Newer Technology for Screening of Obstructive Sleep Apnea

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Introduction

A fully supervised, in-laboratory sleep study is considered to be the reference-standard for diagnosis of obstructive sleep apnea (OSA) and has, since a long time, been utilised as a benchmark against which all other diagnostic modalities have been compared. An overnight polysomnography (PSG) monitors many body functions during sleep and requires the patient to be hooked up to several diagnostic probes, often numbering more than sixteen, while being observed overnight in the setting of a sleep laboratory. Undoubtedly, it is all pervasive but has been the subject of criticism.[1] It requires overnight stay in the hospital, is inconvenient to a large extent, expensive and also requires the presence of a laboratory technologist to be in constant attendance. Most sleep laboratories running at full capacity, an in-laboratory sleep study also has long waiting list. Although several types of procedures have been enlisted (Table-1) as substitutes for such a test, none has been accredited with similar capabilities. Hence a search for a reliable diagnostic test for OSA has been a long cherished dream and a hot pursuit for several research workers in sleep medicine and allied subspecialties. This article shall focus on some of the newer technological developments in the diagnosis of OSA that have recently been the subject matter of discussion. If used judiciously with appropriate calibration and proper decision support, they can be potentially exploited for cost-effective, large scale collection of data and OSA screening purposes.

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Table 1: Types of procedures utilised for diagnosis of OSA[2]

Type of procedure	Portability	No. of Channels	Signals recorded
I	Laboratory–based	14-16	EEG, ECG, EMG, ECG/HR, airflow, effort, SpO_2 (plus others)
II	Portable	≥ 7	EEG, ECG, EMG, ECG HR, airflow, effort, SpO_2 (plus others)
III	Portable	≥ 4	Airflow and/or effort, ECG/HR, SpO_2
IV	Portable	1-3	Not satisfying criteria for type III

EEG: electro-encephalogram ECG: electro-cardiogram EMG; electro-myogram, HR: heart rate, EOG: electro-oculogram, SpO_2: oxygen saturation

Questionnaire Based Screening for OSA

Conventionally the Epworth Sleepiness Scale (ESS) has been used to identify patients with potential sleep disordered breathing (SDB).

A 4-variable screening tool was recently proposed to identify patients with SDB. It utilises gender, blood pressure, body mass index and snoring[3].

It has been compared to STOP, STOP-Bang and ESS questionnaire[4]. The STOP-BANG questionnaire has highest specificity to predict moderate-to-severe (87%) and severe (70.4%) SDB, while the 4-variable screening tool had higher specificity to predict moderate-to-severe and severe SDB (93.2% for both)[4]. Besides Berlin questionnaire, the various other questionnaires like STOP (snoring, tiredness, observed apnoeas, blood pressure),

STOP-BANG (STOP + BMI), age, neck, gender) have been traditionally used for OSA screening[5,6,7]. Other questionnaires like Multivariate Apnea Prediction Index and Pittsburgh Sleep Quality Index has a wide range of sensitivity and specificity depending on the Apnoea Hypopnoea Index (AHI) cut off level[2].

Signals utilised in sleep analysis

Rapid screening of various body signals has now been facilitated by the development of modern signal processing tools and cheaper processing hardware, improved video-processing software and hardware, data fusion and machine-learning techniques. Techniques of home sleep testing have been studied extensively. These have been compared with the reference standard in-laboratory PSG. With widespread availability of the "smart" mobile phone, there is an explosion of applications to monitor sleep quality on the phone. "Apps" for OSA detection combine a screening questionnaire with actigraphy from the in-built accelerometer, and analysis of the audio-signal recorded from the smart-phone's microphone or hands-free kit[8,9]. However there is little scientific evidence to support any recommendation for their routine use.

Magnetic Distance Recording

Measurement of vertical mandibular position during sleep has shown that it is more open in patients with OSA when compared with healthy adults without OSA. Also the mandibular opening increases progressively during apnoeic episodes, decreasing at the termination of apnoea[10,11]. Automated analysis of mandibular movement can be provided by a distance-meter based on the principles of magnetometry. Two coils and capacitors, each embedded in a small cylinder, are placed parallel to each other, perpendicular to the midline of the face. An electronic circuit converts distance into voltage, allowing for the detection of salient mandible movement, which is a surrogate for arousal. Attended full PSG with two methods combining nasal airflow and pulse oximetry recordings, with or without mandibular movement automated analysis for the detection of respiratory events has been compared[12]. Such measurements could also outline the impact of jaw position on upper airway collapsibility during sleep and potentially help determine ideal patients for mandibular advancement device (MAD) therapy[13,14].

Entropy of Tracheal Sounds to Detect Apnoea

Entropy of the acoustic signal from a microphone placed over trachea has been shown to reliably provide an early warning of the onset of obstructive and central apnoea in volunteers under sedation with propofol and remefentanil[15]. In that study, respiratory flow rate and tracheal sounds were recorded using a pneumotachometer and a microphone. The logarithm of the tracheal sound Shannon entropy (Log-E) was calculated to estimate flow rate. An adaptive Log-E threshold was used to distinguish between the presence of normal breath and apnoea. Apnoea detected from tracheal sounds was compared to the apnoea detected from respiratory flow rate. The acoustic method detected obstructive and central apnoea in sedated volunteers with 95% sensitivity and 92% specificity[15]. Non-invasive estimation of neck fluid volume can also be made by acoustic measurements with a microphone placed at the supra-sternal position. The role of accumulation of neck fluid in pathogenesis of OSA can thus be clarified[16].

Acoustic reflection technique using transmitted acoustic waves in the airway

Cross sectional area of the upper airway has been measured non-invasively by acoustic reflection technique using incidental and reflected sound waves introduced through mouth or nostril. Miniaturized microphones and a driver were introduced into the airway to measure transmitted waves in a three-microphone method[17]. The pharyngeal cross-sectional areas including retropalatal and retroglossal regions and the site of airway closure during sleep could thus be visualised. This technology may have a potential role in future in a better understanding and designing of therapeutic interventions in OSA.

Passive infrared (PIR) technology for detection of breathing movement

Breath Motion Detection System (BMDS) is a new concept that uses Passive Infrared (PIR) technology for a contact-less detection of respiratory movements. Every object at temperature above absolute zero emits infrared radiation. When placed on body surface, emitted infrared radiation can be detected by piezo-electric sensors. By

using a differential amplifier between two such points, it is possible to detect the difference in amount of heat received and therefore the heat source motion. The PIR device does not emit an infrared beam but merely passively accepts incoming infrared radiation. Low amplitude movement detection such as chest and abdominal movement produced by respiratory effort or air temperature changes around nose area can easily be thus detected[18]. The technology is safe, inexpensive and simple. The potential clinical application needs to be further studied. Significant physiological information relating to breathing as well as bodily motion can be obtained.

Spectral Analysis of Thoraco-Abdominal Motion and Oximetry

It has been observed commonly that nasal oral airflow sensors are often uncomfortable and prone to signal artifacts. In contrast, thoraco-abdominal motion sensors are well tolerated. The presence of simplified systems have been considered to identify the cyclical pattern of OSA using spectral analysis of PSG signals[19-21]. The low frequency component of the PSG power spectrum carries important information as the periodic nature of OSA events. Frequency and time-frequency spectral analysis of pulse, blood pressure and heart-rate variability demonstrate oscillations in the low frequency range (i.e. 0.01-0.1 Hz) that correlate with the presence of OSA[19-21]. It has been reported that magnitude squared coherence (MSC) analysis of simultaneously recorded airflow and oximetry signals also displays OSA related oscillations in the low frequency band of PSG spectrogram[22].

Low frequency oscillations in the spectral analysis of PSG bio signals is an important diagnostic signature of OSA and possibly can be used to design simplified tools to detect OSA[23].

Non Contract Biomotion Sensor

Non-contact biomotion sensor has been developed for identifying sleep/wake patterns in adults. It uses ultra low-power reflected radiofrequency waves to determine respiratory movement of a patient during sleep. It uses the same principle as radar that is also used in aviation and defence sectors. Recent developments in miniaturization, semiconductor technology and computation have been very helpful. When evaluated against reference-standard polysomnography, the overall per-subject accuracy was 78% with a Cohen's kappa of 0.38.[24] The non-contact biomotion sensor is unobtrusive and offers contact-less and easy measurement of sleep/wake patterns in the home. Patients do not have to remember to wear special headbands, watches etc. It may prove to be a potentially useful home-based device for sleep/wake assessment in circadian rhythm disorders and evaluation of SDB.[24] Its absolute performance has also been compared with actigraphy[25].

Drug induced sleep endoscopy (DISE)

This procedure comprises pharmacologic induction of sedation and flexible fiberoptic endoscopy to visualise upper airway obstruction and/or snoring[26,27]. It is also termed as sleep nasoendoscopy, somnoendoscopy, somnoscopy, sedated endoscopy and propofol-sleep endoscopy. It is indicated when surgery or mandibular repositioning appliance (MRA) therapy is being considered as a treatment option. Severe OSA (AHI > 70 events/hour) and severe obesity are relative contraindications. The pattern of findings is reported as per the VOTE (acronym for velum, oropharynx, tongue base and epiglottis) classification. The VOTE classification system has been recently proposed.[27] It focuses on primary structures that contribute to upper airway obstruction, either alone or in combination. DISE is a qualitative, and not quantitative, assessment of vibration and obstruction event, the clinical cut-off prints being (a) none (b) partial and (c) complete. Common sites of obstruction and vibration are located in the soft palate, lateral pharyngeal walls, including tonsils, and base of tongue. Epiglottic level of obstruction is less common. Surgical procedures may exert differential effects on each of these structures; hence distinguishing between the structural contributions may play an important role in selection of procedure and outcome measurement[27].

The older Fujita classification system included two primary regions of pharyngeal upper airway obstruction namely the palatal/ velo-pharyngeal region and hypopharyngeal/ retrolingual regions.

Pulse Transit Time

Pulse transit time (PTT) is the time taken for the pulse wave to travel from the aortic valve to the peripheral pulse. The velocity of the pulse wave is directly proportional to the inverse of systolic blood pressure. Any increase in the blood pressure results in increase in

vascular tone which, in turn, stiffens the arterial wall. This causes a reduction in PTT and a transient dip in its tracing. The opening of aortic valve is marked by the R wave on ECG. Isometric contraction of the left ventricle, results in a slight delay between opening of aortic valve and R-wave. Prolongation of isometric contraction time, as caused by inspiratory effort, amplifies the PTT signal. It is essential to incorporate ECG leads for recognition of R-wave and oxymetric probes to access the arrival of the pulse wave in the peripheral pulse. Usually the point on the pulse waveform that is 50% the height of the maximum value is utilised for recognition of the R-wave. The normal value of PTT is 200 to 300 milliseconds (with an accuracy of 2 milliseconds) when using the finger probe. An increase in heart rate and blood pressure accompanies every arousal. This results in a change in PTT; thus any change in PTT indicates arousals. As PTT is inversely correlated with blood pressure, a PTT micro-arousal is defined as a transient dip in PTT from baseline. The shape of the area above the curve of PTT must be related to the time course evolution of blood pressure in order to accurately define a PPT arousal. Spontaneous variations in sympathetic activity (and therefore PTT baseline) are common during REM sleep. Therefore identification of true micro arousals during REM sleep is more difficult than during other stages. PTT can be used to analyse respiratory effort and is therefore helpful in recognition of upper airway respiratory syndrome and central events. Cardiac arrhythmias, movements of finger probe, poor oxymetric signal, peripheral arterial disease and poor ECG quality are associated with false PTT values[28].

Peripheral Arterial Tonometry

Peripheral vasoconstriction, caused by increased sympathetic tone, is recognized by a sensor applied to the subject's finger. This method has been validated in a number of studies, both in isolation as well as in combination with oximetry and/or actigraphy. It has the potential to allow estimation of future cardiovascular risk in the identification of endothelial dysfunction[29,30]. The surge in sympathetic activity, as measured by peripheral arterial tonometry, correlates with EEG arousals[31,32,33]. The biggest strength of PAT-based technology is its non-invasive nature. However, it has limited use in patients who have cardiac arrhythmia or those who are on peripheral alpha-blocking agents.

Home Sleep Testing

Home sleep testing (HST) has recently gained popularity in cases of moderate and severe sleep apnoea without any co-morbid disorders. However, this is a debatable topic though data is suggestive of almost equal outcomes in both home sleep testing and traditional approach[34,35]. Several types of equipments are used in the home setting, generally with fewer number of input channels and potentially less data to interpret. It is often opined that, in this respect, the number of channels is less relevant than the sensitivity and specificity of the device and the clinical outcomes that a given device can achieve[36]. Since HST does not monitor sleep and assumes that total recording time is actually not recorded; positional therapy becomes hard to implement. Hypopneas that terminate as arousals from sleep are also ignored in HST. HST devices that assess sleep stages and arousals score better than those without this facility.

Heart Rate Variability

Heart rate as well as amplitude of ECG vary cyclically with sleep apnoea cycles and this can be used for sleep apnoea screening[37,38,39]. Day-night variability of ECG is also useful[40]. A combination of heart rate variability and ECG amplitude imparts accuracy to classification of sleep apnea[41,42].

Capnography

Capnography based on infrared absorption spectroscopy is utilised to record PCO2 during sleep study (end-tidal PCO2). Transcutaneous PCO2 can be sued as an alternative. Recent introduction of novel transcutaneous combined sensor for PCO2 and arterial oxygen saturation monitoring has been clinically implemented[43,44].

PVDF Thermal Sensors

Poly-vinyledene fluoride (PVDF) film thermal sensors have a faster response time than traditional thermal devices. The signal is 1,50,000 times stronger than the signal produced by thermocouple and is more accurate. It can detect both nasal and oral flow[45].

Fiber Grating Vision Sensor

This is a non-contact respiratory monitoring device that can detect changes in volume by measuring movement

of laser spots on body surface (>100 sampling points on upper half of body). It discriminates between OSA and central apnea[46].

Mattress Sensor Technology

Several technical advancements have been made in designing mattresses that can analyse body movements, respiration and cardiac pulses. Electromechanical film transducer sensor, air-tube with differential pressure sensors, polyvinyl tubes filled with air-free water, temperature and humidity monitors, high-resolution force sensors etc have been used for the same purpose[44,47,48].

Intelligent Textile Technology

Textile sensors can now be embedded in smart garments resulting in minimization of weight and size of electronics, reduction of power consumption, designing of specific algorithms for signal conditioning and minimisation of motion artefacts[49]. Specially designed vests can integrate a textile-based piezo-resistive plethysmograph that detects changes in thoracic circumference from which respiratory frequency is derived. The same conductive fibers are processed to design the plethysmograph, connect the transducers with the electronic module, which is hooked to the vest at waist level by a Velcro stip[50].

Telemedicine

With reference to sleep related breathing disorders, telemedicine can improve treatment compliance, remotely download previously recorded data as well as transmit real-time physiological parameters while the patient sleeps[51]. Telemetry based sleep monitors, consisting of a 14-channel wearable wireless monitor and a mobile phone-based gateway to transfer data, including video, in real time from patient's home to a remote sleep centre, are now proposed[52].

Motion Detection

Motion detectors such as actigraphs worn on wrist have been used since 1990s. Rest periods are assumed as sleep. They have been utilised to assess dynamic respiratory movements and screen for SDB[53,54].

Automation and Computer-assisted Scoring Technology

Attempts have been made recently to partially or totally automate scoring of polysomnography data. These approaches are, however, fraught with risks and benefits. Computer aided algorithms are reproducible and help to overcome human fatigue during scoring. On the other hand, manual scoring ensures incorporation of human experience. Robust computational analysis of EEG as well as respiratory events needs further development[36].

Conclusions

Rapid strides have been made and are ongoing in every field of technology. There is ample reason to reaffirm faith that technological advances will redesign the practice of clinical sleep medicine. More extensive evidence is, however, required to translate these changing paradigms and innovative technologies into better and personalized patient-care algorithms.

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