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Multi-night measurement for diagnosis and simplified monitoring of obstructive sleep apnoea

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ABSTRACT

Substantial night-to-night variability in obstructive sleep apnoea (OSA) severity has raised misdiagnosis and misdirected treatment concerns with the current prevailing single-night diagnostic approach. In-home, multi-night sleep monitoring technology may provide a feasible complimentary diagnostic pathway to improve both the speed and accuracy of OSA diagnosis and monitor treatment efficacy. This review describes the latest evidence on night-to-night variability in OSA severity, and its impact on OSA diagnostic misclassification. Emerging evidence for the potential impact of night-to-night variability in OSA severity to influence important health risk outcomes associated with OSA is considered. This review also characterises emerging diagnostic applications of wearable and non-wearable technologies that may provide an alternative, or complimentary, approach to traditional OSA diagnostic pathways. The required evidence to translate these devices into clinical care is also discussed. Appropriately sized randomised controlled trials are needed to determine the most appropriate and effective technologies for OSA diagnosis, as well as the optimal number of nights needed for accurate diagnosis and management. Potential risks versus benefits, patient perspectives, and cost-effectiveness of these novel approaches should be carefully considered in future trials.

1. Introduction

Obstructive sleep apnoea (OSA) is the most common pathological respiratory sleep disorder. Globally, it is estimated that 936 million (95% CI 903–970) adults aged 30–69 years have at least mild OSA, with 425 million (399–450) experiencing moderate to severe OSA [1]. Untreated OSA has been associated with a wide range of adverse health outcomes, including cancer [2,3], cardiovascular disease [4–6], increased motor vehicle accidents [7], decreased cognitive function [8], reduced quality of life [9,10], depression [11], and ultimately, all-cause mortality [5,12,13]. In 2015, the cost of undiagnosed OSA in the US was estimated to be nearly $150 billion, for reasons such as absenteeism and loss of productivity ($87 billion), increased risk of cardio-metabolic disorders, mental health conditions ($30 billion), and motor vehicle accidents ($26 billion) [14].

The severity of OSA can vary widely between nights in many people [15,16]. Night-to-night variability in OSA severity increases the likelihood of misdiagnosis [15,16]. This may increase the health burden and costs associated with overtreatment of patients demonstrating worse OSA severity on their clinical diagnostic study compared to their usual average on other nights. Conversely, missed or undertreatment of patients who exhibited low severity on their single diagnostic night compared to more significant OSA on other nights is also clearly problematic. This review summarises the current diagnostic and management practices of OSA, the limitations of current practices in light of growing literature on the night-to-night variability of OSA, and how emerging sleep technologies may be useful for overcoming the challenges of assessing multi-night OSA severity.

2. Current management of obstructive sleep apnoea

2.1. Definition of OSA severity

In patients with OSA the upper airway frequently collapses, either partially or completely, to cause hypopneas (a significant reduction in

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Abbreviations

AASM	American Academy of Sleep Medicine
AHI	apnoea hypopnoea index
HSAT	Home-sleep-apnoea tests
OSA	Obstructive sleep apnoea
ODI	Oxygen desaturation index

airflow) and apnoeas (complete cessation of airflow), respectively. OSA severity classification and diagnosis are traditionally determined based on the total number of apnoea and hypopnoea events per hour of sleep - the apnoea hypopnoea index (AHI). The gold standard methodology to derive this metric and quantify OSA severity currently relies on overnight polysomnographic recordings. Polysomnography incorporates concurrent electroencephalography, electrooculography, electromyography, electrocardiography, body position and movement, and respiratory-related signals including airflow, chest and abdominal motion, and oximetry. These signals are then scored manually according to international guidelines to classify apnoea and hypopnoea events, from which the AHI is derived. The American Academy of Sleep Medicine's (AASM) current recommended scoring guidelines classify hypopneas as a ≥30% reduction in airflow signals associated with a cortical arousal (at least 3 s of wake like-electroencephalography) or an oxygen desaturation ≥3%. OSA severity is based on predefined AHI cut-off scores, with an AHI between 5 and 15 classified as mild, 15–30 as moderate, and >30 events/h as severe OSA [17].

2.2. Home-sleep apnoea testing

While polysomnography captures rich sleep and respiratory data, it is costly, time-consuming, and can be inaccessible within a short timeframe, and a substantial burden for patients. These limitations, coupled with the scale of OSA prevalence, lack of specialised clinical services, and the burden of disease associated with OSA in the community, make simplified home-based diagnostic tests for sleep apnoea more attractive than in-laboratory polysomnography. Home sleep apnoea tests (HSAT; or polygraphy) have been used for several decades as a complementary, more feasible tool to diagnose OSA in the home environment, which is more representative of the usual sleep environment compared to in laboratory PSG [18]. In polygraphy, electroencephalography, electrooculography and electromyography are not typically recorded, so recording time rather than sleep time is used to estimate the frequency of obstructed breathing events. The AASM defines a technically adequate HSAT as a "device [that] incorporates a minimum of the following sensors: nasal pressure, chest and abdominal respiratory inductance plethysmography, and oximetry; or else peripheral arterial tonometry with oximetry and actigraphy." [19] These devices also need to fulfill technical specifications outlined in the AASM Manual for the Scoring of Sleep and Associated Events [20].

In 2017, the AASM commissioned a task force to review available evidence on the use and validation of HSATs [19]. The task force recommended that HSATs could be used for the diagnosis of OSA, but that if a single home-study was found to be negative, a second full polysomnography sleep study should be performed to help rule in or out OSA. Twenty-six validation studies comparing the diagnostic accuracy of single night HSAT against single night polysomnography were reviewed in the task force report and it was suggested that the accuracy to classify mild, moderate, and severe OSA using HSATs ranged between 70 and 90% [19]. An earlier meta-analysis of 19 validation studies of HSATs suggested that the predictive performance of HSATs were relatively good, with an estimated area under the receiver operating characteristics curve between 0.85 and 0.99, sensitivity between 0.79 and 0.97, and specificity between 0.60 and 0.93 across different apnoea–hypopnea cut-offs [21]. At least two studies since have reported that in participants with high pre-test probability of OSA, HSATs could result in a false negative in as many as 25–50% of cases [22,23]. Thus, these findings further suggest that polysomnography may be useful when an initial negative result is obtained using a HSAT [19]. Nevertheless, multiple randomised controlled trials have shown that diagnosis, management, and treatment decisions based on HSAT data is not inferior to gold-standard polysomnography [24–32]. Furthermore, the existing literature indicates that objective assessment of sleep-related respiratory disturbances, treatment adherence and acceptance, sleepiness, and functional outcomes do not differ between HSAT and polysomnography-based management of OSA, demonstrating the clinical utility of HSATs.

2.3. Wearables and non-wearables for OSA diagnosis

With the growing use of HSATs to diagnose OSA, a plethora of technologies have concurrently emerged that claim to monitor sleep and breathing more easily than conventional HSAT and polysomnography [33]. In the context of this review, a wearable is defined as a sleep monitoring technology worn by the participant (e.g., a watch) whereas a non-wearable is placed near the user (e.g., under-mattress sensors). Some devices can record information on breathing patterns without the need to physically apply any monitoring equipment using techniques such as bedside Doppler [34], infrared video [35] and/or ballistography in instrumented mattresses [36–39]. Other devices, such as smart watches [40,41] or thoracic bands [42] use oximetry and movement of the thoracic cage to estimate OSA severity, respectively. One wearable device, Watch PAT (Itamar Medical, Israel), has been validated extensively in the past 10 years, and has consistently shown good performance against polysomnography in the diagnosis of sleep disordered breathing [43–46]. Several under-the-mattress devices, such as the Withings Sleep Analyzer (Withings, France [15,37]) [11,32], Earlysense (discontinued) [47] and Sleeptracker-AI Monitor (Fullpower Technologies, USA) [48] devices use ballistography-based algorithms to infer sleep and the AHI from body, respiratory and cardiac-related movements studies. Some of these devices have recently been implemented in research trials to investigate potential night-to-night variability in OSA severity [15,49]. Measurement of mandibular movements through a device placed on the chin (Sunrise system; Sunrise, Belgium) has also been shown to reliably estimate OSA severity in adults [50,51] and children [52]. Respiratory effort has been reliably approximated from this device [53], which has recently been shown to better predict hypertension prevalence compared to traditional polysomnography metrics [54]. This device is now being validated as an OSA diagnosis device vs PSG in a large (target N ~900), prospective, randomized, parallel-arm, open-label, multicenter, national (France), controlled study (ClinicalTrials.gov ID NCT04675268). Another device, the Dreem headband (Dreem, France), is the only consumer available wearable devices that measures electroencephalography in addition to breathing frequency, heart rate, and sound. The Dreem headband has been shown to provide relatively accurate estimates of sleep stages compared to polysomnography [55] and can reliably classify mild OSA (specificity 84% and sensitivity 96%). However, these study findings have not yet undergone peer review [56].

Noting the promising findings for estimating sleep and OSA severity with emerging technologies, there are also significant limitations that are impacting the implementation of wearables/non-wearables in clinical care. Firstly, most of these devices (including most HSATs) do not measure electroencephalography. Hence, the calculation of OSA severity is based on recording time or estimated total sleep time, rather than the gold standard measure of sleep duration. Hence quantification of OSA severity derived from these devices, sometimes referred as respiratory event indexes, may be a noisier estimate than gold-standard AHI. Secondly, while many devices have been validated against polysomnography, no randomised controlled trial has studied the potential

benefits to patient outcomes from implementing these technologies into clinical care for OSA. Thirdly, the commercial landscape of sleep monitoring technology is rapidly evolving, and many devices are introduced, refined, and discontinued every year. This makes the clinical validation of devices challenging. Notwithstanding these limitations, wearables and non-wearables allow longitudinal monitoring of OSA symptoms over months, as recently demonstrated [15], which is likely to provide greater insights and improve our understanding of the manifestation of OSA over time and open new pathways for disease management.

3. Night to night variability of obstructive sleep apnoea severity

3.1. OSA misdiagnosis: is one night enough for an accurate diagnosis?

Since the advent of sleep studies, OSA diagnosis has relied upon single-night studies, despite multiple studies showing considerable night-to-night variability in key measures of OSA severity. In the context of this review, misclassification is defined as inaccurate classification of OSA severity, whereas misdiagnosis is defined as an invalid classification of OSA status (yes, no) given a specific AHI threshold.

A study of 10,340 adults undertaking 3 nights of HSAT suggested that approximately 20% of participants with mild or moderate sleep apnoea on the first night were misdiagnosed either as not having sleep apnoea or were misclassified as having a milder disease severity based on the composite AHI score derived from 3 nights of data as the reference (Fig. 1, right). Another study of >65,000 individuals undergoing ~6 months of at-home monitoring of sleep apnoea using an under-the-mattress sensor also indicated that the probability of obtaining a misdiagnosis on any given night was as high as 20%–50% for participants with mild to moderate OSA [15]. Misclassification of OSA severity was also high (Fig. 1, left). These findings are in agreement with earlier reports with smaller sample sizes (up to 300 participants) which report misdiagnosis probability rates of up to 60% with single-night studies [16,49,57–59].

Studies have also investigated the night-to-night variability of OSA severity via studies conducted in sleep laboratories. Under these conditions, participants usually experience worse sleep on the first night, known as the 'first-night effect'. The opposite can occur in people with insomnia, where sleep is improved in the laboratory versus the home environment. Given that insomnia symptoms are also common in many people with OSA [60], these variables first night effects may contribute to variable estimates of OSA severity. A study in 2008 (n = 20) found that the correlation between AHI values determined on 2 consecutive nights of in-laboratory sleep was relatively low (r = 0.44 [61]) [56]. Similar results have been reported in other studies [57,62,63]. A bias towards more first-night supine-time has also been noted in laboratory sleep studies [64]. While the overall group mean difference in AHI across two consecutive nights was relatively small in these studies, a substantial proportion (between 10 and 60%, depending on the definition) of participants had a ≥5 or ≥ 10 events per hour difference between nights. Furthermore, around 20–40% of participants in these studies were alternating between OSA severity categories across between nights. Two consecutive nights of at-home sleep testing instead of polysomnography suggest similar results and conclusions [16,59,65–68]. Furthermore, two alternating nights of polysomnography and HSAT have similar misdiagnosis probabilities 17,18,22,23,64,69, supporting that misclassification and misdiagnosis rates are similar with polysomnography and HSAT and reflects AHI variability between nights rather than reliability effects.

These reports were recently reviewed in a meta-analysis of 24 studies, comprised of 3250 participants [70]. The mean difference in respiratory disturbances indices, including AHI and the oxygen desaturation index (ODI; number of desaturation greater than 3 or 4%) between first and second night was relatively low (−1.7 events per hours) at the population level. However, the proportions of participants who showed a difference of more than 10 events per hours in respiratory disturbances indices was as high as 41% (95% CI 27–57%; Fig. 2). More importantly, as many as 49% (95% CI 32–65%) of participants changed OSA severity category at least once in sequential sleep studies. Such a large misclassification probability in mild to moderate OSA may be particularly problematic given that some current clinical guidelines indicate that an AHI of >15 events/h, even in the absence of symptoms, is sufficient for the initiation of therapy. This may lead to almost one-third of patients being undertreated and 15% overtreated based on a single-night AHI value [71].

The relative contribution to differences in AHI and respiratory disturbances indices between consecutive nights from first-night effects, changes in head and body position across the night, changes in sleep structure, behavioural (e.g. alcohol), physiological changes in OSA severity, or inter-scorer variability in apnoea and hypopnea scoring [72,73] remains to be determined. Nonetheless, the most up to date AASM guidelines recommend that a single night of polysomnography recording is sufficient for the diagnosis of sleep apnoea [19]. Given the consistent published evidence that night-to-night variability leads to high OSA misclassification rates, this recommendation needs to be revisited.

3.2. What is the ideal number of nights for best practice assessment?

If multi-night assessments of OSA severity are required to accurately classify disease severity, then an important consideration is how many

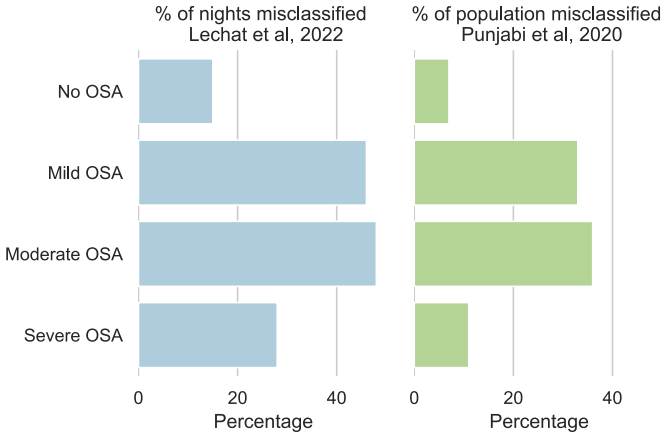

Fig. 1. Obstructive sleep apnoea (OSA) severity category misclassification. Left) Average proportions of night per participant where the OSA severity category is different from the reference OSA severity category. Right) Proportion of participants misclassified compared to the reference category. Adapted from Lechat, Naik [15] and Punjabi, Patil [16].

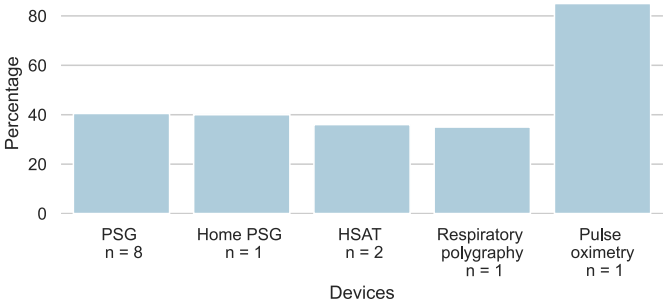

Fig. 2. Percentages of participants with an absolute change in obstructive sleep apnoea (OSA) severity parameter (apnea-hypopnea index [AHI] or oxygen desaturation index [ODI]) over sequential nights >10/hour for different devices. Data from Roeder, Bradicich [70]. N represents the number of studies used in the meta-analysis.

nights are sufficient for an appropriate diagnosis. In Punjabi et al. [16], additional nights of diagnostic testing increased OSA classification performance. For participants that were misclassified as non-OSA using a 1-night diagnostic (20% of the study sample), increasing the number of diagnostic nights improved classification accuracy by 60%. It is possible that the misdiagnosis rate in Punjabi et al. [16] was underestimated given that the "reference" AHI was a composite index based on the three nights of data. Therefore, increased diagnostic confidence is to be expected for a 2-night averaged AHI.

To the best of our knowledge, only 4 studies have investigated night-to-night variability in more than 6 consecutive nights [11,15,53,58,61,66,68,74]. In Fietze, Dingli [74], 35 participants undertook home-based polysomnography sleep studies for 7 consecutive nights. In this study, the ODI was relatively stable across nights. However, the probability of misclassifying a participant on any given night as having normal, mild, or moderate-to-severe OSA was as high as 25%. Furthermore, only 9 participants (26% of the population) remained in the same category throughout all seven recordings. Similar results were obtained in Prasad, Usmani [66], who studied night-to-night variability across 7 consecutive nights in participant with OSA (determined using a baseline polysomnography sleep study). In total, 62% of participants with mild OSA and 24% of participants with moderate-to-severe OSA changed classifications across the 7-night monitoring period. Stoberl, Schwarz [58] examined ODI in 77 participants studied consecutively over 13 nights and found that over 80% of participants showed between-night differences in ODI >10 events per hour and ~78% participants changed sleep apnoea severity categories across the monitoring period. None of these three studies evaluated the number of nights necessary to reduce OSA misdiagnosis probability below a pre-specified level of diagnostic uncertainty.

A study in ~65,000 individuals that recorded sleep and breathing using under-the-mattress sensors over 6 months suggested that increasing the number of monitoring nights (up to 14 days) markedly increased diagnostic confidence [15] (Fig. 3). When using a single-night diagnosis to classify OSA (AHI >15 events/h sleep), the false negative rate (diagnosis of "normal" instead of true OSA) was ~17%. However, using a 14-night period for diagnosis resulted in a low false negative rate of only ~2% compared to a diagnosis based on all available nights. Furthermore, the F1-score (a measure of overall predictive performance, where 1 indicates perfect prediction), was 0.77, 0.83, 0.91, 0.94 for a 1-, 2-,7- and 14- night diagnosis, respectively. These findings suggest that a minimum of 7 nights was required in this study to provide a high confidence estimate of OSA severity. Another recent study suggests that multi-night measurement of OSA severity also provide a much more reliable estimation of health consequences risk (such as hypertension) associated with OSA compared to single night assessment [75]. However, these studies were conducted using a clinically validated under-the-mattress sensor and could not record additional OSA key phenotype characteristics (e.g., hypoxemia, sleep fragmentation, sleep staging, body position) that could potentially help produce a more confident diagnosis using a reduced number of nights. There may also be currently unknown technical reasons that cause higher night-to-night variation with the new under mattress device compared to polysomnography and other sleep study systems.

Collectively, these results support that multi-night monitoring of OSA can provide greater confidence in the diagnosis of OSA and its severity. However, only one study has investigated misdiagnosis probability over an extended (>14 days) recording period, and therefore the ideal number of nights for an accurate diagnosis remains unknown.

3.3. *Predictors of night-to-night variability*

There are several factors that may influence night-to-night variability of OSA. These include body/head position during sleep, non-anatomical OSA endotypes (arousal threshold, loop gain and upper-airway muscle responsiveness), nasal resistance, and behavioural and lifestyle factors (nutrition, physical activity, alcohol, caffeine use, tobacco intake, and medication use) 70–74,76–80. With respect to sleeping positions, a study in 51 participants that measured AHI over 3 consecutive nights using the Watch PAT device concluded that the average variation in nightly AHI of 57% could be partially explained by the amount of time spent in supine sleep, with more supine sleep leading to a higher AHI [49]. A case study of 1 participant undergoing HSAT for 4 consecutive weeks found that the AHI observed during a supine sleeping position (~44 events per hour) was around 10 times higher than during other sleeping positions (~5 events per hours) [81]. Similarly, another study of 25 participants found that the lateral position of the head compared to the trunk was associated with a decrease in AHI in 27% of the sample [80]. In a study of 28 participants (median AHI: 17.2 events/hr), head flexion was also associated with a worsening of OSA with ~13 events/hr increase in AHI, whereas head rotation was associated with a ~11 events/hr decrease in AHI [82]. In another study of 26 participants, variations in OSA severity were correlated with changes in evening leg fluid volume and overnight rostral fluid shift [79].

In addition to postural factors, there have been multiple demographic and sleep factors associated with variable AHI, although the results have been less consistent [65,66]. For example, older age has been associated with a greater likelihood of having a false negative HSAT [22]. Furthermore, many of the in-laboratory studies of night-to-night variability in OSA also reported poorer sleep architecture

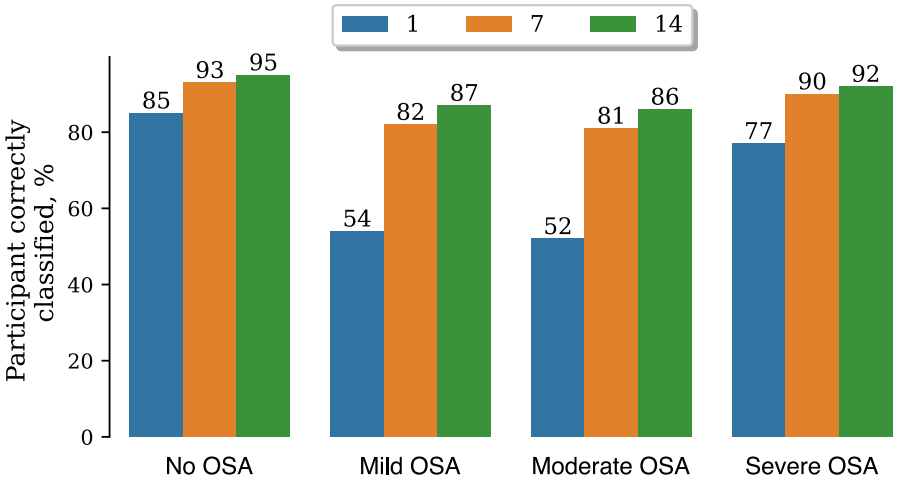

Fig. 3. Percentages of participants classified correctly for a 1- (blue), 7- (orange) and 14- (green) night average apnea-hypopnea index (AHI) compared to reference Obstructive sleep apnoea (OSA) severity category determined on all available nights. Data adapted from Lechat, Naik [15].

on the first night (e.g., reduced total and REM sleep duration) which may also affect OSA severity [63]. Some co-morbid health conditions may also be associated with higher night-to-night variability in OSA severity. For example, patients with heart failure have substantial night-to-night variability in sleep apnea severity markers [83]. Participants with co-morbid insomnia and OSA [84] may also have higher variability than patients with OSA alone, which could explain the higher health burden associated with COMISA compared to OSA [60,85], although the evidence supporting this is currently scarce and requires further investigation.

Multiple studies have also found that OSA variability and misclassification is generally higher in mild compared to more severe cases of OSA [15,16,58,66]. This may be, at least in part, because mild and moderate OSA are more likely to be close to clinical cut-offs used for diagnosis and are therefore more likely to be missclassified. However, it is also possible that OSA is inherently more variable in the mild-to-moderate versus severe severity ranges.

3.4. OSA severity variability as a clinically relevant trait

There is emerging evidence that the degree of night-to-night variation in OSA severity impacts cardiovascular health, including atrial fibrillation. Linz and colleagues [86] simultaneously monitored OSA and atrial fibrillation for a mean of 21 weeks and grouped the AHI values from each night into quartiles for each participant. Compared with the best sleep nights (in their lowest quartiles), nights with the highest AHI (in their highest quartile) conferred a 1.7-fold ($p < 0.001$), 2.3-fold ($p < 0.001$), and 10.2-fold ($p < 0.001$) increased risk of having atrial fibrillation during the next day for at least 5 min, 1 h, and 12 h durations, respectively [86]. These data suggest that even a few nights of elevated AHI may predispose an individual to atrial fibrillation the following day. Another study using an under-mattress sleep sensor and home blood pressure monitor cuff found that variability in OSA severity is associated with hypertension independent of average OSA severity [87].

The intriguing possibility of added risk for individuals with variable OSA is perhaps not surprising, given that variable disease severity for some diseases is associated with worse outcomes compared to “stable” disease severity. For example, blood pressure variability is associated with multiple adverse health outcomes independent of mean blood pressure values, including cardiovascular events, cerebrovascular events, and all-cause mortality [88–91]. Conversely, the impact of short- and long-term variability in OSA severity on important health remains largely unknown and warrants further investigation. Together, these results suggest the need to monitor OSA severity variability together with mean OSA severity for identification of which OSA patients are most at risk of cardiovascular harm.

3.5. Incorporating multi-night measurement in clinical care

Heterogeneity in clinical outcomes observed in trials of treatments for OSA [92–95] has motivated recent efforts towards redefining diagnostic approaches and OSA severity definitions. These efforts have included identification of different endo-phenotypes of OSA [78,96–98] novel markers of OSA severity, such as the hypoxic burden that are more strongly associated with cardiovascular outcomes than the AHI [99,100], and quantifying flow limitation [101] and OSA-related sleep fragmentation [102,103]. While some newer metrics may be amenable to multi-night sleep assessment (e.g., the hypoxic burden), the more invasive measurements needed for detailed OSA physiological endotyping may be too burdensome to administer over more than one occasion per patient. However, recent signal processing and machine learning approaches have shown considerable potential to estimate key OSA endotypes and predict treatment outcomes from standard sleep study recordings [104–107], which may also be feasible using multi-night assessment.

Accordingly, this review highlights that, despite the greater burden of repeated assessments on patients and clinical resources, multi-night monitoring of OSA may be superior in terms of reducing OSA misdiagnosis and better defining health consequences associated with OSA severity compared to single-night OSA assessment. However, these two approaches are not mutually exclusive. Long-term monitoring of OSA severity using simplified technology may be sufficient to diagnose OSA in many cases. More in-depth assessment of hypoxemia, OSA endotypes, REM OSA, comorbid sleep disorders (e.g., insomnia), and sleep fragmentation are likely valuable in more complex manifestations of OSA [60,99,102,108,109]. Therefore, there is a need for appropriately designed randomised-controlled trials to 1) identify OSA patient characteristics that suggest a need for in-depth OSA assessment versus those who may sufficiently benefit from a simplified diagnostic approach (e.g., severe OSA, Fig. 4 left) and 2) test the effectiveness of simplified monitoring of OSA severity and assess the potential benefits of this approach versus current diagnostic practices (Fig. 4, right) including cost effectiveness comparisons. There is also a need for empirical studies to compare different multi-night metrics (AHI, hypoxic burden, endotype), or combinations of thereof, to predict health outcomes and treatment response. Finally, there is also a need to determine which multi-night metrics (average, standard deviation, combination of metrics) are most useful for diagnosis, treatment, and assessment of health outcomes associated with OSA. These considerations could be tested in the trials outlined in Fig. 4.

4. Consumer engagement

To the best of our knowledge, many studies on this topic have not considered patient preference in the diagnostic process. Patient perspectives should be carefully considered in future trials, as there may be financial or personal dis-incentives to seek treatment if the diagnostic process is too burdensome for patients. Consultations with the consumer engagement group at the Flinders Health and Medical Research Institute (FHMRI): Sleep Health (8 members with sleep disorders from around Australia) indicate that consumers are very supportive of this non-invasive, simplified approach. Home based approaches have the potential to reduce wait times and improve diagnostic accuracy, which were expressed as major advantages.

5. Conclusions

There is considerable night-to-night variability in OSA severity in many patients, which can lead to diagnostic misclassification. Misdiagnosis probability based on a single-night sleep study is estimated to be between 20 and 50%, with higher misdiagnosis rates for mild-to-moderate OSA severities closer to widely used clinical diagnostic cut-offs. In addition, high night-to-night variability in AHI may be an important independent predictor of poor health outcomes in OSA. Thus, multi-night, home-based sleep studies facilitated by emerging sleep technologies, used alongside in-laboratory confirmatory studies for complex cases where required, could help to improve diagnostic precision and clinical management (Table 1).

Such a readily available alternative – if successful and when combined with appropriate clinical triage management – has the potential to improve the efficiency, speed (reduce waiting times) and accuracy of OSA diagnosis and severity assessment. Such a simplified diagnostic strategy, if shown to be cost effective, has considerable potential to reduce wait-times and the time to diagnosis, and increase access to care for patients who need it the most. This could reduce the community burden of OSA by reducing daytime sleepiness, motor vehicle accident risk, and potentially cardio-metabolic risks in patients with previously undiagnosed or misdiagnosed OSA.

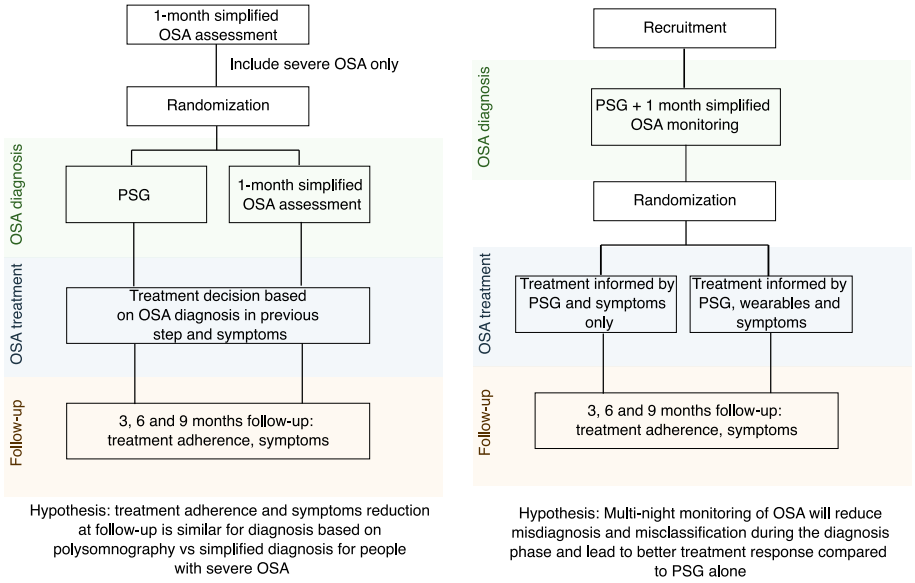

Fig. 4. Concept outline for a trial design to test the potential added benefit of the implementation of simplified monitoring of Obstructive sleep apnoea (OSA) into clinical care.

Table 1
Polysomnography (PSG), home sleep apnoea test (HSAT) and wearables/non-wearables pros and cons for diagnosis and management of obstructive sleep apnoea (OSA). AASM = American Academy of Sleep Medicine.

Device	Monitoring period	Pros	Cons
PSG	1 night	• In-depth assessment of OSA severity (hypoxemia, sleep fragmentation, airflow limitation, potential for endo-phenotyping) • Controlled environment • AASM endorsed	• Expensive • Requires trained technician • High misclassification rates (up to 50%) • Unrealistic environment • Cumbersome for participants • Long waiting times • Variability in manual scoring • Inefficient – many signals collected but low information is derived
HSAT	1 to 3 nights	• Can be done at home • Shown to be as reliable as PSG	• Signal quality may vary • High misclassification rates • Variability in manual scoring
Wearables and non-wearables	>3 nights* *Ideal monitoring time should be determined empirically and consider patient preference	• Multi-night assessment of OSA severity reduces misclassification. • Potential to assess treatment adherence and response. • May provide cheap alternative diagnosis pathway for a subgroup of the population. • Night-to-night variability may be an important marker of OSA that is currently neglected using PSG or HSAT • Devices can be developed and used for targeted measurement (rather than a measure all) – e.g. specific device can be developed to assess snoring. • Automated algorithms are not prone to inter-scorer variability	• Clinical validation is challenging • No study has shown benefits compared/in addition to traditional care • Device accuracy may differ for some population groups

Practice points

- Single-night sleep studies are estimated to misdiagnose and misclassify obstructive sleep apnoea severity in 20–50% of patients due to high night-night variability in the apnea hypopnea index.
- Patients with high night-to-night variability in OSA severity may have greater risk of poorer health outcomes such as hypertension compared to patients with low variability, highlighting the need for multi-night measurement.
- Multi-night assessment of OSA severity using novel, inexpensive and non-invasive technologies may allow for a more reliable estimation of OSA severity and the ability to quantify night-to-night variability as a potentially important clinical phenotype.
- There is a lack of research to assess the cost-effectiveness and potential added benefits of wearable and nearable technologies in clinical care

Research agenda

- With the recent advance of reliable and validated metrics to accurately estimate OSA severity over multiple nights in the home, appropriately designed, randomised-controlled trials are now urgently required to:
  - o Identify OSA patient characteristics that suggest a need for in-depth OSA assessment versus those who may sufficiently benefit from a simplified diagnostic approach and
  - o Test the effectiveness of simplified monitoring of OSA severity versus current diagnostic practices including cost effectiveness comparisons.
- Given the developing evidence of an association between night-to-night variability of OSA severity and health outcomes, there is a need to investigate:
  - o Patient characteristics and OSA endotypes/phenotypes associated with higher night-to-night variability of OSA. This may help reduce diagnostic misclassification and identify treatments more suitable for patients with high night-to-night variability in OSA severity and,
  - o Identify how different characteristics of OSA (hypoxia, sleep fragmentation, flow limitation, endotypes) vary night-to-night, and establish which multi-night metrics (or combination of metrics) best predict health outcomes and treatment response.

Declaration of competing interest

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