased and assembled into an assistive technology system.
[c]Tools require the development of human skill for their use.
[d]'Appliance' refers to devices that provide benefit to the user independent of the user's skill level (Cook et al., 2009).

therapy (CBT); (4) nasotracheal suction mechanical ventilation (NSMV); (5) adaptive servo-ventilation (ASV); (6) light therapy; and (7) positional therapy devices.

Continuous positive airway pressure (CPAP)

Thirteen studies focused on alleviating sleep disorders (SRBD) with the use of a CPAP device. Eleven studies involved patients with stroke (six with ischaemic stroke, one with ischaemic and haemorrhagic, one with acute stroke, and three unclassified) (Bassetti et al., 2006; Bravata et al., 2010, 2011; Broadley et al., 2007; Brown et al., 2013, Hsu et al., 2006; Minnerup et al., 2011; Palombini and Guilleminault, 2006; Ryan et al., 2011; Sandberg et al., 2001; Wessendorf et al., 2001), one involved patients with hypoxic brain damage (Gasa et al., 2013), and one involved patients with TBI (Castriotta et al., 2009). All 11 studies, involving 533 patients with strokes of various severity, differed in the duration of application of CPAP from baseline testing to follow-up assessment, technology manufacturer, the level of sleep studies that reported on CPAP efficacy (level 1: in-laboratory, with a healthcare professional in attendance; level 2: an in-home, unattended sleep study with a portable monitoring device), diagnostic definition of hypopnoea or central apnoea applied in each study, and the rate of adherence/compliance with CPAP application. General improvements of SRBD biological parameters (apnoea-hypopnoea index (AHI), arousals index (AI), Sa_{O2}) have been reported in studies from baseline to follow-up (Bassetti et al., 2006; Bravata et al., 2010, 2011; Brown et al., 2013; Hsu et al., 2006; Minnerup et al., 2011; Palombini and Guilleminault, 2006; Ryan et al., 2011; Wessendorf et al., 2001). Three studies also reported improvement in total sleep time (TST), and some markers of sleep architecture (sleep latency) (Bravata et al., 2010; Castriotta et al., 2009; Ryan et al., 2011). Five studies reported daytime markers of poor sleep (daytime sleepiness) (Brill et al., 2014; Brown et al., 2013; Castriotta et al., 2009; Palombini and Guilleminault, 2006; Ryan et al., 2011). Of other relevant non-sleep-related outcomes, a reduced recurrent vascular event rate and post-stroke symptom severity were observed with CPAP intervention (Bravata et al., 2010, 2011; Brown et al., 2013; Minnerup et al., 2011; Palombini and Guilleminault, 2006; Hsu et al., 2006). Short-term adherence rates varied from 40% and 60% (with some use) reported by Bravata et al. (2011) to 70.5% reported by Wessendorf et al. (2001). Bassetti et al. (2006) reported that CPAP treatment was successfully initiated in 69% of patients with acute stroke, with short-term compliance until patient discharge in 51% of patients, and long-term compliance (up to five years) in 15% of patients. The authors reported that CPAP users did not differ from nonusers with respect to age, sex, body mass index, history of diabetes, or coronary disease (Bassetti et al., 2006). Wessendorf et al. (2001) reported that poor compliance was associated with more severe stroke and aphasia. Palombini and Guilleminault (2006)

Table 2. Characteristics of included studies.

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/exclusion criteria (IC/EC) Sample size (*n*) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results		Benefits of the technology	Limitations Adherence to technology
					Pre-intervention	Post-intervention		
Bassetti et al. (2006) Switzerland, University Hospital	CPAP (AutoSet, treatment mode, software version 3.0)	Study design: prospective study; testing of previously developed diagnostic criteria on consecutive patients. Level: I IC: acute ischaemic stroke, 1 week after stroke onset, AHI 15 or AHI 10 and EDS (SDB) EC: sopor/coma, cardiac, or respiratory insufficiency Enrolled: $n = 152$ Consented: $n = 152$ Assessed at f/u: $n = 132$ ($n = 20$ withdrew) Age: 55.6 ± 13.2 (18–80) Sex: 103/49	In all patients with SDB, CPAP titration was attempted during acute hospitalisation using an auto-CPAP device. After hospital discharge, patients were treated with fixed pressure conventional CPAP. Regular clinical visits occurred usually 1 to 2 times per year	Cardiovascular risk factors; ESS; stroke severity/aetiology; AHI; incidence of vascular events	AHI: 18 ± 16 (≥10 in 58%, ≥30 in 17%)	AHI decreased in subacute phase vs BS ($p < 0.0001$)	Primary: AHI independent risk factor for long-term stroke mortality	Authors suggest aphasia, severity of motor disability can be predictors of poor CPAP compliance
Bravata et al. (2010) USA, Various hospitals in Connecticut	CPAP (AutoSet Spirit; ResMed)	Study design: clinical trial; randomised controlled trial Level: I IC: TIA, ≥45 years of age EC: prior diagnosis of SA, respiratory distress requiring mechanical ventilation, oxygen dependent COPD, pregnancy, life expectancy < 6 months, non-English, outside of Connecticut Enrolled: $n = 70$ Consented: $n = 70$ ($n = 45$ intervention, $n = 25$ control) Assessed at f/u: $n = 36$ intervention ($n = 9$ withdrew); $n = 20$ control ($n = 5$ withdrew) Age: 66.3 ± 11.9 Sex: 23/22 (intervention group)	Patients received auto-CPAP for 2 nights. Only intervention patients with evidence of sleep apnoea received auto-CPAP during 90-day period. Auto-CPAP machine measured and stored information about respiratory events, patient use, mask leak, pressure delivered. Acceptable auto-CPAP adherence was defined as ≥4 hours per night for ≥75% of nights	Polysomnography; AHI; vascular events	AHI: 11.1 ± 11.7 SA prevalence (%): 57 Central event AHI: 0.41 ± 0.59 TST: 5:51 ± 2:33 Mean oxygenation: 94.4 ± 1.6 Oxygen desaturation index: 3.4 ± 4.8 Vascular events: 1(2) (intervention), 3(12) (control)	AHI: 11.0 ± 13.2 SA prevalence (%): 59 Central event AHI: 1.88 ± 7.36 TST: 5:60 ± 1:54 Mean oxygenation: 94.7 ± 1.6 Oxygen desaturation index: 3.5 ± 8.1 Vascular events: 1(8) (no CPAP), 1(6) (some CPAP), 0 (acceptable CPAP)	Primary: Recurrent vascular event rate lowest among patients with acceptable CPAP use (0%, $p = 0.08$). $n = 12$ had acceptable auto-CPAP adherence	$n = 2$ experienced skin irritation from the mask, $n = 2$ experienced sneezing/nasal irritation, $n = 2$ suffered from new stroke $n = 1$ hospitalised for atrial fibrillation, $n = 1$ hospitalised for congestive heart failure, $n = 1$ experienced dehydration $n = 18$ had some CPAP use Authors suggest TIA patients could have higher adherence than stroke patients because TIA patients do not have neurological impairments that could interfere with regular CPAP use

(continued)

Table 2. Continued

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/exclusion criteria (IC/EC)	Sample size (n) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results Pre-intervention	Results Post-intervention	Benefits of the technology	Limitations Adherence to technology
Bravata et al. (2011) USA, Various hospitals in Connecticut	CPAP (AutoSet Spirit; ResMed)	Study design: clinical trial; randomised control trial Level: II IC: acute ischaemic stroke, NIHSS score ≥ 2, age ≥ 50 years EC: prior diagnosis of SA, respiratory distress requiring mechanical ventilation, oxygen dependent COPD, pregnancy, intracranial haemorrhage, thrombolytic therapy, life expectancy < 6 months, non-English, outside of Connecticut	Enrolled: $n = 55$ Consented: $n = 55$ ($n = 31$ intervention, $n = 24$ control) Assessed at f/u: $n = 22$ intervention, $n = 21$ control ($n = 2$ does not want bother of study, $n = 4$ more important things in life, $n = 2$ feeling depressed, $n = 1$ does not believe he had a stroke, $n = 2$ did not return phone calls, $n = 1$ no IRB approval) Age: 70.6 ± 9.4 Sex: 21/10 (intervention group)	Patients received auto-CPAP; auto-CPAP machine measured and stored information about respiratory events, patient use, mask leak, pressure delivered. Machine was interrogated after 2 nights. Acceptable auto-CPAP adherence was defined as ≥ 4 h/night for $\geq 75\%$ nights	polysomnography; AHI; NIHSS	Stroke severity (NIHSS) median change from BS to 30 d: -3.0 (intervention), -1.0 (control) Vascular events: 1 (3.2) (intervention), 3 (12.5) (control)	Stroke severity (NIHSS) median change from BS to 30 d: -0 (no CPAP), -2.5 (some CPAP), -3.0 (acceptable CPAP) Vascular events: 2 (15.4) (no CPAP), 0 (some CPAP), 0 (acceptable CPAP)	Primary: greater improvement was observed among patients with sleep apnoea with increasing auto-CPAP use:-1.0 for control patients not using auto-CPAP; -2.5 for intervention patients with some auto-CPAP use; -3.0 for intervention patients with acceptable auto-CPAP adherence Secondary: intervention patients had greater improvements in NIHSS (-3.0) than control patients (-1.0); $p = 0.03$. Improvement in NIHSS score after treatment greatest for patients with most CPAP use	$n = 1$ reported skin irritation from mask $n = 1$ reported sneezing/nasal irritation because of CPAP machine $n = 2$ refused any CPAP $n = 6$ had some CPAP adherence ($<75\%$ nights for <4 h/night)
Broadley et al. (2007) Australia, Royal Adelaide Hospital	nCPAP	Study design: observational; case-control Level: IV IC: acute stroke, consent EC: patients were excluded if they were not expected to survive the immediate effects of their stroke or if there was another concurrent illness which would preclude them from treatment with nCPAP	Enrolled: $n = 81$ Consented: $n = 66$ ($n = 13$ could not consent due to unconscious state, $n = 2$ could not consent due to dementia) Assessed at f/u: $n = 55$ ($n = 2$ declined to take part, $n = 7$ inappropriate ward setting, $n = 2$ technical difficulties) Age: 40–87 Sex: 32/25	A portable diagnostic system, Embletta® PDS, monitored oxygen saturation (finger pulse oximetry), nasal airflow, chest and abdominal wall movements, patient position. Studies were performed on ward with hourly nurse-monitoring of sleep state	Barthel index; ESS; AHI	2 days post-stroke ($n = 13$): ESS: >9 (18%) AHI: ≥ 10 (58%) AHI: > 15 (42%) OSA: 53% OSA & CSA: 38% CSA only: 5%; index 7	At 6-weeks post-stroke ($n = 11$): AHI: ≥ 10 (100%) CSA index: 4	Primary: No complications from treatment Symptomatic improvement: 46% AHI ≥ 10 persisted in all Frequency of central apnoeas was less at 6 weeks (mean of 4 vs 7 events per hour)	$n = 6$ were not offered nCPAP due to severity of initial stroke or subsequent deterioration $n = 1$ discharged home before the trial $n = 3$ did not agree to start treatment $n = 6$: nCPAP poorly tolerated

(continued)

Table 2. Continued

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/exclusion criteria (IC/EC)	Sample size (n) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results Pre-intervention	Results Post-intervention	Benefits of the technology	Limitations Adherence to technology
Brown et al. (2013) USA, University of Michigan	CPAP	Study design: single-centre pilot, prospective comparative study, randomised, sham controlled trial (values obtained from limited number of patients) Level: II IC: ischaemic stroke ≤ 7 days prior to sleep apnoea assessment, MRS score of > 1 EC: if use of CPAP could cause harm (for example, previous pneumothorax, bullous emphysema, requirement for bilevel positive pressure, acute sinus or ear infection), if short-term use of CPAP may be controversial (such as decompensated heart failure, cardiac or respiratory arrest <3 months, myocardial infarction <3 months, severe pneumonia, hypertension refractory to treatment), previous CPAP or sham CPAP use	Enrolled: $n=87$ Consented: $n=32$ ($n=15$ intervention, $n=17$ control) Assessed at f/u: $n=11$ intervention ($n=1$ did not take CPAP home, $n=2$ withdrew during home treatment, $n=1$ death before f/u); $n=12$ control ($n=2$ withdrawn by team, $n=2$ withdrew due to CPAP intolerance, $n=1$ death before discharge) Age: 61 (46–76) Sex: 5/10 (intervention group)	An auto-titrating device was used to titrate patients. For all patients randomised to active CPAP, the Respironics RemStar Pro (Philips, Andover, MA) with heated humidification was set to deliver a fixed pressure based on the pressure determined by the attended CPAP titration or auto-titration. Treatment persisted for 3 months	Polysomnography; AHI; FSS; ESS; Barthel index; MRS; NIHSS	AHI: 11 (10–35) (active CPAP), 26 (9–31) (sham)	FSS, median (IQR) at f/u 3 months: 2.6 (2.0–4.1) (active CPAP), 2.4 (1.4–3.0) (sham) ESS, median (IQR) at f/u 3 months: 8 (6–9) (active CPAP), 7 (4–10) (sham) PHQ-9, median (IQR) at f/u 3 months: 5 (4–6) (active CPAP), 2 (2–3) (sham) MRS, median (IQR) at f/u 3 months: 2 (1–3) (active CPAP), 2 (1–2) (sham) NIHSS, median (IQR) at f/u 3 months: 1 (0–4) (active CPAP), 2 (0–3) (sham)	Not reported	Difficulties were reported with one-handed removal and application of the headgear and mask, an increase in depression was noted $n=2$ were CPAP intolerant $n=3$ (20%) did not tolerate titration $n=1$ declined to take CPAP unit home Self-report survey revealed: $n=2$ machine/mask caused nosebleeds $n=2$ mask/headgear are difficult to put on $n=3$ mask is uncomfortable/painful $n=1$ equipment is too complicated $n=1$ air feels uncomfortable $n=3$ machine and mask cause nasal congestion or stuffiness $n=1$ machine causes dry eyes, nose, mouth, throat $n=3$ cannot fall asleep with mask on $n=2$ cannot stay asleep with mask on $n=2$ using CPAP is too much of a hassle

(continued)

Table 2. Continued

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/exclusion criteria (IC/EC)	Sample size (n) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results Pre-intervention	Results Post-intervention	Benefits of the technology	Limitations Adherence to technology
									$n = 1$ feel claustrophobic Low CPAP adherence is related to low number of nights that treatment was attempted rather than to the number of hours that CPAP was used per night, implying a lack of motivation. Low CPAP usage could be attributed to more inclusive enrolment criteria, including more severely affected, older stroke patients and those with less severe OSA
Castriotta et al. (2009) USA, Memorial Hermann Hospital–Texas Medical Center, Transitional Learning Center, and Philadelphia Veterans Medical Center	CPAP	Study design: observational; study of non-consecutive patients Level: IV IC: age $> 18, \geq 3$ months post-TBI, OSA EC: circadian rhythm disorder, inability to give informed consent, use of sedating medications	Enrolled: $n = 13$ Consented: $n = 13$ Assessed at f/u: $n = 13$ Age: 38.56 ± 14.75 Sex: not reported	Patients were treated with nasal CPAP, returned subsequent diagnosis for repeat NPSG with appropriate titration of CPAP to eliminate apnoeas, hypoapnoeas, and snoring	MSLT; ESS; AHI; amount of REM sleep; NPSG	TST: 5.9 ± 1.5 SL: 50.9 ± 127 AHI: 31.4 ± 21.5 PLMI: 9.9 ± 17.1 MSLT: 10.3 ± 6.2 SOREM: 1.42 ± 3.1 ESS: 12.2 ± 6.2	TST: 6.1 ± 1.1 SL: 25.7 ± 37.1 AHI: 3.8 ± 3.7 PLMI: 19.8 ± 28.8 MSLT: 12.1 ± 5.1 SOREM: 0.8 ± 2.6 ESS: 13.0 ± 6.4	Primary: AHI improved dramatically; amount of REM sleep increased Secondary: significant decrease in PLMI	No demonstrable improvement in excessive daytime sleepiness as defined by MSLT or ESS after treatment with CPAP. Some OSA patients have residual hypersomnia despite adequate treatment with CPAP
Gasa et al. (2013) France, Various hospitals in France	CPAP	Study design: retrospective cohort study Level: II IC: RES, ESS ≥ 11, OSA, hypoxic brain damage, eligible patients from French National Sleep Registry attending f/u CPAP visits	Enrolled: $n = 1047$ (the patient population was selected from a database which updated on f/u visits) Consented: $n = 1047$ Assessed at f/u: $n = 1047$ Age: 57.38 ± 12.45 Sex: 733/314	Effective CPAP pressure was determined for each patient by manual titration under PSG or by auto-CPAP titration procedures at home. CPAP nightly usage, residual AHI were obtained from CPAP device log.	ESS; AHI; oxygen desaturation index	Patients with ESS ≤ 10 AHI: 42.70 ± 18.73 Oxygen desaturation index (nb h^{-1}): 33.33 ± 22.08 Patients with ESS > 10 AHI: 42.62 ± 20.25 Oxygen desaturation index (nb h^{-1}): 35.57 ± 23.54	Patients with RES ($n = 135$) ESS: 14.17 ± 4.65 AHI: 40.60 ± 20.61 Oxygen desaturation index (nb h^{-1}): 31.71 ± 23.22 Patients without RES ($n = 912$) ESS: 10.91 ± 5.06 AHI: 42.95 ± 19.45	Primary: prevalence of RES decreased when CPAP use increased. Prevalence of RES was significantly lower in patients who used CPAP more than 6 h $night^{-1}$ compared with those who used device < 4 h $night^{-1}$ and	Patients with RES complained significantly more about mouth dryness, asphyxia, psychological discomfort, while device was less tolerated by the patients' family. Side effects were experienced by 11.7% of sample. They include:

(continued)

Table 2. Continued.

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/ exclusion criteria (IC/EC)	Sample size (n) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results		Benefits of the technology	Limitations Adherence to technology
						Pre-intervention	Post-intervention		
		EC: patients using CPAP <3 h, residual AHI $>15\,h^{-1}$, depression scale >7		Residual excessive sleepiness was defined by ESS score at f/u CPAP visit equal to/above 10	ESS; AHI; oxygen desaturation index		Oxygen desaturation index (nb h^{-1}): 34.99 ± 22.87 F/u: Patients with RES ($n=110$) ESS: 15.79 ± 3.16 AHI: 40.93 ± 21.40 Oxygen desaturation index (nb h^{-1}): 32.10 ± 23.54 Patients without RES ($n=492$) ESS: 14.77 ± 2.82 AHI: 14.77 ± 2.82 Oxygen desaturation index (nb h^{-1}): 36.29 ± 23.51	4–5 h $night^{-1}$ (8.7% versus 18.5%, $p<0.01$ and versus 22.3%, $p<0.0001$, respectively). Improvement in ESS from initial visit to CPAP f/u visit increased with CPAP daily use Secondary: mean values of depression, fatigue, global health perception scales significantly improved on CPAP for both groups	Eye irritation (6.2%), Dry mouth (21.7%), Choking sensation (10.3%), Psychological discomfort (10.8%), Headache (2.8%), poor CPAP acceptance by family (5.8%)
Hsu et al. (2006) UK, University hospitals in Edinburgh	CPAP (AutoSet T; ResMed)	Study design: observational; study of non-consecutive patients Level: III IC: 21–90 years of age, stroke 14–19 days previously, pre-stroke MRS score ≤ 2, NIHSS ≥ 4 EC: severe, unstable medical conditions (such as dementia), severe dysphasia/confusion, unusual stroke (venous infarction, vasculitis, brain tumour, myocardial infarction), insufficient hand function	Enrolled: $n=96$ Consented: $n=71$ Assessed at 3 months f/u: $n=15$ intervention, $n=15$ control ($n=5$ did not have recording >5 h, $n=33$ did not have AHI ≥ 30, $n=3$ withdrew before treatment); Assessed at 6 months f/u: $n=14$ intervention, $n=15$ control ($n=1$ died of adult respiratory distress syndrome) Age: 74 (73–81) Sex: 11/4 (intervention group)	Patients received 8 weeks of CPAP treatment for 6 hours per night. Occasional intensive input by sleep research nurse to optimise compliance	SSS; Barthel Index; NIHSS; ACE; HADS; EADL Index; MMSE	ESS: 6 (4–14) SSS: 2 (2–3) NIHSS: 5 (4–9)	EADL at F/u 3 months: 18 (11–27) (CPAP), 30 (16–41) (control) F/u 6 months: 23 (12–33) (CPAP), 28 (18–39) (control) SSS at f/u 3 months: 3 (1–4) (CPAP), 2 (1–3) (control) NIHSS at f/u 3 months: 2 (1–4) (CPAP), 3 (1–6) (control) MMSE at f/u 3 months: 29 (25–29) (CPAP), 29 (25–30) (control)	Secondary: better cognition, less depression were associated with using CPAP machine longer; CPAP use was positively correlated with better Barthel index score	$n=2$ rejected CPAP after mask-fitting $n=1$ rejected CPAP after first night of use $n=1$ rejected CPAP after 1 week of use $n=8$ had problems with mask/machine $n=2$ experienced claustrophobia $n=8$ developed upper airway symptoms after treatment, 3 withdrew due to these symptoms $n=9$ had stroke-related problems that caused noncompliance, including facial palsy, nocturnal confusion, and involuntary movement

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Table 2. Continued

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/ exclusion criteria (IC/EC)	Sample size (n) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results		Benefits of the technology	Limitations Adherence to technology
						Pre-intervention	Post-intervention		
									$n=2$ did not believe that they needed treatment on nightly basis No significant differences in outcome with respect to primary or secondary measures at the 3-month f/u CPAP treatment resulted in no significant improvements ($p>0.1$) in EADL index or in neurological function or sleepiness, and in poorer health status on some measures
Minnerup et al. (2011)Germany, University Hospital of Münster	CPAP (Horizon; Devilbis)	Study design: clinical trial; randomised, open-label, parallel group trial Level: II IC: informed consent, acute ischaemic stroke, 18 to 85 years of age, treatment initiation in first night after symptom onset, NIHSS score from 2 to 20 EC: LOC > 1 for 1 a of NIHSS, pre-stroke mRS > 1, intubation, respiratory insufficiency, congestive heart failure, recurrent vomiting, absence of gag reflex, participation in another RCT	Enrolled: $n=50$ Consented: $n=50$ ($n=25$ intervention, $n=25$ control) Assessed at f/u: $n=50$ Age: 68.6 ± 10.0 Sex: 9/16 (intervention group)	Patients received non-invasive auto-adjust CPAP therapy (pressure support 6–16 cm H_2O, full face mask; Horizon, Devilbis) for 3 nights starting the first night after stroke onset. Excellent CPAP use was defined as mean use > 4 hours per night in first 3 nights	polysomnography; AHI; diffusion-weighted MRI; NIHSS	NIHSS on admission, median (IQR): 7(8)	Efficacy end points: Infarct growth between first day and f/u imaging, mean (SD), mL: 9.4 ± 17.2 (all CPAP users), 5.3 ± 9.8 (excellent CPAP users) NIHSS improvement from treatment initiation/first night to Day 8, mean (SD): 2.00 ± 0.82 (all CPAP users), 2.30 ± 0.68 (excellent CPAP users)	Primary: under CPAP therapy (1–3 nights), AHI was significantly reduced when compared with AHI polysomnography at Night 4 (32.2 ± 25.3–9.8 ± 6.6, $p=0.0001$). $n=10$ reported excellent adherence of the technology Secondary: NIHSS improvement was significantly greater in patients with excellent CPAP use compared with control group (2.30 versus 1.40, $p=0.022$ L)	$n=1$ reported no use of technology $n=14$ reported some use of technology There was a trend toward reduced CPAP use in patients with neglect and higher age

(continued)

Table 2. Continued

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/ exclusion criteria (IC/EC)	Sample size (n) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results		Benefits of the technology	Limitations Adherence to technology
						Pre-intervention	Post-intervention		
Palombini and Guilleminault (2006) USA, Stanford University Sleep Disorders Clinic	CPAP (AutoSet T; ResMed)	Study design: observational; prospective study of non-consecutive patients Level: III IC: stroke, OSA, consent EC: unstable clinical conditions (for example aspiration), Cheyne–Stokes respiration, repetitive sleep apnoea, AHI <10	Enrolled: $n=50$ Consented: $n=39$ ($n=11$ withdrew consent after seeing equipment) Assessed at f/u: $n=7$ ($n=18$ did not respond to clinical entry criteria, $n=5$ discontinued CPAP after 1 week, $n=7$ did not fit polysomnography criteria, $n=2$ refused to use CPAP at home) Age: 62 ± 12.8 Sex: not reported	Patients were treated with nasal auto-CPAP, after calibration. CPAP pressure was 8 ± 4 cmH_2O. Trial lasted for 8 weeks	ESS; AHI; NIHSS; Barthel index	ESS: 7.1 ± 1.0 NIHSS: 4.3 ± 5.5 Barthel index: 13.1 ± 5.6	ESS: 4.3 ± 5.6 NIHSS: 5.6 ± 1.5 Barthel index: 17.6 ± 1.7	Primary: $n=5$ reported clinical improvement related to CPAP, $n=3$ observed decrease in nocturia, $n=1$ reported decrease in daytime sleepiness	$n=5$ rejected CPAP during first week due to discomfort, mask leaks, difficulty taking equipment off because of nocturia, sleep disturbances of family members, increased confusion during hours without daylight. Reasons for poor adherence of CPAP: absence of health professionals during night to help patients/caregivers to help with CPAP usage, presence of cognitive problems (40% of patients in 10 days f/u of an acute stroke and 20% in the 3 months following it); worsening of cognitive dysfunction, disorientation, sundown syndrome, appearance of abnormal behaviour during night; inability to apply headgear, mask, hose, or to readjust equipment after displacement because of motor impairment; overall increase in nocturnal discomfort

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Table 2. Continued

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/ exclusion criteria (IC/EC)	Sample size (n) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results: Pre-intervention	Results: Post-intervention	Benefits of the technology	Limitations Adherence to technology
Ryan et al. (2011) Canada, Toronto Rehabilitation Institute	CPAP (Goodknight 420 G; Tyco Healthcare)	Study design: randomised, open-label, parallel group trial with blind assessment of outcomes Level: I IC: 3 weeks of stroke onset, 18–89 years of age, ischaemic or haemorrhagic stroke, able to follow commands in English, informed consent, OSA EC: brain stem strokes that could increase aspiration risk with CPAP, previously diagnosed OSA, concomitant CNS diseases, history of psychosis, TBI, anosagnosia, global, or Wernicke aphasia	Enrolled: $n = 48$ Consented: $n = 44$ ($n = 22$ intervention, $n = 22$ control) Assessed at f/u: $n = 44$ ($n = 4$ withdrew) Age: 62.8 ± 12.8 Sex: 16/6 (intervention group)	Patients were provided with CPAP machine and instructed to use it for at least 6 hours per night for 4 weeks. CPAP was titrated during PSG to reduce apnoea-hypoapnoea index to < 5 or to highest pressure tolerated	ESS; SSS; functional independence measure; Canadian neurological scale; 6 minute walk test distance; sustained attention response test	ESS: 4.4 ± 1.8 SSS: 2.2 ± 1.1 AHI: 38.5 ± 18.1 TST: 5.66 ± 1.15 ArI (n/hr): 28.6 ± 22.0 Mean sleep SaO_2 (%): 94.4 ± 1.6	ESS: 1.8 ± 1.0 SSS: 1.3 ± 0.6 AHI: 7.6 ± 8.5 TST: 5.83 ± 1.01 ArI (n/hr): 18.8 ± 13.4 Mean sleep SaO_2 (%): 96.0 ± 1.6	Primary: improvements in ESS ($p < 0.001$), motor component of functional independence measure ($p = 0.05$), Chedoke-McMaster stroke assessment of upper and lower limb motor recovery test of leg ($p = 0.001$). Compared to control group, CPAP group experienced significant reduction in AHI as well as increase in minimum sleep oxyhaemoglobin saturation. $n = 22$ experienced excellent CPAP compliance Secondary: significant improvements in total Canadian neurological scale score, significant increase in 6 minute walk distance	Not reported
Sandberg et al. (2001) Sweden, Umeå University	nCPAP (REMstar Choice, Respironics Inc.)	Study design: study of non-consecutive patients Level: III IC: patients from the geriatric stroke rehabilitation unit 2–4 weeks after stroke, AHI ≥ 15 EC: N/A	Enrolled: $n = 63$ Consented: $n = 59$ ($n = 31$ intervention, $n = 28$ control) Assessed at f/u: $n = 59$ Age: 78.1 ± 6.4 Sex: not reported	Mean nCPAP pressure was 5.8 ± 1.4 cmH_2O (range 5.5–8.0). Patients were fitted with appropriate mask and supplied with comfortable air pressure during daytime. Pressure was adjusted until normal nocturnal finger-oximetry was obtained. Treatment was adequate if patient tolerated nCPAP for more than a mean of 4 h per night, during 28 nights	Delirium; MADRS; Barthel-ADL Index; MMSE	Delirium %, mean: 71.0 MADRS: 21.0 ± 10.4 Barthel-ADL Index: 8.4 ± 6.2 MMSE: 16.6 ± 7.4	Delirium %, mean: (F/u 7 nights): 53.8 (F/u 28 nights): 55.6 MADRS (F/u 7 nights): 16.0 (F/u 28 nights): 15.6 Barthel-ADL index (F/u 7 nights): 9.9 (F/u 28 nights): 9.5 MMSE (F/u 7 nights): 18.0 (F/u 28 nights): 19.2	Secondary: depressive symptoms (MADRS total score) in treatment group improved significantly compared to control group ($p = 0.004$); MADRS total score decreased by mean of 5.4 points (25.7%) in treated patients ($n = 31$), between baseline and f/u after 28 nights	No sign of treatment effect was found with regards to delirium, MMSE, or Bartel ADL index $n = 15$ had low adherence to nCPAP (used it for less than mean of 4 h per night) Adherence to nCPAP proves to be problem in stroke patients accompanied by delirium and severe cognitive impairment

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Table 2. Continued

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/ exclusion criteria (IC/EC)	Sample size (n) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results		Benefits of the technology	Limitations Adherence to technology
						Pre-intervention	Post-intervention		
Wessendorf et al. (2001) Germany (Setting not reported)	CPAP (Elite; ResMed, San Diego, CA, USA)	Study design: observational, prospective cohort Level: II IC: stroke, obstructive SDB and an RDI ≥ 15, patients needed to be able to remove mask EC: not reported	Enrolled: $n = 105$ Consented: $n = 105$ Assessed at f/u: $n = 74$ ($n = 31$ rejected CPAP) Age: 60.9 (59.2–62.8) Sex: 80/25	Patients were treated a with conventional fixed pressure CPAP device. Recommended pressure was automatically calculated by device. Heated humidification (HC 100, Fisher and Paykel, Auckland, New Zealand) was only added in patients who complained of nasal stuffiness	Polysomnography; BMI; ESS; RDI; Barthel index	RDI•h^{-1}: 38 ± 20.9 Min SaO_2 %: 76.0 ± 9.8 SWS, %: 8.3 ± 7.2 Arousal index•h^{-1}: 39.4 ± 15.5 Central SA index•h^{-1}: 2.9 ± 4.9	RDI•h^{-1}: 7 ± 7.1 Min SaO_2 %: 89.0 ± 4.6 SWS, %: 12.5 ± 10.9 Arousal index•h^{-1}: 22.9 ± 10.2 Central SA index•h^{-1}: 0.8 ± 1.4	Primary: 80% reduction of respiratory events (RDI 38 ± 20.9 untreated versus 7 ± 7.1 h^{-1} treated, $p < 0.001$), concomitant increase in oxygen saturation, decrease in observed concomitant central apnoeas; significant increase in slow wave sleep (8.3 ± 7.2 versus 12.5 ± 10.9% of sleep period time, $p < 0.001$)	$n = 31$ (29.5%) rejected CPAP during titration night or after few treatments. Reasons included mask discomfort, subjective sleep disturbances. $n = 4$ could not tolerate high titration pressures (≥ 16 cmH_2O), switched to manual mode CPAP acceptance in patients with simple moderate-to-severe OSA ranged between 70% and 80%. Compliers and noncompliers did not differ in baselines characteristics. In simple OSA, long-term compliance is related to initial severity of daytime symptoms related to alertness, performance, and degree of daytime sleepiness
Jiang et al. (2015) China (Setting not reported)	Nasotracheal Suction Mechanical Ventilation	Study design: observational; case series Level: IV IC: cerebral ischaemic stroke, diagnosed with sleep apnoea between 2013 and 2014, OSAHS EC: serious cerebral vascular malformation, mental disorder, disorder of consciousness, severe pulmonary infection, previous nose disease, chronic lung disease, neuromuscular disease	Enrolled: $n = 53$ Consented: $n = 53$ ($n = 29$ intervention, $n = 24$ control) Assessed at f/u: $n = 53$ Age: 63.1 ± 7.2 Sex: 18/11 (intervention group)	Patients received uplink nasoendotracheal suction operation for 4 hours every night. This was done for 7 consecutive days	AHI; oxygen denaturation index; $LSaO_2$; $MSaO_2$; NIHSS; Barthel index	NIHSS Mild OSAHS: 11.40 ± 3.01 Moderate OSAHS: 14.99 ± 1.37 Severe OSAHS: 18.58 ± 3.82 Barthel index Mild OSAHS: 50.43 ± 6.48 Moderate OSAHS: 47.34 ± 4.62 Severe OSAHS: 41.13 ± 5.65 AHI: 6.32 ± 00.57 $LSaO_2$ (%): 72.63 ± 5.21 $MSaO_2$ (%): 82.14 ± 5.02	NIHSS Mild OSAHS: 8.54 ± 1.41 Moderate OSAHS: 9.32 ± 1.69 Severe OSAHS: 11.45 ± 2.31 Barthel index Mild OSAHS: 60.53 ± 9.36 Moderate OSAHS: 55.12 ± 7.18 Severe OSAHS: 54.20 ± 3.49 AHI: 2.93 ± 10.22 $LSaO_2$ (%): 92.12 ± 4.18 $MSaO_2$ (%): 94.84 ± 1.79	Primary: after treatment, AHI score decreased. $n = 21$ claimed intervention was effective Secondary: all patients showed lower NIHSS and increased Barthel scores	$n = 8$ claimed intervention was ineffective

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Table 2. Continued

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/ exclusion criteria (IC/EC)	Sample size (n) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results: Pre-intervention	Results: Post-intervention	Benefits of the technology	Limitations Adherence to technology
Brill, et al. (2014) Switzerland (Setting not reported)	ASV (Autoset CS or CS2; ResMed, Bella Vista, NSW, Australia)	Study design: retrospective, observational single-centre analysis Level: III IC: ischaemic stroke > 1 mo before SDB, non-hypocapnic CSA/CSR with > 50% central apnoeas/hypopnoeas, AI > 5/h, treatment with ASV for ≥ 3 months EC: CHF (heart failure, normal LVEF, normal BNP), acute stroke < 1 mo before SDB	Enrolled: $n = 154$ Consented: $n = 154$ Assessed at f/u: $n = 15$ (only patients diagnosed with hypocapnic CSA, treated with ASV, were included in analysis) Age: 62 ± 9.4 Sex: 13/2	Patients were started on ASV following initial ventilator settings: EEP was set at minimal level of 5 cmH_2O, variable pressure support was set to range of 3–9 cmH_2O. Automatic back-up rate of ventilator was used, which targets 15 breaths/min	ESS; EDS; SDB; polysomnography	AHI (events/h recording) Time of diagnosis: 54.4 (25; 63.7) AI (events/h recording) Time of diagnosis: 29.6 (12; 45.5) ESS Time of diagnosis: 8.6 ± 6.4	AHI (events/h recording) F/u 3 months: 4.7 (0.5; 9.2) F/u 6 months: 6.6 (1.5; 11.9) AI (events/h recording) F/u 3 months: 0.2 (0; 0.6) F/u 6 months: 0.2 (0; 1.8) ESS F/u 3 months: 5.9 ± 2.5 F/u 6 months: 6.1 ± 2.7	Primary: ASV significantly suppressed SDB with reduction of mean AHI (46.7 ± 24.3 vs 8.5 ± 12/h, $p = 0.001$) and reduced ESS (8.7 ± 5.7 vs 5.6 ± 2.5, $p = 0.08$) with mean nightly use of ASV of 5.4 ± 2.4 h at 3 months after initiation of treatment. Results were maintained at 6 months	$n = 1$ experienced persistent mask leakage $n = 2$ stopped ASV due to intolerance of interface
Kim et al. (2004) Korea, Hospital of Oriental Medicine, Kyung Hee Medical Center	Acupuncture	Study design: randomised control study (limited description of study methodology) Level: II IC: persistent insomnia > 3 days, ISI > 15, stroke EC: treatment with sedative, antidepressant, tranquiliser, narcotic analgesics, antihistamine, or amphetamine-containing drugs, disorientation, dysphasia, nocturnal voiding frequency	Enrolled: $n = 32$ Consented: $n = 32$ Assessed at f/u: $n = 15$ intervention, $n = 15$ control ($n = 1$ could not stand pain, $n = 1$ admission of drugs during study) Age: 65.1 ± 9.0 Sex: 8/7 (intervention group)	Patients received intradermal acupuncture treatment with Dong Bang sterile disposable intradermal acupuncture needles. Four needles were inserted into 2 accupoints (Shen-Men and Nei-Kuan) on both arms, then fixed with tape to last for 2 days	MQ; ISI; AIS	Sleep latency at BS: 189.3 ± 138.7 Total sleep time at BS: 116.0 ± 65.0 Sleep quality at BS: 17.3 ± 14.8 Condition upon awakening at BS: 22.0 ± 12.1 Ability to concentrate at BS: 23.3 ± 18.3 Ease of falling asleep at BS: 34.7 ± 28.7 Morning sleepiness at BS: 31.3 ± 20.3 ISI at BS: 21.9 ± 2.0 Athens insomnia at BS: 17.1 ± 1.6	Sleep latency at T1: 126.0 ± 125.2 T2: 126.7 ± 128.7 Total sleep time at T1: 222.0 ± 112.7 T2: 210.0 ± 105.0 Sleep quality at T1: 46.7 ± 28.9 T2: 57.3 ± 24.6 Condition upon awakening at T1: 57.3 ± 24.9 T2: 56.7 ± 26.6 Ability to concentrate at T1: 57.3 ± 32.4 T2: 53.3 ± 30.7 Ease of falling asleep at T1: 68.0 ± 27.8 T2: 62.0 ± 27.7	Primary: significant improvement on insomnia-related scales	$n = 1$ could not stand pain induced by needle insertion

(continued)

Table 2. Continued

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/ exclusion criteria (IC/EC)	Sample size (*n*) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results		Benefits of the technology	Limitations Adherence to technology
						Pre-intervention	Post-intervention		
							Morning sleepiness at T1: 60.0 ± 22.0 T2: 59.3 ± 24.3 ISI at T1: 14.2 ± 5.8 T2: 14.9 ± 5.5 Athens insomnia at T1: 9.4 ± 5.7 T2: 10.6 ± 5.1		
Lee et al. (2009) Korea, Hospital of Oriental Medicine, Kyung Hee Medical Center	Acupuncture	Study design: double-blind randomised control study (limited description of study methodology) Level: II IC: persistent insomnia > 3 days, ISI > 15, stroke EC: treatment with sedative, antidepressant, tranquiliser, narcotic analgesics, antihistamine, or amphetamine-containing drugs, disorientation, dysphasia, nocturnal voiding frequency	Enrolled: $n = 60$ Consented: $n = 60$ Assessed at f/u: $n = 27$ intervention, $n = 25$ control ($n = 8$ withdrew) Age Treatment group: 66.7 ± 11.0 Control group: 66.0 ± 9.6 Sex: 24/28	Patients were randomly assigned to either real intradermal acupuncture group (RA group) or sham acupuncture group (SA group). RA group received intradermal acupuncture treatment with Dong Bang sterile disposable intradermal acupuncture needles (0.18 × 6 mm) at 2 points: Shen-Men (He-7), Nei-Kuan (EH-6). One acupuncture needle was inserted into each point bilaterally, a piece of tape (1 × 1 cm) was placed on each needle to fix it firmly in place for three days. In the SA group, needles were placed on same points, but did not penetrate skin	ISI; AIS; systolic blood pressure (mmHg); diastolic blood pressure (mmHg)	ISI RA group: 18.4 ± 2.7 SA group: 18.1 ± 2.6 AIS RA group: 15.8 ± 2.4 SA group: 14.9 ± 2.2 Systolic BP RA group: 136.3 ± 21.0 SA group: 135.0 ± 18.0 Diastolic BP RA group: 79.2 ± 10.3 SA group: 78.1 ± 8.1	ISI (F/u 3 days) RA group: 13.1 ± 4.3 SA group: 16.5 ± 4.3 AIS (F/u 3 days) RA group: 11.2 ± 3.3 SA group: 13.8 ± 3.3 Systolic BP (F/u 3 days) RA group: 131.8 ± 15.9 SA group: 133.7 ± 16.6 Diastolic BP (F/u 3 days) RA group: 78.1 ± 9.8 SA group: 78.4 ± 8.6	Primary: intradermal acupuncture on Shen-Men (He-7), Nei-Kuan (EH-6) showed significant improvement of insomnia on insomnia-related scales, which had been confirmed to have high consistency, reliability, and validity Secondary: sympathetic hyperactivities, which cause absence of nocturnal BP decline, are stabilised by intradermal acupuncture	Not reported

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Table 2. Continued

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/ exclusion criteria (IC/EC)	Sample size (*n*) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results		Benefits of the technology	Limitations Adherence to technology
						Pre-intervention	Post-intervention		
Zollman et al. (2012) USA, Outpatient rehabilitation clinic	Electro-acupuncture (Ito Co, Ltd, Tokyo, Japan)	Study design: randomised controlled study (values obtained from a limited number of non-consecutive patients) Level: II IC: TBI within 5 years of study entry, complaints of insomnia ($\geq$15 ISI score), Rancho Cognitive Scale level V or above, consent, $\geq$18 years of age EC: respiratory or neurological condition associated with sleep disorders (such as sleep apnoea), pregnancy	Enrolled: $n=24$ Consented: $n=24$ Assessed at f/u: $n=12$ intervention, $n=8$ control ($n=1$ withdrew due to travel time, $n=1$ left city, $n=2$ lost to f/u) Age: 44.50 $\pm$ 15.15 Sex: 7/5 (intervention group)	Acupuncture points included: kidney, heart, bladder, liver, large intestine, pericardium, governor vessel, ear points, Shen-Men. After placement of needles, 4 Hertz electrical stimulation was applied to kidney/ heart, using electro-acupuncture device (IC1107). Each treatment lasted approximately 20 minutes; occurred for 5 weeks, with biweekly appointments	ISI; actigraphy (sleep time); RBANS; PASAT	Sleep time median (mins): 384 ISI median: 20	Sleep time median (mins): 379 ISI median at post-treatment: 20 F/u 1 month: 11	Primary: Perception of sleep (as measured via the ISI) improved in treatment group versus control group. Improvement in perception of sleep was sustained for at least 1 month after cessation of acupuncture Secondary: improvement in PASAT and RBANS total scale; depression improvement was seen	$n=1$ reported headache after usage, but effects did not last over the trial period
Ouellet and Morin (2007) Canada, Outpatient rehabilitation centre	CBT	Study design: single-case design, multiple baselines across participants Level: IV IC: mild to severe TBI in $\leq$5 years, between 18 to 50 years of age, insomnia syndrome EC: major untreated or unstable medical or psychiatric comorbid condition, taking medication known to produce insomnia, sleeping difficulties before TBI, presence of another sleep disorder (such as sleep	Enrolled: $n=13$ Consented: $n=13$ Assessed at f/u: $n=11$ ($n=2$ withdrew before completion) Age: 27.3 (20–46) Sex: 6/5	Patients receive 8 weekly sessions of CBT over an 8- to 10-week period; each session lasted approximately 1 hour. Intervention has 5 components: (1) stimulus control instructions (re-associate bed, bedroom, bedtime stimuli with sleep instead of frustration, anxiety, tension), (2) sleep restriction procedure (limiting time spent in bed to actual total time spent sleeping), (3) cognitive therapy	Sleep diary; TST; sleep efficiency; diagnostic criteria	Total wake time: 128.46 $\pm$ 47.86 Sleep efficiency: 77.20 $\pm$ 8.76 Total sleep time: 425.68 $\pm$ 51.20 ISI score: 17.55 $\pm$ 4.03	Total wake time at post-treatment: 59.29 $\pm$ 39.54 F/u 1 month: 71.49 $\pm$ 42.97 F/u 3 months: 49.66 $\pm$ 27.96 Sleep efficiency at post-treatment: 87.99 $\pm$ 7.99 F/u 1 month: 86.26 $\pm$ 7.92 F/u 3 months: 90.88 $\pm$ 5.29 Total sleep time at post-treatment: 444.43 $\pm$ 58.74 F/u 1 month: 453.43 $\pm$ 59.48	Primary: significant reduction in total wake time, reduction in internight variability, all patients increased their sleep efficiency, significant reduction in ISI scores	No change was observed in terms of 'mental' fatigue despite improvement in sleep. Some patients require more structure/ encouragement, such as from the therapist, in order to ensure the effects of the intervention last and they do not relapse (they need 'booster' sessions)

(continued)

Table 2. Continued

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/ exclusion criteria (IC/EC)	Sample size (*n*) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results		Benefits of the technology	Limitations Adherence to technology
						Pre-intervention	Post-intervention		
		apnoea), having severe pain as cause of sleep disturbance, inability to complete questionnaires due to visual, cognitive, language, or comprehension deficits		of insomnia (designed to identify, challenge, alter set of dysfunctional beliefs, attitudes about sleep), (4) sleep-hygiene education consists of teaching people about impact of certain lifestyle habits and influence of environmental factors on sleep, (5) fatigue management skills training component (aimed at recognising and managing fatigue more effectively; revising dysfunctional attitudes about fatigue/rest)		F/u 3 months: 496.72 ± 50.24 ISI score at post-treatment: 8.78 ± 3.38 F/u 1 month: 11.33 ± 3.74 F/u 3 months: 10.30 ± 5.38		
Sinclair et al. (2013) Australia, Epworth Hospital	Blue Light Therapy (Philips goLITE M2 light therapy device)	Study design: randomised, placebo-controlled design (values obtained from limited number of patients) Level: II IC: 18 to 65 years of age, TBI ≤ 3 months, FSS ≥ 4 and/or ESS ≥ 10 and/or PSQI > 5 EC: presence of other medical illness accounting for fatigue (including neurological disorders, pre-injury sleep disorders, chronic fatigue syndrome), obesity, high risk of OSA on BQ, trans meridian travel, night shift work in < 6 weeks, use of sleep medication	Enrolled: $n = 32$ Consented: $n = 30$ ($n = 10$ blue light therapy, $n = 10$ yellow light therapy, $n = 10$ control) Assessed at f/u: $n = 30$ ($n = 2$ withdrew prior to randomisation) Age: 47.2 ± 13.7 Sex: 8/2 (blue light therapy group)	Patients used blue light therapy device for 45 minutes each morning at home, within 2 hours of waking, over a 4 week period. Patients sat in front of light panel with centre approximately 50 cm in front of eyes, looked into light source for few seconds, every few minutes. Participants were deemed compliant if device was switched on at least 5 days per week on at least 3 of the 4 treatment weeks	FSS; daytime sleepiness; ESS; PSQI; BDI-II; PVT; NAART; CVLT-II	ESS: 10.1 ± 4.5 (treatment group – blue light therapy), 9.6 ± 4.8 (yellow light therapy), 8.8 ± 3.4 (no treatment control) FSS: 5.9 ± 0.8 (treatment group – blue light therapy), 5.6 ± 0.5 (yellow light therapy), 6.2 ± 0.4 (no treatment control)	ESS (ref: no treatment control): 0.89 (treatment group – blue light therapy), 0.88 (yellow light therapy) FSS (ref: no treatment control): −0.30 (treatment group – blue light therapy), −0.37 (yellow light therapy)	Primary: significant reduction in fatigue with blue light therapy Secondary: significant reduction in daytime sleepiness	$n = 1$ reported headache after usage, but effects did not last over the trial period Patients did not report significant improvement in sleep quality

(continued)

Table 2. Continued

References: Author Year Country Setting	Technology (Manufacturer)	Clinical study design Inclusion/ exclusion criteria (IC/EC)	Sample size (*n*) Characteristics Age, sex (M/F)	Usage	Outcome measures	Results		Benefits of the technology	Limitations Adherence to technology
						Pre-intervention	Post-intervention		
Svatikova et al. (2011) USA, University of Michigan	Positional Therapy (SONA Pillow®)	Study design: randomised, controlled, cross-over study Level: II IC: 18 + years of age, acute ischaemic stroke or probable ischaemic stroke, consent, AHI ≥ 5 EC: patients with any medical condition that precluded avoidance of supine posture or dictated need for particular position, currently using positive airway pressure therapy, mechanical ventilation, or supplemental oxygen	Enrolled: $n = 20$ Consented: $n = 20$ Assessed at f/u: $n = 9$ intervention, $n = 9$ control ($n = 2$ discharged from hospital) Age median (IQR): 58 (54, 68) Sex: 11/7	SONA Pillow® was used to avoid supine sleep. Pillow has flat base and double incline on top surface that promotes lateral positioning. Recesses in base create space for lower arm to extend under head. Patients initially positioned to sleep on side least affected by stroke. Patients using standard hospital pillow during control night were positioned ad lib. Angle of bed was set to same degree initially, but patients were not precluded from manipulation of bed angle	NIHSS; AHI (events/h); AHI supine position (events/h); AHI nonsupine position (events/h); oxygen desaturation index; supine time, as % of recording; time supine (min)	NIHSS, median (IQR) Treatment group: 3 (3, 5) Control group: 2 (2, 5)	F/u 3 months AHI (events/h) Treatment group: 27 (22, 47) Control group: 39 (21, 54) AHI supine position (events/h) Treatment group: 51 (6, 55) Control group: 49 (35, 60) AHI nonsupine position (events/h) Treatment group: 27 (18, 45) Control group: 27 (17, 43) Oxygen desaturation index Treatment group: 6 (3, 13) Control group: 7 (4, 14) Supine time, as % of recording Treatment group: 8 (1, 20) Control group: 39 (12, 90) Time supine (min) Treatment group: 30 (3, 66) Control group: 142 (31, 295) (All values reported as median (IQR))	Primary: positional therapy for sleep apnoea after ischaemic stroke shows that positional therapy to minimise supine positioning reduces sleep apnoea severity. Stroke patients showed relative AHI reduction of approximately 20%	$n = 3$ reported no adherence to therapeutic pillow throughout study $n = 2$ reported adherence to pillow on some nights

Abbreviations:
ACE: Addenbrooke's Cognitive Examination; ADL: Activities of Daily Living; AHI: Apnoea–Hypopnea Index; AI: Apnoea Index; AIS: Athens Insomnia Scale; ArI: Arousal Index; ASV: Adaptive servo-ventilation; BDI-II: Beck Depression Inventory; BMI: Body Mass Index; BNP: B-type natriuretic peptide; BQ: Berlin Questionnaire; BS: baseline; CBT: cognitive behavioural therapy; CHF: congestive heart failure; CNS: central nervous system; COPD: chronic obstructive pulmonary disease; CPAP: continuous positive airway pressure; CSA: central sleep apnoea; CSR: Cheyne-Stokes respiration; CVLT-II: California Verbal Learning Test; EADL: Extended Activities of Daily Living; EDS: excessive daytime sleepiness; EEP: end-expiratory pressure; ESS: Epworth Sleepiness Score; F/u: follow-up; FSS: Fatigue Severity Scale; HADS: Hospital Anxiety and Depression Scale; IQR: interquartile range; IRB: Institutional review board; ISI: Insomnia Severity Index; LOC: level of consciousness; LVEF: left-ventricular ejection fraction; MADRS: Montgomery-Asperg Depression Rating Scale; MMSE: Mini-mental state examination; MQ: Morning Questionnaire; MRI: Magnetic resonance imaging; MRS: Modified Rankin Scale; MSLT: mean sleep latency (in minutes); NAART: North American Adult Reading Test; nCPAP: nasal continuous positive airway pressure; NIHSS: National Institutes of Health Stroke Scale; NPSG: nocturnal polysomnography; OSA: obstructive sleep apnoea; OSAHS: obstructive sleep apnea hypopnea syndrome; PASAT: Paced Auditory Serial Addition Test; PLMI: periodic limb movement index (number of periodic limb movements per hour of sleep); PSG: polysomnography; PSQI: Pittsburgh Sleep Quality Index; PVT: Psychomotor Vigilance Task; RBANS: Repeatable Battery for the Assessment of Neuropsychological Status; RA: real acupuncture; RCT: randomised controlled trial; RDI: respiratory disturbance index; REM: rapid eye movement; RES: residual excessive sleepiness; SA: sleep apnoea; SDB: sleep-disordered breathing; SL: sleep latency (from time in minutes from lights out to sleep onset); SOREM: number of sleep-onset REM periods on multiple sleep latency test; SSS: Stanford Sleepiness Scale; SWS: slow wave sleep; TBI: traumatic brain injury; T1: day one; T2: day two; TIA: Transient Ischaemic Attack; TST: total sleep time

reported that 50% of stroke patients who stopped CPAP did so because of problems with cognition, orientation, inability to apply headgear, mask, and hose, and to readjust equipment.

Gasa et al. (2013) inquired whether CPAP was effective at treating residual excessive sleepiness (RES) in patients with obstructive sleep apnoea after suffering from hypoxic brain damage. Prevalence of RES in CPAP-treated obstructive sleep apnoea was 13% and significantly reduced with continued CPAP use, which was observed with improved daytime sleepiness, as assessed by the Epworth sleepiness scale (ESS), from the initial visit to follow-up.

In patients with TBI, Castriotta et al. (2009) examined the effectiveness of CPAP intervention for patients with obstructive sleep apnoea (a form of SRBD). Similar to results obtained from patients with stroke, a dramatic improvement in AHI score was observed with no change in TST or excessive daytime sleepiness, as determined by the multiple sleep latency test (MSLT) and the ESS scores. The attrition rate from the baseline assessment to the post-treatment evaluation (regardless of the aetiology of sleep disorder) was 35%. For more information on CPAP in patients with stroke or TBI, refer to Table 2.

Acupuncture

Three separate studies assessed the efficacy of acupuncture in treating insomnia in patients with TBI (Zollman et al., 2012) and stroke (Kim et al., 2004; Lee et al., 2009). Zollman et al. (2012) conducted a study in which 12 patients with TBI underwent acupuncture delivered by a physician–acupuncturist. The acupuncture point selection was based on the classically described energetic qualities of the given acupuncture points. The TST, measured by actigraphy, increased from baseline to post-acupuncture treatment; sustained perception of sleep quality (as measured by the insomnia severity index (ISI)) improved more in the acupuncture group than in the control group, and overall cognitive functioning and divided attention improved as well, as measured by neuropsychological tests. Moreover, participants were able to taper sleep medications during the first week of the acupuncture treatment. One patient reported a headache after the procedure, which subsided within the trial period. Kim et al. (2004) studied intradermal acupuncture in 15 stroke patients with insomnia. Their study, which involved intradermal acupuncture on *Shen-Men* (He-7) and *Nei-Kuan* (EH-6), showed significant improvements in perceived sleep quality upon awakening and insomnia severity within just two days of treatment, as measured by the ISI and the Athens insomnia scale. Researchers reported that one patient was unable to tolerate pain from acupuncture needles. Lee et al. (2009) also studied intradermal acupuncture, on *Shen-Men* (He-7) and *Nei-Kuan* (EH-6), in 60 stroke patients with insomnia. The intervention showed a significant improvement of insomnia on the insomnia-related scales within only three days of treatment, along with slight reductions in systolic and diastolic blood pressure.

Cognitive behavioural therapy

One study tested the efficacy of CBT for dealing with insomnia in patients with TBI (Ouellet and Morin, 2007). Eleven of 20 (55%) participants that completed the initial assessment and met inclusion criteria underwent a CBT programme for eight weeks. This technology included stimulus control, sleep restriction, cognitive restructuring, sleep-hygiene education, and fatigue management applications. An average reduction of 53.9% in the total wake time was observed across participants from pre-CBT to post-CBT application, with significant improvement in sleep efficiency (from 77.2% to 87.99%), accompanied by a reduction in symptoms of general and physical fatigue. No adverse effects were reported.

Nasotracheal suction mechanical ventilation

Jiang et al. (2015) tested the effectiveness of NSMV in 29 patients with moderate-to-severe sleep apnoea who had ischaemic stroke. The proposed mechanism of action of NSMV includes keeping the airway unobstructed and preventing nasal secretion retention. Application of the technology significantly suppressed respiratory disturbance in sleep and resulted in improvement in indices of brain injury recovery (lower National Institutes of Health Stroke Scale scores and increased Barthel scores), and reduced complications related to brain injury; these results were comparable to those of CPAP application in the control group. Researchers reported that NSMV is best applied in patients who were prescribed CPAP, particularly those at risk of serious respiratory failure due to deficits in the respiratory nerves and muscle weakness.

Adaptive servo-ventilation

Brill et al. (2014) tested the effectiveness of and adherence to ASV technology in 15 patients with central sleep apnoea (CSA) who had suffered from acute ischaemic stroke. The application of the technology significantly suppressed central apnoea occurrence and resulted in a reduction of the AHI from the time of diagnosis to three and six months' follow-up (from 54 to 4.7 and 6.6, respectively) and total arousal index (29.6 to 0.2, at both follow-up periods). The changes were accompanied by a reduction in daytime sleepiness. Researchers reported that ASV was well tolerated by stroke patients, with 67% of patients continuing to use it at six months follow-up, showing improvement in nightly adherence with continuous use. No adverse effects were reported. Two patients stopped using the device because of intolerance of the interface (mask leaks, claustrophobia, noise from the machine).

Light therapy

One study examined the efficacy of home-based blue light therapy (goLITE, Phillips Consumer Lifestyle, American Fork, UT, USA) for 45 minutes per day for four weeks to

alleviate fatigue (primary outcome) and excessive daytime sleepiness (EDS), and enhance sleep quality and sustained attention in patients with TBI (Sinclair et al., 2013). Compliance with the technology application was acceptable if the device was switched on at least five days per week, for at least three of the four weeks. After a four-week period of using the blue light device, participants reported improvement in fatigue ($p < 0.001$) and reduction in EDS ($p < 0.01$) compared to the non-intervention group; however, there was no improvement in sleep quality. Adverse effects included headaches and diarrhoea (one patient each); however, these were considered to be unrelated to the treatment. Compliance was high, with the majority of participants using the light therapy as instructed in the morning, although outside of the two-hour window on just 8% of days during the testing period.

Positional therapy

Body position has an important effect on the severity of sleep apnoea because, in supine position, gravity tends to pull the tongue backward, narrowing or completely closing the airway in sleep. In the general population of patients with sleep apnoea, AHI is reported at least two times higher in the supine position than in the lateral decubitus position (Oksenberg et al., 2006). One study (Svatikova et al., 2011) examined the efficacy of positional therapy using a SONA Pillow® for three months in patients with ischaemic stroke. A ~20% reduction of AHI from the baseline assessment to follow-up has been observed. The authors reported that this reduction was particularly valuable because of the poor tolerance of stroke patients to CPAP, and the high prevalence of supine sleep after stroke. For more information about this study, refer to Table 2.

Discussion and implications

In this study, we have summarised evidence regarding sleep-assistive technology in patients with ABI and highlighted essential elements falling under occupational enablement practices (Townsend and Polatajko, 2013), such as: (a) the presence of an occupational challenge (various sleep disorders) in persons with ABI; (b) a range of solutions that enable sleep occupation in patients with injury to the brain; (c) the need for a client-specific goals/challenges/solutions and client-centred enablement; (d) multidisciplinary knowledge-base; and (e) a reasoning process that can deal with the complexity of assistive technology. Figure 2 summarises this evidence based on the PEO framework. The model helped us analyse complex data pertaining to sleep-assistive technology application and utility, dividing the data into meaningful, structurally defined, and comprehendible smaller domains. At the same time, the model acknowledges the person (P), environment (E), and occupation (O), clearly determined by the model, are interrelated and overlapping concepts that interact with each other, and affect performance (the utility and efficacy of sleep-assistive technology). This is exactly what we think happens and needs to be recognised if sleep-assistive technologies are meant to optimally serve the disabled person's sleep dysfunction.

Person

Our results show that despite the efficacy of sleep-assistive technologies to enable sleep function, clinicians and researchers face significant problems with adherence and compliance in patients with brain injury. The main reasons for poor adherence to CPAP were skin irritation due to mask application (Bravata et al., 2010, 2011; Brown et al., 2013; Palombini and Guilleminault, 2006), nasal congestion/irritation (Bravata et al., 2010, 2011; Brown et al., 2013; Hsu et al., 2006), discomfort (Brown et al., 2013; Gasa et al., 2013; Hsu et al., 2006; Palombini and Guilleminault, 2006; Wessendorf et al., 2001), and difficulty dealing with the equipment (Brown et al., 2013; Hsu et al., 2006; Palombini and Guilleminault, 2006). In several cases, authors attributed low CPAP adherence to neglect and higher age (Minnerup et al., 2011), having cognitive or physical impairments that could interfere with regular CPAP use (Bassetti et al., 2006; Bravata et al., 2010; Palombini and Guilleminault, 2006; Sandberg et al., 2001), and lack of motivation (Brown et al., 2013). The study of ASV had patients complaining of intolerance with the equipment interface and experiencing persistent mask leakage (Brill et al., 2014). Patients who had acupuncture had limited non-serious adverse events, including pain induced by the needle (Kim et al., 2004), and headache (Zollman et al., 2012) (Table 2). To a greater extent, the results can be positioned in the context of the adherence to sleep-assistive technology within the general population from a study more than two decades old (Hayes et al., 1991). In 1991, Hayes and colleagues investigated the acceptance of CPAP therapy by 95 patients from the general population. The main reasons for noncompliance after the first night of treatment were difficulties in falling asleep with the assistive sleep technology on and frequent nocturnal awakenings due to discomfort caused by the mask. While the technology has improved since that time, the complexity of the regime remains quite similar, and recent studies continue to report of adherence of approximately 50% of patients (Pelosi et al., 2016), similar to or even less than what we observed in patients with brain injuries. Hence, adherence with sleep-assistive technology in persons with ABI might be strongly linked to the simplicity of the regime; therefore, they should be taken into account during development of new assistive sleep technologies. This is especially relevant in light of the findings that some patients with brain injury refused to initiate application of sleep-assistive technology (CPAP) after mask-fitting or discontinued its use after the first night (Hsu et al., 2006; Polombini and Guilleminault, 2006).

Similarly, applications of cognitive and behavioural programmes for insomnia require considerable commitment from a patient. In patients with TBI, researchers reported that 45% of the participants failed to complete

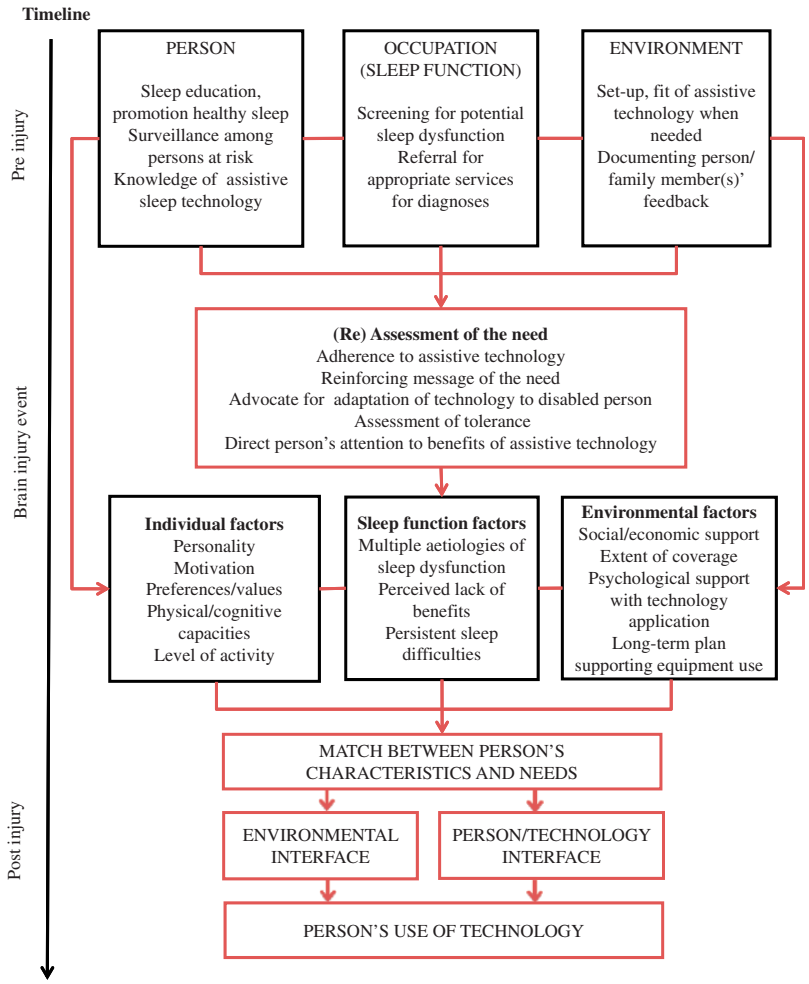

Figure 2. Schematic representation of the longitudinal dimensions informing occupational therapy services directed towards enabling sleep function in patients with brain injury through the application of assistive technology.

the programme (Oullett and Morin, 2007); no reason was provided for this failure. In the general population, factors linked to CBT attrition include having more severe sleep impairments, poorer general health, depression, and a greater tendency to consider the therapist as confrontational (Constantino et al., 2007).

Environment (physical, social, cultural, and institutional)

For many of the sleep-enhancing approaches to be effective, the user must be engaged (Cook et al., 2009). Engagement is a measure of the effectiveness of any approach because it directly affects motivation. If application of sleep-assistive technology can benefit the user at the time of first application, then he/she is more likely to seek the opportunity to use the technology again (Cook et al., 2009). This suggests that the application of a sleep-assistive technology should be individualised, with the period of trial being of utmost importance to ensure benefits, as well as relevance to the patient's needs.

We identified that the potential social aspect (interactions between the professionals and the person as well as family members) is important in the use of assistive technology by patients with brain injury (Table 2). Patients' initial acceptance or rejection of assistive technology and understanding of its purpose is critical to whether the person with brain injury uses it or not (Hsu et al., 2006; Polombini and Guilleminault, 2006). A supportive and encouraging social environment, positive attitudes of healthcare professionals towards an assistive device or programme, and continuous reinforcement of the importance of normalisation of sleep function are likely the keys to enhancing clients' use of the technology.

Further, the role of the cultural context in the effectiveness of sleep-assistive technology must be considered. Culture is a product of our heritage, experiences, family relationships, and other factors (Cook et al., 2009); it might affect how a person with brain injury adapts to assistive technology, his or her views of this technology, and whether the risk of stopping its use is high. No studies exclusively reported on the cultural context within application of sleep-assistive technologies. However, we observed that participants' withdrawal from CPAP studies was lowest in Sweden (Sandberg et al., 2001), followed by Australia (Broadley et al., 2007), Canada (Ryan et al., 2011), Switzerland (Bassetti et al., 2006), Germany (Minnerup et al., 2011; Wessendorf et al., 2001), UK

(Hsu et al., 2006), and USA (Bravata et al., 2010, 2011; Brown et al., 2013; Castriotta et al., 2009; Polombini and Guilleminault, 2006), which may be the result of cultural or social variability between nations.

Other facilitators of sleep technology implementation involve existing policies, practices, and awareness by the various caregivers of patients with ABI. Funding is the most influential element in this context. In Ontario, the largest Canadian province, for example, residents are eligible for health services and products subsidised by the Ministry of Health and Long-Term Care through the province's public health insurance programme. The Assistive Devices Program (ADP) is administered by the Ministry and provides financial assistance to purchase assistive devices that are authorised by a qualified healthcare professional. The ADP pays 75% of the ADP–approved price for CPAP systems, and recipients of certain social assistance programmes may receive 100% support from the ADP. Coverage is not the same in other countries with different healthcare systems. In the USA, for comparison, CPAP is covered by Medicare only when criteria towards evaluation of sleep apnoea, its severity, and the presence of daytime consequences are met; the person then pays 20% of the Medicare-approved amount for the machine rental and supplies, and becomes the owner of the machine after 13 months of use.

Cognitive behavioural techniques as soft technologies to target insomnia in patients with stroke or TBI are applied less commonly, despite being widely encouraged. One reason is that they are time-intensive for both clinicians and clients. In addition, they are not always funded by the public health insurance plan. Recently implemented online products (Espie et al., 2012) may reduce clinicians' involvement and be more cost-effective if monitored by knowledgeable ancillary personnel. Likewise, only some extended health insurance benefits cover acupuncture treatments. Therefore, a full description and understanding of how assistive technologies are funded, the extent of coverage, and the mechanisms for obtaining funding to cover sleep-assistive technologies is a vital facilitator of access to sleep-assistive technologies.

Occupation

The American Occupational Therapy Association classifies sleep as a critical area of occupation (Roley et al., 2008). Sleep dysfunction is highly prevalent in individuals with stroke or TBI, regardless of the type or injury severity. Of all possible cases of ABI, we identified studies that utilised sleep-assistive technologies only in patients with stroke, TBI, and hypoxic brain damage.

Stroke is an incidence of irregular blood flow within the brain causing an interruption in brain function, including sleep. Risk factors for stroke include older age, arterial hypertension, heart disease, alcohol abuse, smoking, diabetes mellitus, and hypercholesterolaemia. SRBD and sleep–wake disturbances (SWD), in general, represent newer risk factors for stroke and stroke-in-evolution (Diaz and Sempere, 2004). Numerous studies have shown that at least 50% of stroke patients exhibit SRBD, predominately obstructive sleep apnoea (OSA), with clinically relevant apnoea-hypopnoea indices (Johnson and Johnson, 2010). Moreover, up to 50% of patients continue to exhibit SRBD months to years after the acute event, with a greater improvement over time reported for haemorrhagic stroke compared to ischaemic stroke (Johnson and Johnson, 2010). The presence of Cheyne–Stokes breathing (caused by instability in ventilator control) has been less commonly reported, induced mostly by supratentorial bilateral lesions (Brown et al., 2013). Stroke can also alter circadian brain functions, such as secretion of melatonin and growth hormone, resulting in difficulty falling asleep, sleep consolidation, and overall sleep quality. Similarly, in TBI, which occurs when the head or brain is struck by an external force, sleep disorders of all major categories (insomnias, SRBD, hypersomnia not due to breathing disorders, circadian rhythm sleep disorders (CRSD), sleep-related movement disorders), as defined by the International Classification of Sleep Disorders, are highly prevalent and persist for a long time after the injury. Given that no study today can reliably differentiate between functional impairments stemming from a sleep disorder and from those of structural brain damage, the possibility to improve sleep function in patients with ABI cannot be ignored.

By addressing sleep impairments, healthcare professionals might not only enhance functioning for patients with ABI at the level of self-care, productivity, and leisure, but also provide evidence of the pervasive impact sleep dysfunction has on occupational engagement and daytime functional abilities. Figure 2 represents an overall system schema of the application of sleep-assistive technology in patients with ABI. Recognising that the successful application of assistive technologies involves the favourable interaction of multiple factors (person/technology interface, environmental interface, coincidence of patient characteristics and needs, and technology target), we recommend that application of sleep-assistive technologies in persons with ABI follow the PEO framework. Occupational therapy professionals are likely in the best position of all other health-related occupations to determine the need (that is, define the presence of an occupational challenge), discuss with the disabled client and his/her family the possibility of solutions that enable sleep occupation, set client-specific goals/challenges/solutions based on the multidisciplinary knowledge-base, and ensure the complexity of the issue will not discourage the client and his environment from following through with the use of assistive sleep technology (Figure 2).

Limitations

Assessment of the quality of the included studies was not formally reported within the article regarding the conceptual difficulty arising from the lack of an agreed definition on what 'quality' implies with regards to our research questions, which aimed to describe the types of assistive

technology and its applications in patients with ABI, falling under the descriptive (narrative) synthesis review category. The complexity in performing a formal study quality assessment also comes from the heterogeneous study methodology (cohort, case-control, RCT, case series) of included studies. Furthermore, the population of interest was heterogeneous in terms of aetiology, injury severity, etc., as well as type of sleep disorder and the assistive technology utilised to deal with it. This heterogeneity at multiple levels precluded us from performing a meaningful formal assessment of the included study quality. Nonetheless, the Centre for Reviews and Dissemination Guidelines and the *Cochrane Reviewers' Handbook* both suggest that 'quality' is important to consider when performing reviews, with 'quality' related to the extent to which the study minimises bias and maximises internal and external validity. To ensure these goals are met in our review, we included studies published only in peer-reviewed journals, screened articles for potential risk of biases (excluding those with insufficient information reported), and extracted and reported all information about the studies (intervention, population, context, sample sizes, outcomes, and the level of evidence on the hierarchy of scientific evidence). Finally, Table 2 is structured such that it allows the observation of the similarities and differences between included studies' characteristics and outcomes.

Another limitation concerns inclusion of only peer-reviewed studies published in English, omitting publications in other languages and their possibly relevant results. Finally, information on assessment of the risk of sleep disorder in patients with ABI, while highly relevant to the scope of occupational therapy practice, fell outside the scope of this review and therefore was not covered. Previous studies highlight the assessment criteria for sleep disorders (Mollayeva et al., 2013).

A brief justification of the inclusion of acupuncture and CBT as assistive technologies

In our review, which summarises all the sleep-assistive technologies applied to date in the treatment/management of sleep dysfunction in ABI, we faced the dilemma of whether or not to include acupuncture and CBT among the technologies reviewed. Acupuncture is a key treatment in traditional Chinese medicine, involving the placement of thin needles on parts of the body, not surgically implanted, and described in their capacity to improve sleep in persons with ABI in two reviewed studies. Our decision to include acupuncture was based on the Individuals with Disabilities Education Act's definition of an assistive technology as:

> any item, piece of equipment or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of persons with disabilities. The term does not include a medical device that is surgically implanted or the replacement of such device (Assistive Technology Act, 2004).

According to classifications of assistive technologies, they can be divided into hard and soft. Hard technologies refer to readily available components that can be purchased and assembled into an assistive technology system, while soft assistive technologies require human efforts in decision-making, strategies, training, concept formation, and service delivery. Given that CBT is an action-oriented form of psychosocial therapy that assumes maladaptive or faulty thinking patterns cause maladaptive behaviour and negative emotions, and focuses on changing an individual's thoughts (cognitive patterns) in order to change his/her behaviour and emotional state, which arguably involves skill development, we feel it is conceptually correct to consider CBT as a soft technology, and therefore we kept this technology within our review. Our decision by no means points to the need to change the current position of acupuncture and CBT in the taxonomy of health technologies, but rather concerns the effort to increase knowledge about all current practices which may serve the role of improving sleep function in persons with disabilities aroused from ABI.

Conclusion

The application of sleep-assistive technology to enable sleep function in patients with ABI (namely stroke, hypoxic brain damage, and TBI) represents a clinical, technical, and logistic challenge. The greatest advances in the application of assistive technology have been for sleep-related breathing abnormalities (CPAP) in patients with stroke. The application of sleep-assistive technologies that focus on changing an individual's thoughts (cognitive patterns) to change his or her behaviour and emotional state as a means to improve sleep function has been limited in the past. Despite strong evidence supporting the efficacy of assistive technology in alleviating sleep dysfunction in patients with brain injury, acceptability and adherence issues persist. Strong efforts should be directed towards understanding an individual patient's physical, cognitive, and occupational competence within his/her social, cultural, and institutional environments to develop and apply user-friendly sleep-assistive technologies. Occupational therapists are in the position to lead the incorporation of such technologies in managing sleep in individuals with brain pathology.

Key findings

- We identified sleep-assistive technologies applied to manage sleep-related breathing disorder, circadian rhythm sleep disturbances, insomnia, and adverse daytime consequences of poor sleep in patients with ABI.
- Solutions to enable sleep in patients with ABI falling within the occupational therapy practice exist; to be most beneficial, they should integrate a client-centred, disorder-specific approach, and environmental enablement.

What the study has added

This is the first study summarising scientific evidence on sleep-assistive technology in patients with ABI. The results support occupational therapy professionals to deal with sleep dysfunction in their clients.

Research ethics

Ethical approval was not required for this review.

Declaration of conflicting interests

The authors confirm that there is no conflict of interest.

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Supplementary material

Supplementary material and Appendix for this paper can be found at http://journals.sagepub.com/doi/suppl/10.1177/0308022616688017.

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