Sleep Studies

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A sleep study monitors, records, and documents various physiological parameters during sleep, allowing the physician to both evaluate sleep and diagnose sleep-related disorders. These disorders decrease quality of life and productivity while increasing morbidity and mortality and generally fall into one of four categories.

The first, dyssomnias, include both difficulty falling asleep (insomnia) and staying awake (hypersomnia), sleep apnea (cessation of breathing), and narcolepsy (irrepressible attack of sleep during waking hours). The second is the group of parasomnias that includes sleepwalking, night terrors, sleep talking, nocturnal leg cramps, and other unwanted physical events occurring during sleep. The third category includes disorders related to other medical or psychiatric conditions that may cause cardiac ischemia and peptic ulcers. The fourth category, pertaining solely to researchers, consists of proposed sleep disorders that have not been conclusively proven to exist.

Typically, a sleep study is performed in a facility outside the study subject's home, although monitoring of some parameters can be achieved using a specialized digital recorder at home. The study setting resembles a hotel room or bedroom, often with an adjacent lavatory to facilitate bedtime preparations, away from typical hospital activity. Usually there is a room adjacent to the study setting (or it may be common to several study rooms) containing the medical equipment used to perform the study as well as one or more medical personnel to react to any life-threatening situation (e.g., severe apnea, dangerous cardiac arrhythmias, etc.) occurring during the study. Normally the study subject will "check-in" late at night, prepare for bed, and the study will typically take place from 11 p.m. to 7 a.m., during the normal sleep hours.

The standard protocol for a sleep study includes limited electroencephalography (EEG), electrooculography (EOG), electrocardiography (ECG), electromyography (EMG), airflow monitoring, respiration and blood oxygenation measurements, and audio-visual information on the study subject's behavior during sleep.

Current Technology

Although the equipment necessary to perform a sleep study may be cobbled together from excess equipment, the best arrangement is to employ a dedicated polysomnography analyzer. Some analyzers can handle two or more simultaneous studies performed in different rooms while other analyzers monitor only a single bed. The basic analyzer consists of a computer (with its monitor and printer), a time code generator, a video recorder, a video monitor, a junction box (called a 'headbox', similar to that used an EEG), and a video camera. The camera and junction box are located in the study setting, with the remainder of the equipment located in the adjacent room, allowing both monitoring and adjustments to be made without disturbing the subject. The time code generator is a critical item, feeding data to all the other devices to ensure a consistent time relationship between device outputs, audio-visual data, and significant events. The computer emulates and incorporates a number of other medical devices via the headbox and often contains a modem or Ethernet connection so the collected information can be analyzed remotely.

The headbox, which is normally located at the head of the study subject, performs two critical tasks. It is similar to the headbox used for EEGs, but it also contains a full body diagram and jacks for connecting other electrodes and sensors in addition to the head diagram used for the EEG leads. Here, the various monitoring cables join at a central point located to facilitate normal sleep movements and not interfere with the subject lying on his or her side, back or stomach. These cables are not as cumbersome as one might think. For example, sleep study EEGs use montages of between four and eight of the 21 regular electrodes to generate one to six traces instead of the typically 16 simultaneous traces in full EEGs. Sleep study EEGs use either scalp electrodes affixed with a conductive adhesive or an electrode cap containing gelled electrodes to allow normal sleep subject movement during slumber. Since the electrodes detect analog signals, the electrode box also contains the necessary analog-to-digital converter circuitry to send sleep study information to the computer for storage and future analysis. Lastly, the box usually connects to the computer's cable with a quick-disconnect electrical fitting to facilitate bathroom visits. Medical and other types of devices incorporated into the system are described below.

Electrooculography (EOG). In a sleep study, a simplified form of EOG is used to simply record eye movements using two pair of electrodes, one pair placed on either side of each eye, connected to the headbox where indicated on the full body diagram. Recorded eye movements determine the time periods during which the subject is in rapid-eye-movement (REM) sleep. Coupled with the EEG, the EOG can help determine the time between getting into bed and the onset of sleep, total sleep time, the amount of time spent in each sleep stage, and the numbers of arousals from sleep.

Electrocardiograph (ECG). Normally, sleep studies employ a single channel ECG using only two electrodes. The electrodes are placed atypically, with one usually placed on the left side of the chest and a second placed near the breastbone. The electrodes also are connected to the headbox where indicated on the body diagram. The millivoltages picked up by the electrodes correlate directly to the heart's electrical activity, are amplified and processed by the computer. If the physician suspects nocturnal angina or other cardiac problem, either additional electrodes are used or a full ECG is recorded.

Electromyography (EMG). This technique is similar to EOG since both measure the electrical potential generated during muscular contractions. But in the case of EMG, the muscles are not limited to the eye and EMGs frequently induce electrical potentials into muscles to both measure transit time and test muscle function. The sleep study EMG generally uses two channels, one measuring submental EMG activity and one measuring limb movements. The submental electrodes are generally placed under the chin and affixed with either collodion (like the EEG electrodes) or an adhesive paste; their leads connected to the headbox. The limb electrodes are often applied over opposing anterior tibial muscles, run up the study subject's body, and connected to the headbox where because they are connected to lower extremities, are separately connected to the headbox where indicated.

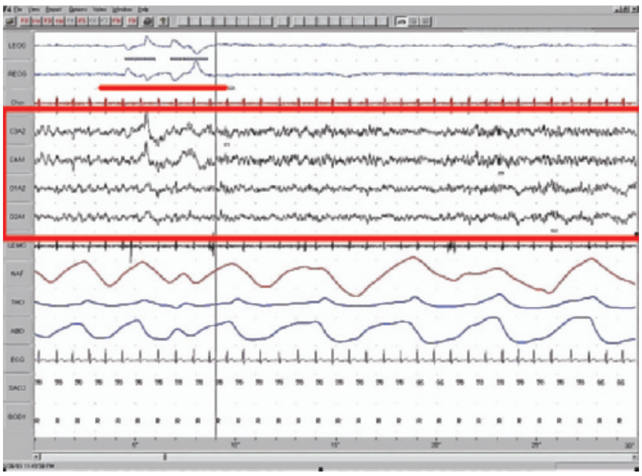
Respiratory assessment. Assessment of respiratory effort and airflow can be made both directly and indirectly, but since the assessment is to be done while the subject is sleeping, indirect assessment is the method of choice. The most popular indirect methods are impedance pneumography, inductive plethysmography, and pneumatic abdominal sensors. Impedance pneumography passes a high-frequency low current through electrodes placed on either side of the chest. Impedance variations caused by expansion and contraction of the chest cavity are detected and are interpreted as breaths.

Inductive plethysmography employs two electrode bands encircling the thorax and abdomen, creating an electromagnetic field. As the subject breathes, movement of the bands changes the electromagnetic field and these changes are interpreted as breaths.

A pneumatic abdominal sensor is simply an encapsulated pressure-sensitive capsule placed on the subject's abdomen. Since the abdomen expands and contracts as the subject breathes, the pressure felt by the capsule increases and decreases, allowing the analyzer to indirectly measure breathing.

All three methods merely reflect the subject's attempt to breathe without actually determining if there was air movement. To confirm there was air movement in and out of the subject's lungs, a thermistor is placed in front of the nostrils and mouth to sense the changes in temperature as the subject inhales and exhales. These temperature changes (a decrease on inhalation and an increase on exhalation) confirm that an actual air exchange had taken place. As with the other electrodes and sensors, these plug into the headbox as well.

Respiratory dysfunction is evaluated by monitoring blood oxygenation. Considering the methods available to assess oxygen saturation in blood, pulse oximetry is the



This is a screenshot of a polysomnographic record (30 seconds) representing Rapid Eye Movement Sleep. Photo credit: Wikipedia, public domain

method of choice for the subject since it is both low cost and noninvasive. The basic principle of pulse oximetry is that deoxyhemoglobin absorbs red light and oxyhemoglobin absorbs infrared light in proportion to the carbon dioxide and oxygen present in the blood. By shining both visible red (around 660 nm) and infrared (IR, around 930 nm) light through a small appendage to a photodetector on the other side (and correcting for the pulsation of arterial blood) oxygen saturation can be determined. The visible and IR light emitting diodes (LEDs) and photodetector are physically located on either side of a clamshell-designed sensor mechanism that either fits over a finger or clips to an earlobe. Like the other electrodes used in polysomnography, the pulse oximetry sensor plugs into a designated jack in the headbox. However, some designs depend on an external off-the-shelf pulse oximeter integrated into the system, with its output sent to the computer.

Another component of a sleep study protocol is capnography, the measurement of CO_2 in the subject's exhalate. Fortunately, both CO_2 and water vapor absorb certain frequencies of infrared light, so measurement of a sample is relatively simple to perform using spectrophotometry technology. The sample is obtained by placing a cannula (similar to that used to provide supplemental oxygen) by the nose, connecting it to a sampling pump to obtain a continuous sample of the exhalate, and passing it through a colorimeter to measure the absorbance. The capnograph is connected directly to the analyzer, but its hose is not normally connected to the headbox. A few analyzers use a more direct method to determine expired CO_2, but this sidestream method is the most common.

Other optional parameters, depending on physician preference and specialty application, include but are not limited to an intraesophageal pH probe measuring gastroesophageal reflux, strain gauges to measure penile tumescence, and moisture sensors for detecting enuresis (bedwetting) episodes.

Video and other equipment. The video camera located in the study setting serves a number of functions. It, along with the accompanying microphone, records both the body position and the sounds of snoring, other movements during sleep such as tossing, turning, limb movements, etc., and any seizures that might occur. The video camera provides a full-body view and must be able to record in low and near-no-light conditions. The camera should be remote controlled, with not only pan and tilt movement capability, but also equipped with a zoom lens to concentrate on observer-noted events such as facial movements, twitches, tics, and other involuntary events. Some camera-microphone systems are sensitive enough to pick up low volume vocalizations (muttering, sleep talking, etc.) and respiratory sounds.

The video monitor connected to the video camera allows staff to monitor subject movements in real time, triggering an event designator, and make observation log entries when necessary. Because sleep studies are usually performed on otherwise healthy individuals, most polysomnography analyzers lack the typical alarm functions (for ECG, respiration, and pulse oximetry, for example) found on patient monitors used in wards. Therefore, the monitor is essential in detecting life-threatening conditions, especially where one technologist is simultaneously monitoring studies on different subjects. Also, certain movements, such as sitting up, are not very well documented without the video recording since other monitored parameters do not adequately reflect this activity. The technologist observing this activity can also trigger the event designator.

The video recorder (VCR in legacy units, CD/DVD in current designs) provides permanent documentation of all movements, and often sounds, of the subject. If the camera employs a remote-controlled zoom lens, even relatively minor and apparently insignificant twitches can be documented for focused review. One of the key features of the resultant recording is the time key stamped on each frame of the tape, allowing the clinician to correlate instrument readings with body movements.

The time code generator synchronizes the time relationships between the various monitored parameters, audio-visual recordings, and documented significant events such as observed parasomnias such as sleep apnea. Its most important use is to coordinate the different readings taken during a significant event and aid in establishing a precise sequence of parameter changes during a significant event. Depending on the design of the individual analyzer system, the generator may be part of the computer, may accept timing pulses from the computer for synchronization, or may provide a synchronization signal to the computer. In all cases, the time code generator output appears as a time stamp on each reading of each device, including the video recording of the sleep study session.

The computer is the heart of the polysomnography monitor. It provides the single collection point for the data acquired during the sleep study via the headbox, its software emulates a number of medical devices, and accepts data from and coordinates the actions of the external devices. Many times it also provides the master or synchronizing time signal for the time code generator.

The computer monitor displays the waveforms acquired by the system and often allows the practitioner to prepare, print, and transmit study evaluation reports as well as to record the acquired data in digital format for later use. The computer monitor displays the data gathered as it is recorded and stored and allows the technologist or clinician to indicate regions, times, and/or areas of interest for later examination with some interactive device like the keyboard, a mouse, or even a touchscreen.

The printer is used to produce color hard-copy documentation of waveforms, and many systems include imbedded word processor and spreadsheet applications to allow the clinician to provide complete narrative study reports along with the waveforms. A typical analyzer will contain, in addition to the hard-copy printer, other methods of storing data such as an external hard disk drive, a CD/DVD, or a tape drive. Lastly, many times the computer contains Ethernet communication capability. This is valuable when sharing study data for outside study, linking analyzers in a networked application, updating software, etc.

Managing the Device

Like many complex and expensive medical devices, polysomnography analyzers should be individually managed. Routine maintenance, such as preventive maintenance, calibration, and electrical safety testing, as well as remedial maintenance should be uniquely tracked by serial number or a locally assigned asset tracking number. The maintenance activity should maintain a detailed maintenance history of these actions as well as the application of periodic software upgrades and software patches. If adequate manufacturer's literature is available, the analyzer can be maintained with in-house assets. Generally these

Decoding the Mysteries of Sleep

The history of sleep studies and polysomnography is relatively short, in relation to the overall history of medicine and medical devices, because this is a relatively new field. In 1935, researchers documenting "normal" sleep patterns discovered Rapid Eye Movement (REM) sleep.

In the following years, researchers tried using electroencephalography to gain insight into and document sleep-related events. This, however, provided a very limited understanding of sleep and the pathologic processes that affect sleep.

Efforts to improve the EEG as a research tool led researchers to observe other physical characteristics of sleep, which led to the use of additional modalities, such as electrooculography (EOG) to document eye muscle movement during REM sleep. At that time, technology did not allow for easy correlation of multiple instrument readings, so research into sleep proceeded at a snail's pace.

It was not until the advent of the personal computer that researchers were able to assemble the voluminous data from EEG, EOG, ECG, EMG, pulse oximetry, and (eventually) instrumentation to assess breathing ease or difficulty, airflow, and gas exchange measurements into a single display of physiological events occurring during sleep studies. Once this remarkable tool was accepted by medical practitioners, polysomnography moved out of the research laboratory and into the clinical setting. Here the computer turned a wealth of data into information that was much more revealing and more easily interpreted by the physician.

Over the past decade, physicians began ordering sleep studies to confirm or rule out a number of conditions ranging from narcolepsy and vigorous movements during nightmares to breathing difficulties and snoring caused by obstructive sleep apnea.

analyzers are quite reliable, so first-call, or billable as-needed services are a consideration if software upgrades can be included in the first-call contract or purchased as a billable service.

Regulations

Aside from the normal Health Insurance Portability and Accountability Act (HIPAA) of 1996 concerns regarding personal medical information that may be stored in the computer portion of the analyzer, there are no specific regulations covering polysomnography analyzers.

Risk Management Issues

Risk management is almost completely within control of the technologist. For example, the collodion often used to attach the EEG electrodes to the scalp is not only highly flammable, but also may irritate the skin. Therefore, collodion and acetone should be used with extreme caution on subjects using supplemental oxygen. Also, as with any medical device having a plethora of electrodes and lead wires, there is always the possibility of connecting unprotected electrode wires to an electrical source such as a power cord mistaken for a device input cable.

Common Problems and Solutions

Although the computer emulates a number of otherwise discreet medical devices, it does not make the analyzer immune to their common problems. Each computer-emulated portion of the analyzer is susceptible to the same problems as its stand-alone equivalent. Fingernail polish and false nails cause problems for pulse oximeters and poor surface preparation can cause artifact problems for EEGs and ECGs. As with EEGs, ECGs, EOGs, and EMGs, improper electrode placement and incorrect filter settings can result in misleading waveforms. Additionally, external electromagnetic fields can induce interference into any of the electrode wires connecting the subject to the headbox. Fortunately, most of these problems are recognized and corrected by experienced technologists and clinicians, but occasionally studies are compromised by electrical interference no matter what the operator tries. At this point it is incumbent on the biomedical equipment technician to look holistically outside the immediate testing area.

Training and Equipment Needed to Service EEGs

As with all computer-based medical devices, computer literacy is a requirement. Additionally, the biomed must be conversant with the basics of each subsystem as well as how they are integrated into the complete polysomnography analyzer. In large sleep study laboratories, computer networking knowledge is a definite plus. Lastly, if it is available, manufacturer training is almost essential to understand how the individual subsystems are combined into the analyzer as well as the intricacies of the system software.

Normal handtools and service aids such as patient simulators are required to service polysomnography analyzers. Fortunately, the computer platform is normally quite stable and hard failures are rare. The service person should have the necessary passwords and rights to reload operating software and patches as well as application software and upgrades when necessary.

Future Development of EEGs

Polysomnography systems entered clinical use in the mid-to-late 1960s. Compared with the vast array of medical devices available to today's medical practitioners, they are essentially new technology even though it is almost 40 years old. Although the first polysomnographs used ink pens to record waveforms on moving paper, computer-based instruments quickly replaced them in the field of sleep study. Efforts to effect continual product improvement are ongoing. Expect improvements in software, the inclusion of even more devices, and improvements and expansion in home-based data acquisition via a small Holter Monitor-like device. This new tool also allows the clinician to make side-by-side comparisons of readings taken during the study subject's waking hours with those taken during a sleep study.

Whether it uses a Polysomnography Analyzer (commercially available as a single piece of equipment) or a collection of discreet items that provides some of the same information, the purpose of a sleep study is straightforward. This article covered the single analyzer, but the fundamentals covered here apply to any discreet device that performs the same function. ■

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