REVIEW ARTICLE

Recent Technological Advancements in Sleep Medicine: A Narrative Review

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Abstract

Sleep medicine is a specialty historically rooted in the rapid adoption of technological advancements. Recently, there has been an acceleration in the development of newer technologies related to sleep health. While most of these technologies are meant for consumer use, a few have been found robust enough for clinical applications. The artificial intelligence revolution and the COVID-19 pandemic have been two significant drivers for technological innovation that can simplify sleep disorders management and permit remote healthcare delivery. This review discusses the issues related to artificial intelligence, newer consumer and clinical sleep technologies, and their applications in sleep medicine.

Keywords: Artificial intelligence, Consumer technology, Peripheral arterial tonometry, Photoplethysmography, Sleep medicine.

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Introduction

Sleep medicine is unique among medical specialties in its dependence on technology for diagnosis and treatment. The advancement of digital technology and the advent of computers has revolutionized the diagnosis and treatment of sleep-disordered breathing (SDB). Initially devised as a manually scored pen and paper test, the polysomnogram quickly underwent digital transformation. In this process, scoring became more manageable, and the wealth of information derived from the polysomnogram amplified manifold. Similarly, treatment of SDB with positive airway pressure (PAP) therapy has advanced remarkably in the past few decades with new device modes using complex algorithms, such as auto-PAP, adaptive servo-ventilation (ASV), and volume-assure pressure support (VAPS). Additionally, downloads from PAP devices have become commonplace to monitor adherence, efficacy, and leaks during treatment.

Artificial intelligence (AI) is advancing at a dizzying pace with the ongoing fourth industrial revolution. Sleep medicine is set to undergo transformative changes in diagnosis and treatment with the adoption of AI.[1] There is already a mushrooming of medical and consumer technologies devoted to sleep health. The COVID-19 pandemic and the push for telehealth have provided further impetus for developing these newer technologies, which often generate massive amounts of health information and open possibilities for remote delivery of patient care.[2] This article briefly delves into the recent advances in clinical and consumer technologies and artificial intelligence in sleep medicine. We discuss how these developments are changing the management of sleep disorders.

Artificial Intelligence in Sleep Medicine

The term AI refers to the ability of machines to perform complex tasks that mimic human intelligence.[1] Machine learning (ML) is a type of AI wherein the machine develops statistical algorithms to perform tasks or processes after being exposed to training datasets. These datasets provide known inputs and outputs (supervised learning) or unknown inputs and outputs (unsupervised learning). Deep learning (DL) is a subtype of ML using deep neural networks with multiple layers to learn features from data and perform complex tasks.

Today, AI is gaining diverse applications in medicine. Several newer medical devices have AI capabilities. Additionally, AI-based software may be used for medical applications without being part of dedicated hardware equipment (e.g., mobile applications). In sleep medicine, one of the first applications of AI/ML/DL has been to support scoring sleep and respiratory events in polysomnography records.[1] Not only does AI/ML/DL have the potential to improve the speed and accuracy of polysomnography scoring, but it may reveal newer insights into sleep scoring and sleep apnea phenotypes.[3] Recently introduced home sleep apnea testing (HSAT) devices have also used proprietary AI/ML/DL-based algorithms for sleep and respiratory event scoring. Another potential use of AI/ML/DL is in PAP-usage monitoring software that can provide feedback to users and troubleshoot potential problems with therapy. When applied to large amounts of health data being generated by healthcare providers and patients, AI may reveal newer insights into the role of sleep on public health and the association of sleep with other medical conditions.

However, there are potential limitations associated with AI/ML/DL. Since AI/ML/DL models are trained on datasets, they are prone

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to bias if the dataset is too restrictive. Ideally, a large and diverse dataset would yield a more robust model. Furthermore, validation of the model on a population different from the training dataset is necessary to ensure reliable performance. Information about the characteristics of the population (e.g., age, sex, ethnicity, health status, etc.) on which the AI/ML/DL model has been trained and validated should be available in the public domain to help ensure that specific AI-enabled technologies are applied on the correct population (e.g., children vs adults, healthy vs sleep apneic). There are also ethical and legal considerations regarding the use of AI/ML/DL in medicine.[4] These are discussed in the next section on newer technologies.

Newer Clinical and Consumer Technologies

The number of newer technologies, including wearables, nearables, and mobile applications, has rapidly increased over the past few years. Many of these technologies employ AI/ML/DL models. While a large proportion of these are meant for consumer use, a few have been tested and found robust for clinical use. Additionally, many of these technologies are deemed hybrid or transitional.[5] Hybrid technologies may have one or more sensors of clinical grade combined with other sensors in a consumer product. Transitional technologies are those that were introduced for consumer use but are in the process of being repurposed for clinical use.

Herein, it is essential to understand the distinction between consumer and clinical technologies (Table 1). In the United States of America, the Food and Drug Administration (FDA) is responsible for classifying medical devices.[6] Accordingly, devices can be class I (low risk), II (moderate risk), or III (high risk). Class I devices are usually consumer devices meant for general wellness and may optionally be "FDA registered." Class II devices can be used for clinical indications on prescription and generally require to be "FDA cleared" before marketing, wherein the device is shown to be equivalent to a predicate device in purpose and technology. An alternative pathway for novel technologies with no predicate similar devices is to achieve an "FDA granted" status. Class III devices require clinical efficacy and safety studies for acquiring a premarketing "FDA approval." The FDA status of a given medical device can be determined on the Devices@FDA database on the FDA website (URL: https://www.accessdata.fda.gov/scripts/cdrh/devicesatfda/index.cfm).

Even though many novel technologies are consumer-oriented, clinicians must have the resources to evaluate these technologies. Patients frequently bring data from their wearable (e.g., smartwatches, rings, headbands, etc.) or nearable devices (e.g., special mattresses or bedside devices) or mobile applications for tracking sleep. To evaluate these technologies, clinicians need to determine the following basic details about the device:[5]

- The FDA status
- The claimed capabilities of the device, including the definitions of the sleep-related outcomes (note: different devices might define sleep and related parameters differently; for example, the sleep scoring may be as sleep vs wake, deep sleep vs light sleep vs wake, or as R vs N3 vs N2 vs N1 vs wake)
- Sensors used and their technical details (e.g., photoplethysmography, three-dimensional accelerometers, etc.)
- The use of AI/ML/DL and the training/validation populations for the same
- Any clinical studies of efficacy or safety for the claimed capabilities
- How the data are stored and who can access it (including issues relating to data privacy and confidentiality)

As the pace at which newer technologies are emerging is rapid, it is a daunting task for a clinician to remain updated regarding these details. Hence, the American Academy of Sleep Medicine (AASM) has created a #SleepTechnology resource for its members on their website, providing these details for novel wearables, nearables, applications, and mobile settings.

Some significant concerns with newer sleep technologies, including AI ones, relate to ethical or legal issues.[4] Large volumes of data generated by these technologies are stored on cloud databases. The ownership, accessibility, and security of the data are significant concerns, especially because healthcare data are subject to confidentiality and are common targets for hackers. Finally, AI-based technologies that provide advice or feedback to users need to be examined from an ethical standpoint, as an AI system may not be capable of assuming responsibility for the consequences of such advice.

Table 1: Differences between clinical and consumer sleep technologies

	Clinical technologies	*Consumer technologies*
Purpose	Diagnosis and/or management of sleep disorders	General wellness
FDA status	Require FDA approval, clearance or granted before marketing	May be FDA registered, not mandatory for marketing
Availability	Usually on prescription of physician	Freely available in the market
Research	Usually require validation studies or clinical trials	Do not require validation studies or clinical trials

Impact of Recent Advances on the Management of Sleep Disorders

This section will discuss the application of newer technologies in managing sleep disorders.

Diagnosis of Sleep Disorders

Over the past few years, new wearable home sleep apnea testing (HSAT) devices have been marketed, employing newer technologies highlighted above. Some examples include the WatchPAT system (Itamar Medical) and the NightOwl (ResMed). These devices heavily rely on photoplethysmography and three-dimensional accelerometers, often placed on fingers or wrists. Photoplethysmography is a technique wherein a light source of prespecified wavelengths is directed toward the vascular tissue, and the reflected or transmitted light is captured on a photosensor.[7] Accordingly, the proportion of absorbed light can be calculated. The photoplethysmography wave has two components: the AC component represents pulsatile arterial blood flow, and the DC component represents the reflected/transmitted light from the tissue. However, even the DC component has low volume fluctuations due to respiratory variations in venous and capillary blood content of the tissues.

Furthermore, the absorption of light of different wavelengths differs according to the oxygenation status of blood (i.e., deoxygenated hemoglobin absorbs more red light while oxygenated blood absorbs more infrared light). Hence, the heart

rate, respiratory rate, heart rate variability, and blood oxygen saturation (SpO_2) can be assessed. Additionally, AI/ML/DL has been employed to develop proprietary algorithms based on the peripheral arterial tone determined by photoplethysmography and the actigraphy signal from the accelerometers to detect sleep, sleep stages, and respiratory events.[7] Clinical studies have shown a reasonable correlation in detecting obstructive sleep apnea (OSA) between the WatchPAT/NightOwl systems and in-lab polysomnography.[8,9]

Treatment of Sleep Disorders and Monitoring Response

There has been a growing recognition that treating OSA should not follow a one-size-fits-all approach. Over the past few years, there has been considerable cynicism regarding the supremacy of the apnea-hypopnea index (AHI) as the sole diagnostic marker of OSA, fueled by the description of various OSA phenotypes and endotypes.[10] Despite this shift in thinking, there has not been much change in the management of OSA yet. In this regard, incorporating AI/ML/DL approaches to traditional in-lab polysomnography and HSAT systems may reveal new avenues for phenotyping and endotyping OSA in the future for directing personalized care.[3] For instance, it has been hypothesized that a low arousal threshold may respond to the combination of low-dose sedatives and PAP therapy. In contrast, a mildly collapsible upper airway may respond to hypoglossal nerve stimulation. More research is needed before such approaches become adopted in clinical practice.

Meanwhile, telemedicine and remote monitoring of SDB patients have gained momentum, especially during the COVID-19 pandemic. Digital technologies that measure PAP adherence, efficacy, and leaks and transmit the information on cloud databases for clinician access between in-patient visits can prompt remote interventions that may improve patient outcomes.[11] Artificial intelligent-enabled software can inform patients if their PAP usage is suboptimal and provide feedback for improvement. However, concerns exist here as well. Not only is the cloud data subject to privacy breaches but remotely controlled devices like PAP machines and pacemakers can be potentially manipulated by hackers. Hence, the development of these clinical interventions needs to be done alongside foolproof cybersecurity measures.

Conclusion

Sleep medicine is a specialty historically rooted in the rapid adoption of technological advances. Hence, the AI revolution promises to usher in a glorious new era of improved diagnosis and patient care for sleep disorders. On the one hand, diagnosis is likely to become more straightforward using sophisticated and accurate HSAT devices. On the other hand, treatment may become more personalized with better phenotyping and endotyping of SDB. Already, PAP data downloads have shown the promise of technology in treatment monitoring and remote healthcare delivery. However, researchers must rapidly validate these technologies to match their development. Furthermore, ethical and legal concerns, including data privacy and cybersecurity, will be important considerations.

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