Telemedicine in Sleep-Disordered Breathing

Expanding the Horizons

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KEYWORDS

- Teliagnosis • Telemonitoring • CPAP • Compliance • Telecounseling • Therapy reinforcement
- Behavior • Patient engagement

KEY POINTS

- Telemedicine has applications in all stages of the diagnosis, treatment, and follow-up of patients with sleep-disordered breathing. Diagnostic applications include telemonitored polysomnography, communication of test results and therapeutic options, and remote continuous positive airway pressure titration.
- Online compliance monitoring results in similar and in some cases improved compliance when compared with traditional face-to-face evaluations. The impact of telemedicine on compliance depends on the preexisting organization of standard care in the routine setting.
- Combining theory-driven behavioral approaches with telemedicine technology could hold the answer to increasing real-world adherence rates.
- Targeted troubleshooting and support based on individual patient data, web-, and/or app-based teaching, and combinations via a smartphone app or coaching website is feasible.
- Telemedicine is likely cost-effective but requires better evidence.

INTRODUCTION

Sleep medicine services have already undergone several disruptive changes related to new diagnostic and treatment technologies for the management of obstructive sleep apnea (OSA).^{1,2} Telemedicine, the remote delivery of care with the use of technology, is an emerging field in the twenty-first century and has currently received widespread acceptance among diverse medical specialties across the globe thanks to the rapid proliferation of mobile and home-based devices.³ Many sleep disorders are chronic conditions and require continuous treatment and monitoring of therapy success.⁴ Telemedicine provides flexibility for using e-care in none, some, or many of the steps in OSA evaluation, diagnosis, and management.

Telemedicine-ready continuous positive airway pressure (CPAP) devices supporting the

transmission of information on use time (hours per night), the apnea-hypopnea index (AHI), and leakage are available. The gathered data are sent via wireless networks to a secure server on the Internet, where it can be retrieved by the attending physician or sleep center. This opens new teleopportunities and e-opportunities for OSA care to replace, supplement, provide additional interim care and education, or improve practice workflows and costs for each of the different OSA treatments. Chronic management strategies, and big data deep learning applications may also be realized. With this, it is possible to serve patients better, to address problems early, and to inform on adverse side effects as well. In the end, this improves patient satisfaction and treatment adherence.

A recent position paper from the American Academy of Sleep Medicine related to the use of telemedicine in sleep disorders stressed that “the

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practice of telemedicine should aim to promote a care model in which sleep specialists, patients, primary care providers, and other members of the healthcare team aim to improve the value of healthcare delivery in a coordinated fashion.”⁵

Studies to date have used heterogeneous strategies and reported conflicting results.^{6–10} Telehealth applications may be inserted in 1 or more of the workflow steps for diagnosis pathways, evaluation pathways, CPAP and non-CPAP treatments, and long-term follow-up. The current telemedicine applications are found to a smaller extent in the diagnostic procedures and to a much greater extent in the monitoring of therapy compliance for sleep apnea treatment. In this review, we will provide an overview of current practices, with the recent scientific progresses in telemonitoring for sleep-disordered breathing and their potential clinical applications for diagnosis and therapy, with emphasis on promising approaches to optimize adaptation and compliance:

- Diagnostic telemedicine applications: telerriage, telemonitored polysomnography (telesupervision, teletransmission), telecommunication of test results and treatment options
- Telemaskfitting and teleteaching (OSA and CPAP education)
- Tele CPAP titration
- Telemonitoring and problem solving:
 - Usual care
 - Remote monitoring CPAP therapy
 - Filter settings and fine-tuning of CPAP devices
- Telecounseling and therapy reinforcement: by combining and integrating the most promising elements of both psychoeducational interventions and technological innovations (active calls, digitized human speech, web-based access for patients to own CPAP data, automated messaging, and patient engagement tools)
- Telemanagement of comorbidities in OSA
- Telemedicine in particular populations
- Patient satisfaction and economic aspects (staff time, equipment, access to health care, addition of artificial intelligence, reimbursement, need for cost-benefit studies) will be highlighted.
- Changing paradigms and expanding horizons will be discussed.

Finally, also concerns related to telemedicine use and the remaining barriers and problems related to telemedicine implementation will also be addressed. In our opinion, all these telemedicine applications

should be simple, with easy connectivity to external caregivers, achieving adequate training of nurses and physicians and should be directed to a specific group of patients.

DIAGNOSTIC TELEMEDICINE APPLICATIONS

Telerriage of Patients with Suspicion of Obstructive Sleep Apnea

Patients with OSA enter sleep center workflows through different pathways. Before testing and diagnosis, patients initially may be evaluated by the general physician, by somnologists or other specialists, or eventually by self-referral.^{5,11,12} Proper identification for possible comorbid apnea conditions and inherent risks during the assessment and before testing is important in the choice of any OSA workflow path.¹³ Telemedicine enables the documentation of baseline and follow-up OSA symptoms, sleepiness, quality of life, blood pressure, body mass index, comorbid disorders and traffic accident assessment, by making use of sleep medicine questionnaires that may be completed by patients through E-health patient portals, OSA risk assessment software or by phone.¹⁴ Apart from the clinical guidelines for OSA test type, deep learning and artificial intelligence models using phenotyping, E-health record data, and other consumer or medical sensor devices and applications may provide insight for OSA risk assessment and test prioritization, or selection of tailored treatment paths.^{15–19}

A thorough physical examination is not always possible when the patient is at home. In the assessment for possible OSA, tonsils can be difficult to estimate in size in 2-dimensional viewing. The clearest view of the oropharynx can be obtained if the patient or partner takes a photo on the smartphone and texts or emails it to the clinician. Also, the video from the camera on the back-side of the smartphone may be more likely to provide a clearer view of the oropharynx than the selfie view. Other important parts of the physical examination that are missing on virtual visits are overall appearance, evaluation of nasal turbinates, molar occlusion, heart, lungs, and eventually blood pressure. This difficulty can be overcome by creating special telemedicine hubs that include tools and equipment, including an intraoral camera, and a medical assistant who facilitates the transmission of this information.²⁰ Finally, coordination of care is more straightforward at the physical checkout counter, where appointments can be scheduled and paperwork can be printed and provided directly to the patient.

Telediagnosis (Teletransmission, Telesupervision)

Telemonitored polysomnography (PSG) has the premise to overcome the disadvantages of home recordings and could provide an organizational solution to the overloading of specialized sleep centers. Telemedicine can be used in the context of sleep studies for 2 purposes.²¹ The first is to facilitate swift transmission of data of home PSG for further analysis. The second purpose for the application of telemedicine for sleep recording has been to ensure the quality of unattended PSG, by intermittent or continuous remote supervision of recording. Dedicated technicians regularly verify, at a distance, the quality of the PSG recordings by means of periodic access to the PSG monitoring device. From their telemonitoring control panel, they are able to insert comments in the recording, adjust transducer gain and, in the event of an artifact or an undesirable accident (disconnected wires, misplaced equipment), inform the patient by telephone.²² However, evidence on the efficacy of telemonitored (P)SG is weak. Gagnadoux and colleagues²³ reported that PSG performed in a local hospital and telemonitored by a sleep laboratory was clearly superior to unattended home PSG. Kristo and colleagues²⁴ proposed a telemedicine protocol for the online transfer of PSGs from a remote site to a centralized sleep laboratory, that had practitioners for diagnosis, which provided a cost-saving approach for the diagnosis of OSA. Their system was based on the transmission of data using an Internet FTP protocol, which is the conventional system for file transfer. Kayyali and colleagues²⁵ presented a new compact telemetry-based sleep monitor (PSG@Home), consisting of a 14-channel wearable wireless monitor and a cell phone-based Gateway to transfer data, including video, in real time from the patient's home to a remote sleep center. The monitor can easily be worn and transported, and it offers reliable recordings.²⁵ The receiver is a separate unit connected with the back of the display. Internal Bluetooth receivers, usually included in laptops, can also be used instead of a dedicated external Bluetooth receiver. A major problem encountered with home sleep studies is the potential loss of data in about 4.7% to 20.0% of the cases, which results in lower than expected cost savings.²⁶ Using Sleepbox technology (Medatec, Brussels, Belgium), a wireless system able to communicate with the polysomnograph and with Internet through a WiFi/3G interface, and communicating via Skype, the authors were able to deliver recordings with excellent quality in 90% of the cases.²⁷ This opens an

interesting perspective to decrease the failure rate of home sleep studies, although still problematic, and some technical aspects need to be improved. Pelletier-Fleury and colleagues²⁸ comparatively evaluated the cost and effectiveness of PSG telemonitoring and PSG by conventional unsupervised home monitoring, and demonstrated that remote telemonitoring made the procedure clearly superior from a technical point of view and was preferred by the patients. They obtained a cost of \$US244 for PSG telemonitoring, whereas the PSG with conventional unsupervised home monitoring was \$US153. The health care infrastructure savings have to be taken into account as well. If we add up the working days that the patients did not lose and the roundtrip travel costs they avoided, we could estimate that the real cost would be similar or lower than that of conventional PSG.²⁹ Placement of polygraphy was performed by the local nursing staff, under remote supervision from a central sleep laboratory, in patients likely to suffer from OSA. Continuous video monitoring via a webcam was also included.²⁹ Masa and colleagues³⁰ compared the costs made between device transportation and telematic transmission of data, with comparable results. Having devices moved by a transportation company or sent telematically as raw data proved cost effective and equally beneficial. Borsini and colleagues³¹ from Buenos Aires performed polygraphy at home, but fitted by nonexpert technicians. Raw data were sent by e-mail to the sleep center the following day. The failure rate was 4%, and 12% needed an additional in-laboratory PSG.

These positive results can allow health care providers to enhance accessibility to sleep tests in large countries with few expert sleep centers and for patients who live a long way from the hospital or those with limited mobility.^{30,31} Fields and colleagues³² demonstrated the feasibility of a comprehensive, telemedicine-based OSA evaluation and management pathway in comparison with a more traditional, in-person care model. They combined video consultation for intake with home sleep testing using a type 3 portable monitor with remote download, and autoCPAP titration with wireless modem technology. Patient satisfaction, CPAP adherence, and compliance and improvement in quality of life was similar in both groups.

Although not applied routinely in current practice, these studies have confirmed the feasibility and the potential interest in telemonitored sleep studies. Moreover, this approach to diagnosis is considered to be more convenient for the patient than staying at a clinic overnight. The widespread use of telediagnosis is slowed down by the costs

and the complexity of the technical aspects, and also requires a change to the current model of care delivery, because as it will become patient and home centered, rather than hospital centered. Such disruptive changes are going to take time to be effectuated.

New Simplified Diagnostic Telemedicine Applications

In clinical practice, the use of PSG is a standard procedure to assess sleep-disordered breathing. However, PSG is not suitable for chronic monitoring in the home environment and not very convenient to the patient. New telemedicine applications have become available using a home appliance as a precautionary measure for monitoring snoring and OSA. Seo and colleagues³³ developed a nonintrusive health monitoring home system to monitor patients' ECG results, weight, motor activity, and snoring. Choi and colleagues³⁴ proposed a ubiquitous health monitoring system in a bedroom, which monitors the electrocardiogram, body movements, and snoring with nonconscious sensors. Böhning and colleagues³⁵ evaluated the feasibility of night-time pulse oximetry telemedicine to screen patients at risk for OSA. They concluded the technique seemed to be suitable and cost effective, with high sensitivity and specificity. This approach can be applied in a telemedicine referral network for early diagnosis of OSA, where the reading could be transmitted to the relevant sleep laboratory, examined, and the results returned to the referring physician.³⁶

Of note, several consumer device technologies with pulse oximetry, heart rate variability, actigraphy and deep learning algorithms are undergoing US Food and Drug Administration evaluation as home sleep apnea testing devices.³⁷

Devices available today offer a wireless transmission of recording modules to the main body unit worn at the chest (by Blue-tooth technology), also called body area network.³⁸ In some cases, a Bluetooth application can be used to send data to a smartphone or a tablet for online continuous monitoring. Also, the storage of data is wireless by making use of cloud-based storing.⁴

Telecommunication of Test Results and Treatment Options

In line with OSA best practice and quality measure guidelines, the communication of the test results and treatment options with the patient may be done at face-to-face visits or using telemedicine tools such as videoconferencing, teleconferencing, and e-health portal messaging.³² In Spain, Coma-del-Corral and colleagues²⁹ applied

teleconsultation in patients with confirmed OSA. After a telemonitored polygraphy, patients were randomised to receive either a teleconsultation or a face-to-face consultation to receive the results of their sleep study. The teleconsultation was organized via video conferencing. In those patients that finally were treated with CPAP, adherence was not different between the groups: 85% for the face-to-face consultation and 75% for the teleconsultation group. In many telehealth services, there is considerable variation in who communicates the test results to patients, among them somnologists or other specialists, nurses, physician assistants, sleep laboratory technicians, respiratory therapists, noninvasive ventilation therapists, or other trained staff.^{5,19,32,39} The impact of communicating test results cannot enough be emphasized. When patients view results of their diagnostic study with an explanation of the frequency and duration of respiratory events, it results in increased compliance of 0.7 to 1.2 hours per night on average.^{40–42} Clinicians can show raw data and trends from the PSG virtually by the share screen feature to visually explain the extent and severity of the sleep-disordered breathing.

TELETHERAPY

Tele-Mask Fitting and Teleteaching (Obstructive Sleep Apnea and Continuous Positive Airway Pressure)

In standard care, CPAP setup and teaching is offered by trained sleep technicians and respiratory therapists, which is recognized to be labor intensive, but critical for final compliance. Switching to video CPAP setups and remote education may offer decreased labor time while maintaining improved or equivalent CPAP compliance and satisfaction.⁵ Facial recognition software, application of mask sizers, mask fit packs and artificial intelligence analysis of mask fitting selection phenotypes may support remote CPAP mask selection and setup options.⁴³ Although early educational interventions before CPAP initiation are strongly recommended, the effect of tele-education alone on overall compliance does not seem robust, which could be explained by confounding factors such as the variability of the initial and following tele-education deliveries, and easy availability of Internet-based OSA and CPAP educational resources for patients with OSA.⁴⁴ Different authors found improved compliance for patients given Web access to their data and companion educational resources.^{45–47} Smith and colleagues⁴⁸ tested a teleconferencing approach in which a nurse visually assessed mask fit and

patients' CPAP procedures and provided counseling and reinforcement to patients who were trying CPAP again after an initial 3-month period of poor compliance. Although the patient education materials supplied during the initial period did not impact adherence rates, the nurse teleconferencing sessions during the second trial period substantially improved the adherence of the intervention group (9 of 10 patients vs 4 of 9 in the placebo intervention group), suggesting that intensity of one-on-one counseling and feedback by a care provider is a relevant variable.⁴⁸ Isetta and colleagues⁴⁹ performed a randomized controlled trial (RCT) in which 20 patients with OSA received standard face-to-face training, and another 20 received the CPAP training via videoconference. Patients demonstrated comparable knowledge about OSA and CPAP therapy, while performance of practical skills (mask and headgear placement, leak avoidance) and knowledge related to OSA was also similar between the 2 groups (94% correct answers in the videoconference groups vs 92%).⁴⁹ In another study of the same group in 139 patients with OSA, similar levels of CPAP compliance, and improved daytime sleepiness, quality of life, side effects and degree of satisfaction was found in a telemedicine-based CPAP follow-up strategy (televisits via video conference based on Skype, e-mail, web tool support) compared with face-to-face management.⁵⁰ Interestingly, the telemedicine group made more extra visits than the face-to-face group, but most of them were not OSA related.

Tele Continuous Positive Airway Pressure Titration

An exploratory study was set up to perform real-time titration of domiciliary CPAP.⁵¹ The novelty of this approach is that a telemetry unit is connected to a commercially available CPAP device to allow a low-cost, 2-way communication channel in real time between the sleep laboratory technician and the CPAP device in the patient's home. The approach requires no special telemedicine approach, nor does it require the patient's active cooperation or any kind of communication infrastructure (computer or the Internet) in the patient's home. This interesting exploratory study allowed sleep technicians to avoid potential failures of automatic positive airway pressure (APAP) trials at home. Unfortunately, no larger scale trials have been performed. However, in times of home-APAP titration, it can be wondered whether it is really necessary to obtain a remote real-time control of titration. In contrast, a routine visit to the hospital shortly after home APAP titration to

check the CPAP device data can be avoided with a remote-attended titration strategy. A barrier to this approach could be related to the contraindications rather than to technical aspects. In our local experience, the proportion of patients who can benefit from home APAP titration is less than 40% (unpublished data). The presence of comorbidities (neuropsychiatric, cardiorespiratory comorbidities and comorbid insomnia and morbid obesity) also restricts access to this pathway.⁵² Nevertheless, it permits flexibility in resetting the therapy remotely through online pressure adjustments as clinically needed.^{52–54}

Telemonitoring of Continuous Positive Airway Pressure Compliance and Adherence and Problem Solving

Usual care (or standard care)

Because CPAP is a self-administered treatment, its efficacy is critically dependent on the patient's willingness to use the device and apply the nasal mask during sleep, regardless of how well a CPAP machine corrects apnea. In this context, the term adherence is used to describe continued use of the machine (uptake), and compliance expresses the use of CPAP for a certain amount of time.⁵⁵ Unfortunately, these terms are often inadequately used and mutually exchanged. A user is defined as a patient that uses his device for more than 4 hours per night. Commonly used definitions of adequate compliance are use of more than 4 hours per night for 70% of days or more than 4 hours per night for more than 5 days per week.^{56,57}

Early compliance (at 1 week or 1 month) is associated with better compliance at 6 months, indicating that early interventions and support should be offered to patients.⁵⁸

Different studies have shown that the rates of CPAP use are between 30% and 60%. Of importance, patients who become nonadherent in the first days of CPAP treatment generally remain nonadherent.⁵⁹ Without optimal CPAP use, patients will fail to achieve the full cardiovascular and symptomatic benefits of therapy. Hence, compliance for CPAP should be regarded as the main determinant for success.⁵⁵ Usually, the patient is seen by a qualified sleep professional to assess CPAP use (hours of use and hours of application), to check the machine settings, and to ensure the interface (mask, pillows, and so forth) is in good condition. Short-term and long-term follow-up are crucial to adherence and compliance, but monitoring efficacy is also critical to adherence, compliance, and successful therapy. In one study, compliance monitoring, including consistent follow-up, troubleshooting, and feedback to both

patients and physicians, achieved good CPAP compliance rates (>4 hours per night) of more than 80% over 6 months.⁶⁰ In contrast, close follow-up has not been consistently shown to improve compliance, but is worth doing.⁴⁹ Even more effective is to establish adherence and compliance patterns early in treatment initiation, which can help to resolve problems in a timely manner and is essential in the effort to establish a pattern of treatment adherence and good compliance.⁶¹ Intervention early in therapy may improve the patient's early response to CPAP therapy and increase the likelihood that the patient will become a regular and compliant user, thereby enhancing clinical outcome. CPAP follow-up appointments vary from 3 months to yearly, according to physician preferences and availability of resources, without check-ups between follow-up visits. For those patients who are doing well with their current therapy, the annual compliance visit may deliver little value because many visits are not associated with any meaningful changes in management.⁶² This model results in lost time at work for patients, decreased productivity for their employers, and less space in a busy clinician's agenda to manage more complex patients.^{29,50,63} Finally, it can be frustrating for patients and clinicians when the patient is seen in office yet forgets to bring their problematic mask, tubing, or machine.

Rationale for improving compliance

The challenge with CPAP therapy is to obtain adequate adherence and compliance, usually defined as use of CPAP during at least 4 hours per night and for more than 70% of the nights.⁶⁴ This threshold is somewhat arbitrary and has been debated because a dose-response relationship between PAP use and clinical outcomes in OSA has been demonstrated. However, there is general acknowledgment that more is better with respect to CPAP use. A systematic review of 66 clinical trials and cohort studies published between 1994 and 2015 found a weighted average compliance of 4.5 hours per night, with no meaningful improvement in compliance rates over the 2 decades of data available since objective CPAP monitoring was introduced.⁶⁵ The literature to date suggests a dose-response relationship between CPAP use and a range of outcomes, including sleepiness, functional status, and blood pressure. Weaver and colleagues⁶⁴ could demonstrate that when using the Functional Outcomes of Sleep Questionnaire, a greater improvement in memory was obtained when CPAP was used more than 6 hours per night in comparison with less than 2 hours. In a Spanish study, Barbé and

colleagues⁶⁶ demonstrated in a cohort of 359 patients with OSA that nightly use longer than 5.65 hours achieved better blood pressure and sleepiness reduction. Gasa and colleagues⁶⁷ reported that the prevalence of residual excessive sleepiness is significantly lower in individuals using CPAP more than 6 hours per night compared with those who use the device less than 4 hours per night (8.7% vs 18.5%). A recent randomized study in a cohort of 3100 CPAP-treated patients, randomized in intensive versus standard interventions, also confirmed the positive effect of a greater CPAP use (6.9 vs 5.2 hours per night) on cardiovascular outcomes, indicating that a regular 5 to 6 hours of use per night is required.⁶⁸ In a recent Cochrane Database Systematic Review that pooled data from 30 low-to-moderate quality studies it was reported that supportive, educational, and behavioral therapy increases compliance by a respective amount of 50, 35, and 104 minutes per night, resulting in a greater proportion of patients using CPAP for more than 4 hours per night.⁶⁹ A meta-analysis of 12 trials (572 patients) concluded that each 1-hour improvement in CPAP compliance was associated with a reduction in mean blood pressure of 1.4 mm Hg.⁷⁰ Bratton and colleagues⁷¹ showed that a 1-hour per night increase in mean CPAP use was associated with an additional decrease in the systolic blood pressure of 1.5 mm Hg and an additional reduction in diastolic blood pressure of 0.9 mm Hg. CPAP compliance is usually defined as simply hours per night rather than as a proportion of total sleep time, which is usually not measured.⁷² Therefore, it is unclear as to whether short sleep duration (eg, 4 h) with 100% CPAP compliance would lead to greater impairment than longer sleep duration (eg, 8 h) with 50% CPAP compliance, even though the CPAP use is identical in both instances. Finally, suboptimal CPAP use has prevented a thorough understanding of important trials designed to clarify the impact of OSA on cardiovascular risk and the role of CPAP in mitigating that risk.^{73,74}

(Cloud-based) remote compliance monitoring: Technical aspects

Many CPAP devices have an integrated digital storage to record patient use data, which allows to download previously recorded data.^{10,48,60,75} It allows recording with little subject interference under normal and experimental conditions.⁴ CPAP devices are now equipped with simple global system for mobile communication modules to transmit exactly these use and aggregated diagnostic data to medical service providers. Patients can transmit CPAP data on a daily basis into a

database (eg, the Encore Anywhere database, Philips; ResTraxx database, ResMed), where data extraction takes place. Because PAP manufacturers use proprietary cloud-based data platforms and use different algorithms for respiratory event detection, this can be a potential non-patient-related barrier to telemedicine adoption (**Table 1**). As a result, health care professionals may require access to several different databases and because not all patients use the same brand of CPAP devices, technical standards are needed to enable aggregation into one's health care record.⁴⁷ In the past, a universal telemonitoring unit was available (T4P, SRETT Medical, France), which offered the possibility to be added to the majority of CPAP devices, and to be switched from one patient to another for a determined duration, according to the patient needs.⁷⁶ This system also made use of a telemedicine web platform (T4P Vision Web Portal) that was the same for all patients. Unfortunately, the company does not exist anymore. Another universal telemonitoring unit is called NOWAPI, but is poorly examined.⁷⁷ An apnea was considered when a tidal volume of less than 20% of the patient reference tidal volume was detected (for ≥ 10 s), whereas a hypopnea was counted if a tidal volume between 20% and 50% of the patient reference tidal volume was found (for ≥ 10 s). Of interest, there was a concern related to low satisfaction rate of the patients about the traffic light indicator.

Fine tuning of continuous positive airway pressure devices and filter settings for interventions during telemonitoring

One of the capabilities of telemedicine is probably the early detection of problems (such as persistent

respiratory events or leakage), thus facilitating appropriate interventions, and thereby improving the patients early experience with CPAP.³⁹ Hoet and colleagues⁷⁶ showed that telemonitoring significantly reduced the delay to the first intervention for CPAP treatment (29 ± 25 vs 47 ± 30 days). For this purpose, the data have to be analyzed against a set of preestablished criteria or filters. The dataset can be scanned for multiple criteria and compared with thresholds for adherence and compliance, trends, AHI, periodic breathing, occurrence of central apneas and mask leaks.⁷⁷

A selection of filter settings reported in the literature or by companies is shown in **Table 2**.^{6,7,76,78,79,80,81}

For example, CPAP data are automatically sent to the health care provider on a daily basis and trigger automatic alarms in case of poor use for 2 consecutive nights (<4 h) or excessive mask leakage (>0.5 L/s).⁸¹ Automatically triggered clinical actions can then be scheduled (**Fig. 1**). The final goal of such a platform is to proactively identify and address issues that can negatively influence CPAP adherence and compliance. By providing patient data early in the course of CPAP treatment, it is believed that this technology would be extremely useful in improving compliance and acceptance of the device in patients with sleep apnea.^{9,10,48,75,82–86} All that is needed is a personal computer, an Internet connection, and the proprietary software. Detailed reports can be generated to show use information and then forwarded electronically to referral laboratories or physicians without generating additional paperwork. Wireless applications with an in-built telemonitoring module connects the CPAP unit in the patient's home with a server each evening

Table 1
Problems with the platforms for CPAP telemonitoring

Problem	Comment
Communication protocol depends on manufacturer	Ideally, communication software should adapt to different manufacturers. In practice, a universal system is not feasible, also taking into account the implementation of data encryption by the communication device.
Type and quality of measured data depend on manufacturer's technology	PAP devices detect snoring and respiratory events by airway pressure vibrations or flow changes.
Detection of respiratory events is dictated by algorithms developed by the PAP manufacturer	Criteria for respiratory events are based on the magnitude reduction of the flow signal ($<50\%$ for hypopneas; $<10\%$ for apneas). However, baseline value is not adequately defined and even does not remain constant during sleep.

Table 2
Proposed filter settings for interventions during telemonitoring

	Compliance	Leaks	Residual AHI
Fox et al, ⁶ 2012	<4 h use on 2 consecutive days (check every week day)	Mask leak >40 L/min for >30% of the night	>10 events/h, and 90th percentile of pressure >16 cm H ₂ O
Frasnelli et al, ⁷⁸ 2016	<4 h use on 2 consecutive days	>30 L/min for more than 2 d	Not included
Munafo et al, ⁷ 2016	No CPAP data for 2 consecutive days <4 h use for 3 consecutive days	>30 L/min for >2 d	>15/h for 5 consecutive days
Chumpangern et al, ⁷⁹ 2021	<4 h use on 2 consecutive days	>27 L/min on 2 consecutive days	>5/h on 2 consecutive days
Hoet et al, ⁷⁶ 2017	<3 h use on 3 consecutive days	>50 L/min	>10/h
Turino et al, ⁸⁰ 2017	<4 h use on 2 consecutive days	>30 L/min for >30% of the night	NA
Prigent et al, ⁸¹ 2020	<4 h use over a period of 7 consecutive days. During the initiation period: compliance check each 72 h	1 h of relevant leaks (Philips) Nonintentional leaks: ith 95th percentile >24 L/min (nasal mask ResMed) With 95th percentile >36 L/min (oronasal mask ResMed) Overall leakage >60 L/min (Fisher and Paykel) Overall leakage of >95 L/min (Devilbiss) Nonintentional leaks with a mean ≥ 20 L/min Nonintentional leaks with 95th percentile ≥60 L/min Percent elevated leakage ≥15% (Löwenstein) ≥5% of the use time above the leakage limit (Sefam)	≥10/h in a progressive window of 7 d

and transmits adherence and compliance data on a daily base. This technology eliminates the need for data cards or home telephone lines, and frequent patient visits. The compliance server analyzes the data and notifies the physician of any patients with poor CPAP use. Patient confidentiality is secured through a password and login-protected system that provides protection for the patients' information. Such system provides accurate, thorough, and advanced information to the clinician and ensures that each patient is receiving the maximum benefit from CPAP therapy. A patient's own data can be checked at a glance with physician summary reports. Visual color coding

allows the caregiver to easily identify patients who require attention. Remote settings changes are available to fine tune therapy and optimize patient management. Historical data can be searched at any time to retrieve data that were not transmitted via the monitoring schedule. Telemonitoring of CPAP data may enable early identification of central sleep apnea or Cheyne–Stokes breathing and congestive heart failure occurrence or progression.^{39,87} This technology has the potential also to be used for noninvasive ventilation in other types of patients and in more advanced devices for respiratory support.⁸⁸ Telemonitoring may be useful in patients with sleep apnea who

Fig. 1. A decision tree for telemonitoring of PAP therapy.

require other modes of PAP therapy. Patients with noninvasive ventilation require a much closer therapy control protocol compared with patients with sleep apnea.

One of the drawbacks of CPAP unit residual AHI is that this parameter is based on recording time and may include snoring and vibration in the total residual event calculation (CPAP AHI is not similar to PSG AHI).^{89,90}

Again, we have to take into account that major differences exist between manufacturer definitions of residual events (see Table 1) and that an AHI flow is not associated with nonadherence.^{90–92} The key advantage of this technology is that the individual's CPAP data are now automatically collected, remotely accessible, and actionable by both providers and patients.⁹³ However, it suffers from the limitation that it leads to data overload when trying to manage a large patient population.

Fine tuning of continuous positive airway pressure devices: Responsibilities

If such a feature is implemented, additional regulations have to be considered. Who is liable if the pressure adjustment is not functioning properly? Is this a matter of data transmission, or was the device in use with another patient? Before bidirectional telemedicine is implemented in the therapy of sleep apnea on a large scale, several legal questions need to be clarified.⁴ Roles, expectations, and responsibilities of providers involved in the delivery of such services should be defined and communicated, including those at originating sites and distant sites.⁵ The assumptions parties may have in such encounters and roles should be explicitly documented. In general, the standards

for supervision should follow the same general guidelines as those for technicians, respiratory care practitioners, and nurses working with physicians in the live setting. All providers involved have to review their facilities' and institutions' bylaws and human resource documents. Moreover, relevant regulatory documents related to the provision of care are to be followed, and organizations and providers are to ensure such care is consistent with policies regarding scope of practice and state licensing laws of all involved parties.^{5,94} However, it is questionable whether a service provider could be allowed to fine tune CPAP settings independently, because changing treatment regimens is the physician's privilege and responsibility for centuries. To overcome this problem, the physician must be available by telephone to provide assistance and direction if needed. Telemedicine could be readily used to augment general supervision, and asynchronous methods could be used.⁵ One more barrier, in some countries, is that CPAP fitting and troubleshooting is not eligible for reimbursement, when performed via telemedicine by respiratory therapists and sleep technologists.⁹⁵ Who gets access to these data with personal use information also varies from country to country according to local medical data regulations. Some countries regulations are very restrictive and require a clear distinction of tasks among health insurance, service provider, and sleep physician.

(Cloud-based) remote compliance monitoring: evidence

Unlike pill-based treatments, CPAP is unique in that detailed, night-by-night compliance data are

collected routinely and can be made available in real time to both patients and providers.

Some study results suggest that the use of telemonitored CPAP compliance and efficacy data seems to be as good as standard care in its effect on compliance rates and outcomes in new CPAP users, although conflicting data remain.^{10,96,97} However, the results from other RCTs regarding improvement in compliance are disappointing (**Table 3**), given many studies do not show any improvement in compliance with telemonitoring. In contrast, in some of these studies, despite the application of telemonitoring, compliance remained extremely low, questioning the level of usual care in these centers.^{6,9} Nevertheless, telemonitoring offers the possibility for the sleep medicine providers to detect “problematic” patient and to act properly. Stepnowsky and colleagues¹⁰ demonstrated that a telemonitored clinical care group had a compliance rate of 4.1 hours per night after 2 months, which represents a 46% increase in compliance over the mean compliance level of the standard clinical care group (2.8 hours per night). However, this trial was certainly underpowered to reach significance ($P < .07$) but provided a rationale for conducting larger clinical and cost-effectiveness trials. There were also some concerns regarding the potential loss of data through wireless transmission. However, the loss was negligible and once the wireless unit was properly connected, data from previous nights stored on the flow generator device could be retransmitted and obtained wirelessly. Anttalainen and colleagues⁹⁸ compared a group of wireless telemonitored CPAP users with a usual care group, after CPAP titration. They found equal CPAP compliance and residual AHI at the 1-year follow up. The median nursing time was 39 minutes in the telemonitored group and shorter compared with that of 58 minutes per patient in the usual care group. Fernandes and colleagues¹⁰³ reported that in the presence of a comprehensive educational program during positive airway pressure adaptation, telemonitoring patients did not show significant benefits concerning compliance and efficacy. A larger follow-up period was proposed to evaluate the long-term results of a telemonitoring program.

Long-term follow-up

Because OSA may change with aging, weight, menopause, and intake of some medications, long-term OSA monitoring for all treatments is indicated.^{106,107} Studies confirmed the feasibility of teleconsultation as a parallel route to face-to-face consultations, not only during the critical CPAP habituation phase, but also on the long run. This type of telemedicine seems to be easier to practice,

because it does not require changes in the model of care delivery, just a pragmatic teleconference platform. This approach is associated with numerous advantages for patients, including the removal of the need to travel to and from the sleep medicine center. Baig and colleagues¹⁰⁸ demonstrated the long-term effectiveness of a 5-year telemedicine program: the delay to obtain CPAP was reduced from more than 2 months to less than 1 week, the total number of sleep consultations decreased, and the waiting list time for the sleep clinic shortened. Murphie and colleagues reported high satisfaction in a Scottish cohort, and Isetta and colleagues found similar satisfaction rates after video-based PAP follow-up encounters.^{49,109}

In contrast, the limitation of synchronous telemedicine is that it still requires face-to-face provider time, and its impact on care efficiency is modest at the best.⁹³ To be so, it requires adoption of elements that largely fall under the umbrella of asynchronous telemedicine. Parikh and colleagues⁶³ compared teleconsultation delivered by video conferencing with face-to-face consultation for follow-up of CPAP therapy in 90 patients. The proportion of compliant patients and levels of patient satisfaction were not different between the 2 groups. Nevertheless, the ideal frequency of face-to-face follow-up for maintenance of CPAP adherence remains to be elucidated. Murase and colleagues¹⁰⁵ could demonstrate a favorable effect of a telemedicine intervention on treatment adherence in long-term CPAP users, and found that visits every 3 months with a monthly telemedicine intervention had a beneficial change in adherence similar to monthly visits. This finding may suggest that telemedicine interventions can assume some of the merits of close face-to-face follow-up for the maintenance of CPAP adherence. No improvement was found in CPAP compliance data. Because those participants were familiar with using CPAP, they probably appreciated the decrease in the number of clinic visits. The greater level of satisfaction in the telemedicine group may be a strong rationale to promote this approach.

Telemedicine monitoring of sleep apnea therapy is currently limited to CPAP and related ventilator-support devices. However, alternative treatment modalities are coming in place, like mandibular advancement device and sleep position trainers. For example, it has been shown that mandibular advancement devices can be monitored objectively as well by in-built thermosensors, with wireless transmission of adherence and compliance data.¹¹⁰ For these devices, ongoing remote data monitoring of adherence is needed as well. However, the frequency of follow-up testing for these

Table 3
Randomized studies comparing telemedicine monitoring versus standard care in CPAP therapy

	N	AHI	Telemonitoring Method	Follow-up	Compliance TM	Compliance UC	P Value
Taylor et al, ⁷⁵ 2006	114	>5	Internet support + feedback	1 mo	4.3 h	4.2 h	NS
Stepnowsky et al, ¹⁰ 2007	45	>15	Interactive web site with own CPAP data and instructions for troubleshooting	2 mo	4.1 h	3.4 h	S
Sparrow et al, ⁹ 2010	250	>10	Interactive voice response system	6 mo	2.4 h	1.48 h	S
Fox et al, ⁶ 2012	75	>15	Feedback by phone	3 mo	3.2 h	1.7 h	S
Isetta et al, ⁵⁰ 2015	139	Mean 49	Feedback by webtools	6 mo	4.4 h	4.2 h	NS
Anttalainen et al, ⁹⁸ 2016	111	Mean 34	Nurse-adjusted phone/visits	12 mo	6.4 h	6.1 h	NS
Frasnelli et al, ⁷⁸ 2016	223	37 (TM) 40 (UC)	Telemonitoring and messaging	1 mo	53 h	4.6 h	S
Munafo et al, ⁷ 2016	132	34 (TM) 27 (UC)	Multimedia approach to contact patient about their CPAP use	1 mo	5.1 h	4.7 h	NS
Turino et al, ⁸⁰ 2017	140	52 (TM) 53 (UC)	Telemonitoring	3 mo	5.1 h	4.9 h	NS
Hostler et al, ⁹⁹ 2017	61	19 (TM) 18 (UC)	Telemonitoring, patient engagement tool	11 wk	4.0 h	2.7 h	NS
Hwang et al, ⁴⁴ 2018	1455	23 (TM) 23 (TE) 22 (UC)	Telemonitoring, messaging, web-based OSA education	3 mo	4.8 h	3.8	S
Hoet et al, ⁷⁶ 2017	46	50 (TM) 49 (UC)	Telemonitoring	3 mo	5.7	4.2	S
Kotzian et al, ¹⁰⁰ 2019	33	37 (TM) 37 (UC)	CPAP training + monitoring	3 mo 12 mo	6.3 h 5.9 h	5.0 h 5.1 h	S NS
Nilius et al, ¹⁰¹ 2019	80	41 (TM) 38 (UC)	Short telephone calls	6 mo	4.4 h	2.1 h	S
Pépin et al, ¹⁰² 2019	306	47 (TM) 45 (UC)	Multimodal telemonitoring Home blood pressure and physical activity	6 mo	5.28 h	4.75 h	S
Fernandes et al, ¹⁰³ 2019	51	38 (TM) 36 (UC) 36 (PC)	Remote monitoring and intervention	4 wk	5.0 h	5.1 h	NS
Schoch et al, ⁸ 2019	240	37 (TM) 46 (UC)	Remote monitoring and phone calls	6 mo	5.6 h	4.8 h	NS
Tamisier et al, ¹⁰⁴ 2020	206	45 (TM) 42 (UC)	Multimodal telemonitoring	6 mo	4.73 h	5.08 h	NS
Murase et al, ¹⁰⁵ 2020	483	161 (TM) 166 (UC)	Remote monitoring and phone calls	6 mo	5.45	5.12	NS
Chumpangern et al, ⁷⁹ 2021	57	49 (TM) 52 (UC)	Remote monitoring and intervention	4 wk	5.16	4.42	NS

Abbreviations: NS, not significant; S, significant; TM, telemonitoring; UC, usual care.

non-CPAP therapies does not seem clear. Altogether, telemedicine technologies could change the classical visits toward an outside clinic visit program, with shorter and more frequent visits realized by different communication methods.

PATIENT COUNSELING AND THERAPY REINFORCEMENT

The use of telemedicine has the ability to quickly collect, transmit, and incorporate data, making it a swift and viable means of communication between patients and their providers.¹¹¹ These features have a significant potential for the management of patients with OSA, particularly for education and counseling, apart from optimizing CPAP adherence and close monitoring of effective compliance. This type of intervention also has the added potential benefit of fostering patient empowerment. Patients who take ownership, who are involved in their own care, and possess the knowledge and skills to manage their disease are more likely to comply with lifestyle modifications and treatment regimens, which in turn improves clinical outcomes.¹¹² In this way, telemedicine can have a substantial impact on health care use, strengthen the sleep professional–patient interaction, and enhance self-management skills.¹¹³

Patient Counseling and Personalized Feedback (Video and Teleconferencing)

Video and telephone contacts provide both direct and indirect benefits to patients. Direct benefits include decreased waiting time, and increased physician availability. Indirect benefits include avoidance of barriers to in-person visits, such as the cost and time associated with travel or missed work.¹¹⁴ Video visits could accommodate chronic routine follow-up appointments. Patient specific data, such as diaries for insomnia and CPAP machine downloads for OSA, could be reviewed at such visits, as could routine challenges with equipment or medications.¹¹⁴ As mentioned elsewhere in this article, a concern could be that the doctor might need to perform some physical examination. However, in sleep medicine it may be that stable patients could be adequately assessed without performing a physical examination that requires the physician to be present in the same room. In addition, certain elements of the examination, such as weight or blood pressure measurement could be performed at home or by the family physician. In a series of 90 patients with OSA, 56 were seen by a physician at the sleep center and 34 by videoconference. Satisfaction did not differ between the groups.⁶³ A successful telemedicine encounter should mirror the live visits as much

as possible.⁹⁵ Therefore, close attention should be paid to the technical quality of the encounter, starting with the video and audio specifications.

Video teleconferencing may improve access to care without compromising important clinical outcomes. Cost and provider time analyses have not been not undertaken so far.

Promotion and Reinforcement of Patient Adherence and Compliance

The optimal use of CPAP requires a level of patient engagement that exceeds what is needed to follow a pill-based regimen. Although teaching is likely necessary to provide foundational knowledge for behavior change, information may not be enough to induce significant and sustained behavior changes. Also, it can be questioned whether technology-based delivery of education can be a more cost-effective approach. Instead, addition of motivational elements such as personalized goal setting or other methods such as accountability may be essential.

Behavioral determinants explain up to approximately 20% of the total variance in CPAP compliance emphasizing the complexity of compliance behaviors and providing an explanation for why simplistic interventions such as alternative pressure modes have not made a substantial impact on compliance.^{115–119} A Cochrane meta-analysis of nontechnical methods to improve CPAP compliance in the general OSA population showed that supportive and educational interventions can modestly increase use and that cognitive behavioral therapies may lead to a larger increase of machine use.⁶⁹ In most studies where telemedicine was used, a cognitive behavioral intervention was applied by telephone,^{6,9,75,83,84,120} the Internet,^{6,75} or videoconference.^{20,48,63}

Active calls and automated telephone-linked communication/digitized human speech

Demolles and colleagues⁸⁴ used a daily computer-based telephone system to monitor patients' self-reported compliance behavior and provided automated counseling through a structured dialogue. The impact of the intervention was not significant in comparison to standard care. However, the findings suggest that concurrent education and reinforcement during the initial and early treatment period are effective countermeasures to patient-reported attenuated compliance. Sparrow and colleagues⁹ applied an automated telemedicine intervention system, based on an algorithmic interactive voice response system designed to improve CPAP adherence and compliance. The system monitors CPAP-related symptoms and patients'

self-reported behavior and provides feedback and counseling through a structured dialogue to promote CPAP use. The monitor uses digitized human speech to speak to the patients and the patients communicate via the touch-tone keypad of their telephones. Each call began with an assessment of the self-reported duration and frequency of CPAP use during the past week, followed by one of several motivational counseling modules. If the participant reported excessive side effects or OSA symptoms, the system then recommended the patient to contact his or her physician to discuss the problems. The computer system called the patients if they did not make a call at the expected times. Routine printed reports were sent to the participants' physician biweekly during the first month and the month thereafter. It was found that this telemedicine approach resulted in a median CPAP use that was 0.9 hours per night (at 6 months) and 2.0 hours per night (at 12 months) higher than that of an attention control group.⁹ Chervin and colleagues performed an RCT among 33 patients of 2 interventions to improve compliance: 1 group received weekly telephone calls to uncover any problems and encourage use, a second group received written information about OSA and the importance of CPAP adherence, and finally, a third group served as a control group. The authors reported that intervention improved CPAP compliance and that the effect was especially strong when intervention occurred during the first month of CPAP treatment.⁶⁰ Isetta and colleagues⁴⁹ found in a series of 50 consecutive patients with OSA that most of them were satisfied with the teleconsultation method, and 66% agreed that the teleconsultation could replace more than half of their CPAP follow-up visits. Finally, Coma del Corral and colleagues²⁹ found that the level of good CPAP compliance was 85% at 6 months in patients attending the sleep center for a face-to-face meeting, whereas it was 75% in the teleconsultation arm.

Sedhaoui and colleagues performed an RCT in 379 patients with OSA, comparing standard support completed or not within 3 months of coaching sessions, based on telephone-based counseling by competent staff. Of the patients in the standard group, 65% showed a compliance rate of greater than 3 hours per night versus 75% for the coached group. The mean CPAP use was 26 minutes longer in the coached group versus standard group.¹²¹

These automated interventions improved adherence in part by improving motivation, altering the

perception of treatment efficacy, and affect psychological constructs that determine behavior change.

Web-based access to own positive airway pressure data

Kuna and colleagues¹²² tracked website use and found in an RCT that providing patients with daily web-based access to their own PAP use improves compliance (4.7 ± 3.3 hours in the usual care group, 5.9 ± 2.5 hours, and 6.3 ± 2.5 hours in the web access groups with and without financial incentive respectively). However, only about one-half of the participants logged in during the first week, and the proportion of patients using the website decreased with time. Inclusion of a financial incentive in the first week had no additive effect in improving compliance. These findings are consistent with a similar study evaluating the effect on compliance when an interactive website providing PAP data to both patients and providers is used.⁸⁹ This website, called MyCPAP, included the following components: (1) basic education regarding OSA and CPAP, (2) patient access to their own data, (3) questionnaires to assess subjective symptoms, (4) interactive guide to learn about practical solutions to their identified CPAP problem, and (5) education regarding how to use and care for CPAP and accessories.⁸⁹ Taylor and colleagues⁷⁵ used computers to provide daily Internet-based informational support and feedback (Health Buddy, daily survey) for problems experienced during CPAP use. Questions related to CPAP use, hours of sleep and quality of sleep were sent to the participants via a computer. The patient's responses were monitored by the sleep medicine practitioner, and the patient telephoned if deemed necessary. They found no significant differences between the telemedicine intervention and standard care group at 30 days in patient functional status and satisfaction with CPAP. This intervention only provided self-reported data to the health care provider, whereas objective compliance and detailed physiologic information may have been more useful in effectively troubleshooting problems and may have improved CPAP compliance.^{20,75,85} Furthermore, in a RCT, Fox and colleagues⁶ demonstrated improved CPAP compliance with a web-based telemedicine monitoring system. An autoCPAP machine transmitted physiologic data (residual AHI, air leak, compliance) daily to a website that could be reviewed. In case problems were identified from data from the website, the patient was contacted by telephone as necessary.⁶ After 3 months, the mean compliance rate was significantly greater in the telemedicine arm (191 min/d), compared with the usual care

arm (105 minutes), but even then CPAP compliance was low. In contrast, 67 minutes of technician time was spent on the patients in the telemedicine arm compared with the standard approach.

Automated messaging (reinforcement emails or texts)

Various forms of telecommunication, which may include automated message data alerts, coaching and reinforcement emails, texts, and calls, as well as online educational and motivational support, have shown similar or increased CPAP compliance.¹⁹ It is particularly interesting that this feedback process (sending positive or warning messages in the case of good or poor compliance, respectively) can be performed automatically, therefore minimizing health staff cost. Frasnelli and colleagues⁷⁸ used short text messages by SMS with treatment reinforcement was sent out weekly, if no phone calls were necessary. The Tele-OSA study of automated messaging associated with telemonitoring gave early improvement in CPAP adherence, but this effect gradually declined after discontinuation of automated feedback messaging.⁹³ The majority preferred to receive messages via email (31.7%), followed by text messaging (17.5%), and phone (2.3%), whereas 40% preferred a combination of approaches.⁴⁴ In the study of Hwang and colleagues,⁴⁴ the overall improvement in adherence with telemonitoring was substantial, but the degree of response varied between individual patients. In a prospective, open, multicenter study involving 122 patients with OSA, effectiveness and coaching costs were evaluated using U-Sleep, a web-based automated telehealth program.⁷ In this study, the telehealth group received emails and/or text messages, whereas in the standard care arm, follow-up consisted of scheduled phone calls on days 1, 7, 14, and 30. Results of this study revealed that there was no statistically significant difference in CPAP compliance, CPAP efficacy or change in Epworth Sleepiness Scale scores between telehealth and standard care groups, but the trend favored the telehealth group. The coaching time required was significantly lower in the telehealth Group, making it a time-efficient option. The authors concluded that this automated telemedicine strategy needs to be continued indefinitely for sustained effect. Altogether, the use of technology-based approaches should be considered as 1 solution among a larger set of management strategies to personalize the care for individual patients. The potential impact of changing thresholds to

increase message frequency or the possibility of personalizing automated messages for each patient, based specifically on what would motivate them the most, and individual goal setting have to be further explored.

Mobile device applications: Patient engagement tools

With increasing Internet access, there is a developing role for web-based patient engagement applications to assist patients in self-management of OSA. Recently, manufacturers of CPAP devices have designed and implemented such theory-driven coaching and support services, including a dashboard summarizing therapy data, troubleshooting and educational videos, and goal-focused automated e-mails/texting. These tools are described as patient engagement tools, self-management platforms or patient-facing applications, and should ideally include the following components: (1) remote electronic delivery, (2) personalized invitation, (3) interactive, (4) viewable on demand and as often as desired, and (5) concise and easy to understand.⁹³ These platforms operate through mobile device applications (U-Sleep and MyAir: ResMed, Australia; SleepMapper later DreamMapper: Philips, Amsterdam, the Netherlands), sync automatically with the CPAP vendors software program, providing personal CPAP data in comprehensive graphs to each patients, and also incorporating CPAP troubleshooting materials. The data are transferred from the patients' CPAP to a remote database, the same platform used by sleep professionals to access a comprehensive report of CPAP treatment data to monitor patients. At the same time, all these patients have access to their personal CPAP data via a mobile device application or via a web portal.¹²³ These systems also use structured motivational enhancement techniques such as feedback and goal setting, to encourage use. Patients receive positive feedback by sending text messages to congratulate participants about their successful CPAP adherence. In contrast, feedback to patients with a poor night of adherence may motivate improved use on the subsequent night. These concepts are part of social cognitive theory, which considers self-efficacy as a major determinant of behavior change.^{58,124,125} Strong self-efficacy beliefs are associated with the ability to withstand treatment failure and persist in efforts.^{126,127} Altogether, these patient engagement tools enhance self-monitoring by providing the patient with easy-to-view reports of trends in use, AHI, and feedback about mask leak. MyAir also monitors mask off/on events in addition, and gives a summary score based on

proprietary weighting of the aforementioned factors. Although MyCPAP provides troubleshooting tips and educational materials, they must be selected by the patient. In contrast, the commercial platforms serve up educational suggestions, based on the monitoring as well as suggestions for selecting intermediate goals of care, possibly better equipping patients to problem solve and to set goals.⁴⁷ As said, these applications also serve as a portal to educational videos about OSA and CPAP therapy, which facilitate patients to trouble shoot as problems arise.

Such an approach has shown benefit when delivered by health care providers in different studies (Table 4).^{45,89,99,128,129,130}

Engleman and colleagues¹³¹ presented a retrospective study (data from Philips) comparing CPAP use in an old-fashioned OSA cohort versus a new feature OSA cohort, including remote monitoring, device display and a patient support phone app. In the 817 included patients, the implementation of multiple telemedicine supporting tools resulted in an increase in daily CPAP use of 1.1 hours per night during the first 12 weeks of CPAP therapy. Pittard and colleagues¹²⁸ reported similar significant results with the DreamMapper. Hardy and colleagues reported that 78% of those who used SleepMapper were compliant at 90 days compared with 56% of those who did not, and they used CPAP for an average of 1.4 hours longer per night.⁴⁶ U-Sleep patients do have a better CPAP use at 3 months (83% vs 73%), but without statistical significance.⁷ However, they found that fewer coaching minutes were required during the

3-month follow-up period for the U-Sleep (24 vs 58 minutes for usual care). This suggests that U-Sleep could be a cost-effective solution by potentially replacing traditional follow-up protocols without drop-off in CPAP adherence. Hostler and colleagues reported an 18% increase in nights with more than 4 hours of use, and patients in the SleepMapper Group were more than 3 times as likely to meet adherence criteria (>4 hours per night for 70% of nights), a trend that just missed statistical significance ($P = .06$). This should translate into significant improvements at the individual and population level.⁹⁹ A retrospective analysis of 1000 patients found that 77% of those who opted to engage with such a tool used CPAP for 4 hours or more per night, compared with 63% of those who opted out. A retrospective review of 15,000 patients in a database showed 78% of those who used SleepMapper were compliant at 90 days and used CPAP.⁹³ Similarly, a retrospective analysis of 128,037 patients found that a greater proportion of those who opted into the same patient engagement technology were compliant compared with those who did not (87.3% vs 70.4%, respectively).¹³⁰

In a study that used data from a large German home care provider, it was shown that the use of a proactive patient management program supported by remote access to PAP therapy data significantly lowered therapy termination rate (5.4% vs 11.0%) and time to therapy termination was significantly longer (348 vs 337 days).¹³² In another study, Woehrle and colleagues¹²⁹ also reported that the therapy termination rate was lower

Table 4
Patient engagement tools and compliance

	N	AHI	Patient Engagement Tool	Follow-up	Compliance Patient Engagement Tools	Compliance Usual Care	P Value
Stepnowsky et al, ⁸⁹ 2013	241	36	MyCPAP	120 d	3.9 h	3.2 h	S
Pittard et al, ¹²⁸ 2015	2173	N/A	DreamMapper	60 d	5 h	3.9 h	S
Hardy et al, ⁴⁵ 2016	172678	N/A	DreamMapper	90 d	5 h	3.9 h	S
Hostler et al, ⁹⁹ 2017	61	18–19	SleepMapper	77 d	4 h	2.7 h	S
Woehrle et al, ¹²⁹ 2018	1000	N/A	myAir	180 d	5.4 h	4.2 h	S
Malhotra et al, ¹³⁰ 2018	128037	N/A	myAir	90 d	5.9 h	4.9 h	S

Abbreviation: N/A, not applicable.

in the patient engagement group, with higher device use and lower leak. The AHI was equal in both groups. The addition of a patient engagement tool was associated with a significant improvement in device use in patients receiving CPAP therapy for the first time. Increases were seen in both the number of days with device use and in the hours of device use each night. Moreover, there was a significant reduction in leak in patients managed using a patient engagement approach compared with telemonitoring alone.¹²⁹ Potential explanations for this observation include better education and feedback compared with usual care. Patient engagement tools add another level to telemonitoring. Patients can get involved via shared decision-making with their health care givers and by increasing their health literacy (accessing, understanding and implementing health information). Moreover, the use of real-time feedback could help to keep patients actively engaged with their therapy, and remind and motivate them to use their device. Also, such technology facilitates the input of real-time clinical data and allows real-time responses that incorporate personalized recommendations based on the data received. Key features of patients engagement tools are (1) the patient believes that they have an important role to play in their own health care, (2) the patient is provided with the confidence and knowledge to take action, (3) the patient takes action to maintain and improve their health, and (4) the patient persists with the program even during times of stress.^{129,133} Hwang and colleagues⁴⁴ demonstrated that Web-OSA education added to an automated CPAP follow-up program impacted CPAP adherence to a greater degree than either of those platforms used in isolation.

Apart from an improved adherence to PAP therapy, patient engagement tools are inexpensive, do not draw on health care resources, and show promise in improving PAP therapy for OSA.⁴⁷ Use of these platforms was associated with using PAP for significantly more hours per night (range of 0.7–1.3 hours more). In contrast, it could be that this difference has a minimal effect on symptom improvement, because the scores could be affected by coexisting conditions. Traditional telemonitoring systems require health care professional-initiated patient contact and deployment of health care resources, whereas patient engagement tools engage patients directly without placing additional burden on health care.⁴⁷ In a real-life big data study with 4,181,490 patients, those who registered to use an engagement tool consistently had better adherence (80%–85%) than those who did not (65%–70%).¹³⁴ Patient

engagement tool use was associated with a greater than 2-fold increase in the probability of achieving sufficient adherence. The possibility arises that some patients may have been experienced PAP users before joining trials with patient engagement tools rather than new PAP users.^{129,130} Such patients might behave differently to patient engagement tools than PAP-naïve patients. However, prior studies show that PAP use is established soon after PAP initiation, and it seems unlikely that providing feedback data and recommendations to experienced users would result in greater improvement in PAP adherence than what was observed in PAP-naïve patients.¹²² Further efforts are needed to identify key features, their effect on outcomes of interest, and which patients would benefit from them most.

TELEMANAGEMENT OF COMORBIDITIES

Improved outcomes have been reported using telemedicine in conditions like diabetes mellitus, hypertension, stroke, and HIV.^{113,135–138} This opens new horizons for patients with OSA and comorbidities. Obesity is the most frequent condition associated with OSA, which deserves close attention.

Appel and colleagues¹³⁹ evaluated the effectiveness of a telemedicine behavioral weight loss intervention among 415 obese patients with at least one cardiovascular risk factor for 2 years. Participants were randomized to the following groups: (1) remote weight loss support (by telephone, website, and email), (2) in-person support together with the 3 remote means of support, and (3) a control group with self-directed weight-loss management. After 2 years, the mean change in weight from baseline and percentage of participants who lost 5% or more of their initial weight was significantly greater in the remote support groups (with or without additional in-person interventions), when compared with the control group (with self-directed weight-loss management). Hence, the remote support interventions facilitated greater weight loss, and did not require in-person support. Another known comorbidity associated with OSA is diabetes, which has also been looked into with the use of telemedicine. Wang and colleagues¹⁴⁰ evaluated the use of U-health care, a remote platform based on an Internet interface that transmits glycemic data immediately through a glucometer. The intervention group received information about medicines, diet, and exercise through the platform, whereas the control group received conventional medical treatment without any additional intervention. After 18 months follow up, the intervention group achieved better glycemic control, improved hemoglobin A1c levels and decreased triglyceride levels.

This approach also improved patients' adherence to the medical team's instructions.

Heart failure can also be associated with OSA, and is one of the first fields where telemedicine has been applied. Bashi and colleagues¹⁴¹ analyzed 19 systematic reviews of remote interventions that focused on the control of heart failure. The use of telemonitoring of physiologic parameters (heart rate, blood pressure, electrocardiogram, and weight) showed a reduction in heart failure hospitalization, all-cause hospitalization, mortality and an improvement in quality of life. However, there is a lack of evidence to support the effectiveness of interventions involving mobile phone use, videoconferences, or other devices.

Nevertheless, the application of new technologies is not suitable for all populations.^{142,143} Therefore, it is mandatory to choose wisely the appropriate outcomes and patient populations for telehealth strategies.

TELEMEDICINE IN PARTICULAR POPULATIONS

It is remarkable that primarily those telemedicine concepts were able to increase use time in which the control group used the CPAP device for less than 4 hours per night. In contrast, when the control group is greater than the threshold of 4 hours per night, usually no further improvement is achieved.

A recent meta-analysis revealed that telemedicine care was associated with significantly greater CPAP compliance compared with usual care, with a pooled mean difference of 0.68 hours per night.⁹⁷ However, the findings need to be interpreted with caution, given the varying methodologic quality of the included studies, the high heterogeneity of the recruited studies, as well as the fact that the included type and intensity of both usual care and experimental interventions varied considerably. Another meta-analysis included 22 studies, and showed that telemedicine interventions are able to increase adherence to CPAP treatment.⁹⁶ However, in 10 studies no significant effect was found on compliance, although 57% of the patients were from a single center that was in favor of telemonitoring. Hence, the exact level of educational and supportive concepts in the control groups contributed to the additional effect of telemedical interventions. Probably, a ceiling effect regarding educational actions must be considered.¹⁰¹ Similarly, Schoch and colleagues⁸ concluded that the telemedicine intervention did not significantly improve CPAP use in an unselected OSA population, which was explained by a relatively high adherence in the control arm. In contrast, the same group found a positive impact on CPAP use in a subgroup of patients with a

milder form of OSA. Also, significant improvement in quality of life was found, which was not related to the hours of CPAP use, but was most pronounced in the telemedicine arm. This brings us to a more general aspect concerning the target population, namely whether the whole CPAP-treated population should be included, or only particular phenotypes that are better served for different aspects of telehealth options.¹⁴⁴

It could be argued that telemonitoring might be more useful in specific populations (eg, poorly adherent patients or those with few symptoms) and also reinforces the concept that better adherence and treatment effectiveness can only be ensured by using distinctive tailored management strategies, with or without telemonitoring, according to the OSA phenotype.¹⁴⁵ For patients with comorbid insomnia, telemedicine also opens opportunities to exchange and automatically process sleep diaries, smartphone applications of sleep-wake data and follow online programs related to cognitive behavioral therapy.^{146–148} This way, the insomnia field can probably be transitioned from evaluating more basic, noninteractive online programs to personalized, interactive online programs. For example, the group of Espie and colleagues¹⁴⁷ used a virtual therapist to help deliver a web-based cognitive behavioral therapy-i program. Such approach may likely have more important roles in managing insomnia in the future. Apart from insomnia, it has been shown that the cognitive behavioral therapy approach is also effective in a context of OSA to improve CPAP adherence.¹⁴⁹ In case of inadequate sleep hygiene, platforms can be programmed with automated messages to encourage behavioral change, without direct interaction with the sleep provider.¹⁵⁰

One major limitation in telemonitoring studies is the failure to reach a sufficient sample size. In a recent French study it was found that 1646 patients would have been needed to reach a power of 0.8 to show a significant difference of 0.34 hour per night in compliance, whereas 788 patients would have been needed to meet a threshold of greater than 0.5 hours with a power of 0.80.¹⁰⁴ This may also suggest that it is unlikely that a meaningful increase in CPAP adherence of less than 30 minutes is clinically significant.

Hence, the American Academy of Sleep Medicine guideline recommends telemonitoring-guided interventions during the initial period of PAP therapy in adults with OSA, but only at conditional level of recommendation.^{53,54} It seems that a wise balance between enthusiasm and skepticism, which is inherently linked with solid science, would be the best way to consolidate useful results for routine application of telemedicine for

PAP follow-up in OSA. The field is at a very early stage for pediatric patients compared with adult ones, and no systematic reviews have been carried out on telemedicine for pediatric OSA. So, it is unclear whether the results could be generalized to younger populations. Finally, in stroke patients, Kotzian and colleagues¹⁰⁰ reported a higher compliance in telemonitored patients after 3 months, after 1 year there was no significant difference. Nilius and colleagues¹⁰¹ studied stroke patients as well and found a higher compliance after 6 months of home therapy.

PATIENT SATISFACTION

There are a multitude of potential benefits to incorporating telemedicine into adult sleep practices, including and not limited to saving travel time and costs, less missed work time, and eventually bringing multiple caregivers together. Smartphones allow almost all health care professionals to connect seamlessly and attend telemedicine appointments. Such approach may also decrease appointment no-show rates. Surprisingly, in the study of Turino and colleagues telemonitoring system was unexpectedly associated with lower patient satisfaction. The study observed no significant difference in neither percentage of patients with good adherence nor 3-month use hour per night between the 2 groups. This finding was explained by the lack of in-person contact in the intervention arm, whereas clinical appointments were only scheduled for the control arm.⁸⁰ Also, in the study of Bros and colleagues,¹⁵¹ a majority (78%) of patients expressed a favorable attitude toward telemonitoring, but nearly 40% considered the telemonitoring device like intrusive. Telemonitoring also encompasses the risk to mask some aspects of care, by relying excessively on technical parameters, forgetting the clinical context.²¹ This could result in a decrease in medical quality and dehumanization of care, missing the fact that monitoring CPAP use can be satisfying, but in a patient suffering from residual excessive daytime sleepiness, it is not the complete picture.⁶⁷ Whereas dehumanization of care with telemonitoring is a significant concern for the physician-patient relationship, this parallel route should not be underestimated. Moreover, it is very unlikely that telemedicine will completely replace face-to-face contacts. Importantly, the perfect match of both routes (with and without in-person visits) will likely improve health care as a whole.¹⁵²

ECONOMIC APPROACH

Cost effectiveness is an important factor to consider when discussing the role of telemedicine

in OSA, keeping in mind the ever-increasing health care expenses. Telemedicine can contribute to the improved cost effectiveness of OSA management during both the diagnostic and therapeutic phases. However, we must be cautious when applying these methods to the clinical setting, given that some studies have described that the intervention could not always be cost effective or even could induce negative outcomes. The evidence for unequivocally positive outcomes on patient health is still limited. Costs mostly depend on staff time and hardware expenses. Nevertheless, in a simulation of the cost effect, it was shown that if half of the patients were managed by telemedicine, the nationwide annual cost for management of patients with OSA would decrease with 17%.¹⁰⁵

Staff Time

Telemonitoring could be a time- and human resource-intensive tool for sleep centers and homecare providers. Frequent involvement of staff through in-person contacts or automated feedback triggering may counteract cost-effectiveness, because the same effects might be achieved through routine phone calls without the use of telemedicine device.⁸ Reviewing the downloaded information every week day is labor intensive and may not be feasible in all settings. One misunderstanding could be that patients consider their physicians to be routinely monitoring their data on a regular basis. However, such expectations cannot be met without having intermediary support (such as respiratory therapists or home-care providers) to assign certain trigger thresholds for the PAP compliance data to trigger when compliance is not being met.³⁹ Fox and colleagues⁶ quantified provider time and found that an additional 67 minutes on average per patient was spent managing the patients that were remotely monitored. A much greater number of interventions can be expected in the telemonitored patients. In patients with OSA with at least 1 intervention, an overall 59% increase in the number of physician interventions and 54% increase in the number of homecare provider's interventions was shown.¹⁰⁴ This finding emphasizes the need for a cost-effectiveness validation of such a strategy, given the greater burden of caregivers' interventions for both medical (persistent high residual AHI, residual sleepiness) and technical (masks, humidifiers) reasons. It could be speculated that a usual care intervention might be more efficient from a cost perspective, given that an average of 30 minutes may be necessary to respond to or to manage each alert.¹⁰⁴ In contrast, multimedia approaches could also help save nursing time, which

could inherently allow more patients to be managed with the same manpower.^{7,98} Recent studies demonstrated a reduction in labor requirements, nursing time and cost owing to telemedical care.^{7,80,98} Office staff telemonitoring of voluminous nightly data from entire practices of patients is daunting and generally not reimbursable. However, telemedicine may provide a pragmatic solution for practices attempting to manage huge amounts of nightly CPAP data for PAP patients over years. It is also not clear how long special patient groups, like people who had a stroke, might benefit from telemedicine while treated with PAP. In stroke patients, the costs seemed to be low, since the use increase was achieved with an average of 4.7 contacts per patient over a period of 6 months.¹⁰¹ The telemedicine concept led to a reduction of daytime sleepiness and blood pressure and might help increase quality of life after the stroke. Thanks to targeting of interventions to patients with problems observed, one can focus precious working hours on those PAP patients who really need additional support.

Equipment

Furthermore, telemedicine is rather expensive, and this is related to the complex technology required to implement telecare. These costs could be decreased by wider use of telemedicine in the future. As discussed earlier, Coma-del-Corral and colleagues²⁹ investigated telemonitored polygraphy in patients with clinical suspicion of OSAS. Telemedicine-polygraphy was performed on 40 patients, in a virtual sleep unit, in another hospital some 80 km from the central sleep laboratory. The sleep laboratory nurses performed real-time continuous telemedicine-polygraphy check. Continuous video monitoring (via a webcam) was also available. No polygraphy failure was observed, but data transmission failed for 2.5% of the recordings. The cost analysis showed also that telemedicine is associated with additional costs: telemedicine-polygraphy cost 277 € compared with 145 € for a PSG.^{29,153}

Access to health care

Another interesting aspect is that telemedicine can improve the efficiency of health care delivery in terms of costs and time. Of course, when setting up a telemedicine visit, the patients should be reassured that they will still receive the same level of care as they would get face to face. Studies reported a decrease in travel costs and office room rentals, which will likely not apply in all countries, because economic times and public transportation policies strongly differ. Russo and colleagues¹⁵⁴ analyzed the savings associated with

a telemedicine program conducted between 2005 and 2013. This program was associated with average travel savings of 145 miles and 142 minutes per visit, and access to health care services was streamlined and made more convenient for patients. Other wider benefits include decreased fuel consumption and carbon emissions associated with traveling to a clinical review. It is clear that these cost savings are most substantial for individuals in rural areas or areas without a sleep clinic.²⁰ Surprisingly, the use of supporting tools generally results in better adherence, although it is not effective to change lifestyle and behaviors.¹⁰² Furthermore, the application of advanced devices depends largely on individual income, and thus is not useful for most patients of lower socioeconomic status.⁹⁷ A few studies were conducted among Asian patients with OSA. Murase and colleagues¹⁰⁵ showed the noninferiority of a telemonitoring system at 3-month follow-up in CPAP adherence, whereas Chumpangern and colleagues^{79,155,156} reported an insignificantly higher CPAP compliance, and adherence was significantly higher in the telemonitoring group.

More Efficient Management of Resources: Addition of Artificial Intelligence

Telemedicine and Internet of things provide unprecedented opportunities for integrating comanagement approaches, multi-actor interactions and patient empowerment, and will generate a data deluge that could be addressed by advanced analytics.³⁹ Integrating information from diagnostic testing and positive airway pressure compliance databases could allow providers and systems to more efficiently manage resources. As an example, artificial intelligence could phenotype certain patient groups based on demographics or comorbidities and help providers allocate resources to those patients who have more complex diseases while providing lower cost care to patients who are doing well and unlikely to benefit from the more resource intensive model of care.¹⁵⁷ Instead of managing all patients in a similar fashion, data-driven decision-making could allow providers to better allocate resources, maintain or improve quality, reduce the cost of care, and improve value for insurers, providers, and patients.¹⁵⁷ In such a model, coordination of care with improved quality and efficiency will be valued more than the quantity of care that currently drives the traditional fee-for-service system.

Reimbursement

The promise of expanded OSA telemedicine applications is accompanied with cautious

considerations. Practical implementation into clinical OSA workflows requires an understanding of local payment for teleservices as well as assessment of available resources.

Practices may want to project potential lost in-person clinic revenue during telemedicine clinics and balance potential financial gains, because telemedicine visits may not be reimbursed at parity with in-person visits. Reimbursement at a relevant level for services rendered is the cornerstone of long-term revenue. Nevertheless, telemonitoring-guided support for PAP-treated patients reduces the number of patients terminating therapy, can improve PAP use, reduce the workload associated with follow-up for care providers, and will improve the economic model of treating sleep apnea patients at the end.¹²⁹

Need for Cost-Benefit Studies

Further studies are needed to clarify if personalized concepts with telemonitoring and direct patient contact or fully automated feedback messaging systems are more cost effective and achieve similar adherence results.¹⁰¹ The likelihood of improved adherence with telemedicine interventions will need to be balanced against the resources needed to implement the program and will require robust cost effectiveness evaluations. Well-designed and adequately powered trials are needed to establish whether this approach is a clinically effective and cost-effective option for CPAP management. Future studies could specifically adopt both societal and health care perspectives in examining cost effectiveness in comparison with usual care.

CHANGING PARADIGMS AND EXPANDING HORIZONS

Based on evidence from the literature discussed in this article, outcomes seem to favor telemedicine approaches. The evolution of sleep medicine care is full of incredible opportunities given its natural reliance of technology and relevance to so many medical specialties.³⁹ The potential for telemedicine to change and restructure current care management paradigms is immense. Telemedicine can provide the links between sleep specialists, primary care, industry, and the multidisciplinary sleep team.

Management Outside the Office

Evidence supports the noninferiority of synchronous telemonitoring compared with usual care for adherence. Using a combination of face-to-face telemedicine appointments, cloud-based positive airway pressure compliance monitoring,

and Internet-based communications and coaching, it is likely that many patients with uncomplicated OSA could be managed successfully outside of the office setting.^{7,44,76} For those patients who are doing well with their positive airway pressure therapy (or other treatments), a simple tele-health visit or Internet-based communication could suffice, leaving more time for patients with more complex problems to be evaluated in an office setting.¹⁵⁸ Also, self-monitoring of blood pressure and weight is gaining interest. Mendelson and colleagues¹⁵⁹ showed the feasibility of patient entry of blood pressure, CPAP use, sleepiness and quality of life data for clinician review, and McManus and colleagues¹⁶⁰ reported that patient self-monitoring of blood pressure, with or without telemonitoring, decreased blood pressure values after 1 year. These trends will certainly modify the patient-physician relationships.

Monitoring of Therapies Other Than Continuous Positive Airway Pressure

Emerging technologies are available that have sleep (position) e-monitoring capabilities.¹⁶¹ For instance, telemonitoring of oral appliance compliance data is feasible, based on temperature-sensing data chips embedded in the oral appliance. When combining with triple axis accelerometer technologies, oral appliance use times as well as supine versus nonsupine data can be monitored, and eventually shared web based between patient and care giver.¹⁶¹ Similar developments take place for hypoglossal nerve stimulation devices.¹⁶²

Lifestyle Modification

Telemonitoring of CPAP devices is now proposed as one component of a more complex and integrated strategy that use mobile health applications and wearable sensors to monitor physiologic parameters, such as blood pressure, body weight, sleep duration, and physical activity. This also emphasizes the changing perspective regarding sleep, as it is currently considered at least as important as exercise or diet in general health.¹⁶³ As stated elsewhere in this article, regarding comorbidities, CPAP treatment supported by a telemedicine system that included monitoring of blood pressure and sent reminders for physical activity and healthy diet via smartphones did not demonstrate efficacy in reducing cardiovascular risk in patients with OSA when used as secondary prevention.¹⁵⁹

In another study, telemonitoring was not superior to usual CPAP care for improving home blood pressure in patients with OSA and high

cardiovascular risk.¹⁰² CPAP compliance was 0.53 hours higher compared with usual care, which was statistically significant, but the modest difference in CPAP adherence between the 2 arms was probably not enough to induce a significant reduction in blood pressure. In contrast, total cholesterol and triglyceride levels were significantly lowered, and high-density lipoprotein cholesterol improved in the telemonitoring arm. Also, patient-centered outcomes, namely, sleepiness and quality of life, improved. In symptomatic patients with OSA with low cardiovascular risk, the implementation of multimodal telemonitoring did not give better CPAP adherence than usual care. The success of telemonitoring may be dependent on knowing who best responds to these new telemedicine approaches (age, education, geographic setting, race, phenotype, cluster).

Expanding Applications of Smartphone Apps and Wearables

Sleep apps remain among the most popular apps downloaded for Apple and Android devices.¹⁶⁴ The number of apps is continuously growing, and a multitude of them claim to track and define sleep-related metrics, improve sleep quality, and even screen for sleep disorders. Unfortunately, these apps lack minimal validation regarding the ability to accurately perform these functions. Equally, consumer sleep technologies (wearables) are self-described lifestyle/entertainment devices that are not subject to US Food and Drug Administration approval. Although patients may not be as concerned about this lack of validation, they seem to recognize some shortcomings of consumer health-related technology. At the best, these apps and wearables could be considered in the context of a comprehensive sleep evaluation, but should not replace validated diagnostic instruments. Also, minimal validation data exist regarding the ability of consumer sleep technologies to perform the functions that they purport to. However, these devices become increasingly sophisticated, some may undergo validation and ultimately have a role in clinical care. So, it is important to acknowledge them as adjuncts that may help with communication with patients, goal setting, and increasing patient engagement.¹⁶⁵ Even more, by making use of environmental factors, like ambient light, ambient noise, accelerometer analysis to detect nonmovement patterns, and smartphone use patterns allows clinicians to accurately estimate the owner's wake and sleep behavior. One promising approach is to add low-cost oximetry probes to a smartphone. Given the need of a continuous oximetry curve over a full night, this would put additional demands on the

system in terms of battery power. Also, beat-to-beat processing is important to maintain the rapid changes in oximetry, which are very typical for sleep apnea and not observed in other conditions.⁴ Apps could also be helpful to empower patients. Isetta and colleagues developed an mHealth app called APPnea, aimed at promoting patients self-monitoring of CPAP treatment. APPnea gave patients daily reminders to answer 3 questions about their OSA treatment ("Did you use your CPAP more than 4 hour last night? Did you perform any physical activity yesterday? Did you follow the dietary advice given? and once weekly the app prompted the user to answer "How much do you weigh?"). Those patients who used APPnea regularly showed a trend toward higher CPAP compliance (+0.5 hours per night).¹⁶⁶ The world of wearables and apps is here to stay, and our job is to figure out how to unlock the unlimited possibilities. Integration of these wearable sensors may add further actionable data that can potentially facilitate disease management.

Integration in the e-Health Sleep Record

Ideally, the data from CPAP devices should to be incorporated with the data regarding the physical status of the patients into the e-health sleep record. In a later stage, other aspects of digital technology will most likely be incorporated. Among them, integration of relevant health-related data collected from everyday apparel, wearable sensors and household appliances, increased interactivity between patients and health care provider, anticipation, and thus, hopefully prevent, worsening of medical disease states based on validated algorithms. Moreover, some consumer sleep technologies, usually smartphone- or tablet-based, to track or modify sleep are becoming widely available.¹⁶⁷ These applications are transitioning to reliably track snoring, sleep, oximetry, heart rate and presence of sleep apnea. At the same time, artificial intelligence algorithms and software to collect individual and group analysis of body weight, blood pressure, sleepiness, and other data for prediction models are advancing. Pathways need to be explored for special populations or patients with combination sleep, breathing, medical, or comorbid disorders. How to best incorporate these and other new entities into best-practice standard, hybrid, and telemedicine OSA workflows currently seems a moving average.

Remaining Barriers in the Incorporation of Telemedicine into Routine Clinical Practice

Generalization of the use of telemedicine has been hampered by multiple practical barriers,

such as the use of different CPAP brands, the lack of standardization of parameters used by different providers, preventing interoperability for health care professionals and the management of data within the existing electronic patient files.¹²³ Some concerns could be raised because of the limitation to perform a physical examination during teleconsultations. However, some elements of the examination, such as blood pressure or body weight can be easily obtained by the nurse or primary care physician.¹²³ Moreover, elderly subjects, who may benefit most from telemedicine services, may be disadvantaged because of cultural and practical barriers.¹⁶⁸ Similarly, economic issues may prevent use of telemedicine services in subjects with low socioeconomic status. From a data safety and health care regulation point of view, there is ongoing discussion about which data have to be regarded as general wellness and lifestyle data and which data have to be regarded as health care data to be used for medical diagnostic purposes.⁴ Many regulatory aspects are still open to this kind of application. Also, reimbursement issues remain.

COVID-19: Changing the Interest in Telemedicine

Since the start of the lockdown for COVID-19, the clinical activity regarding patients with sleep-disordered breathing has stopped owing to the limited access of patients to the hospital, and the risk of droplet dispersion associated with the use of ©PAP.¹⁶⁹ According to a multicenter European study, a minority of sleep centers used telemedicine regularly during the first COVID-19 lockdown, mostly to monitor compliance to treatment rather than for full clinical management.¹⁷⁰ Care for patients with OSA is a highly specialized, because they are often aged and have multiple comorbidities.¹⁷¹ The high prevalence of OSA in the general population is associated with long waiting lists, further lengthened during the pandemic. Telemedicine could potentially tackle this problem,^{21,123} but has not been included yet among the services provided by many health care systems.¹⁶⁹ A paradigm shift in sleep medicine practice after the COVID-19 pandemic has been foreseen, not only for OSA, but also for other sleep problems.¹⁷² Last year, interest in telemedicine for the management of patients with OSA is emerging, with identification of advantages and drawbacks.¹⁷³ Studies have mostly addressed questions regarding the role of

telemedicine in monitoring compliance to CPAP treatment, or follow-up after the initiation of treatment for OSA, but overall advantages over usual care were small, as the results of telemedicine care were comparable to, and costs were slightly lower than the usual sleep laboratory-centered management.⁵⁰ The COVID-19 pandemic has dramatically raised the issue of safety, changing the balance in favor of telemedicine, and will likely grow in the future. COVID-19 has also accelerated efforts to regulate but also to bill telehealth care, which will fasten the implementation of telemedicine.

SUMMARY

In this review, we demonstrated that telemedicine applications can be useful to monitor and motivate sleep apnea patients on a large scale. However, the effect sizes for compliance for telemedicine approaches are not as large as what has been achieved with the use of theory-driven approaches such as cognitive behavioral therapy, and the impacts on patient and provider satisfaction and cost effectiveness are not yet clear. These aspects of OSA care do not require substantial changes in care programs and strategies. In contrast, remotely monitored sleep studies and CPAP titration require more resources together with a change in patient care management. Given the turning hospital strategies toward more ambulatory care, telemedicine is going to evolve and it is very likely that there will be an increasing development of tools and activities in all areas of sleep medicine. Currently, efforts are being made to regulate but also to bill telehealth care, which will accelerate the implementation of telemedicine. This will certainly change the daily clinical practice, but we have to take into account the limitations of these techniques.

In future, large-scale adequately powered pragmatic clinical trials are needed to better understand the effectiveness and the role of the telemedicine approach in managing sleep-disordered breathing. Evidence for the long-term follow-up effectiveness of telemonitoring interventions in improving adherence to CPAP treatment remains undecided owing to a scarcity of available studies and their mixed results. What happens when patients are no longer monitored or followed-up by visits to the clinic after their first months using the CPAP machine? Challenges and growing pains are to be expected, but clinical needs, existing technology, and opportunities for growth abound.

CLINICS CARE POINTS

- Careful telemedicine management will provide a more seamless communication flow, to the benefit of medical providers, the global health care system, and ultimately for patients.
- Telemedicine ensures communication during the pandemic despite environmental barriers.
- Telemedicine can facilitate access to sleep medicine, and is not necessarily limited to rural areas.
- Use of filters is mandatory in order not to be overloaded by a tsunami of data.
- Advantages of telemedicine have to be weighed versus the resources required to offer qualitative telemedicine care.
- Although synchronous telemonitoring is non-inferior compared to usual care, ceiling effects regarding compliance play a role if the standard care is already of high quality.
- The success of telemonitoring may be dependent on knowing who best responds to these new telemedicine approaches (age, education, geographic setting, race, phenotype, cluster, patients with certain conditions), and special considerations could be necessary in specific target groups.

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