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THIRD EDITION Sudhansu Chokroverty
Sleep Disorders Medicine
Basic Science, Technical Considerations, and Clinical Aspects

Part II – Technical Considerations

Chapter 11 – Polysomnographic Technique : An Overview

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INTRODUCTION

The term *polysomnography* (PSG) was proposed by Holland, Dement, and Raynal[1] in 1974 to describe the recording, analysis, and interpretation of multiple, simultaneous physiologic parameters during sleep. PSG is an essential tool in the formulation of diagnoses for sleep disorders patients and in the enhancement of our understanding of normal sleep.[2–14] It is a complex procedure that should be performed by a trained technologist. Innovations for monitoring changes in physiology during sleep continue to hold great promise in the quest to understand healthy sleep and to diagnose sleep disorders.

Recent publications in polysomnography include the 2005 American Academy of Sleep Medicine (AASM) standards of practice and practice parameters guidelines for polysomnography.[15] As well, the *International Classification of Sleep Disorders: Diagnostic & Coding Manual*[16] describing more than 85 sleep disorders was revised in 2005. In the same year, an AASM task force was established to review and revise scoring of PSG data. The first papers from that process are published (see Chapter 18). Numerous atlases of PSG data have been published, expanding the knowledge of PSG, normal sleep, and sleep disorders.[17–23] The reader is directed to other references[24–38] for current indications and standards of practice articles that have appeared in the literature since the previous edition of this text. Summaries of key relevant points have been incorporated into this chapter. Currently, the Board of Registered Polysomnographic Technologists reports more than 7000 registered PSG technologists around the world. In January 2006, the AASM established an accreditation program for training PSG technologists.

This chapter is a review of the technical aspects of PSG, providing a step-by-step approach to traditional, classic in-laboratory PSG recording techniques. Problems likely to be encountered during a recording are examined, as are ways to alleviate them. Figures and actual tracings augment the text and help identify artifacts. An entire chapter in this text (see Chapter 18) is dedicated to the use of digital PSG systems. A brief discussion of digital recording and comparisons between analog and digital systems are made throughout this chapter. Digital systems have become the primary tool to collect, manipulate, display, and store data from sleep studies. Elsewhere in this volume, specified protocols are discussed and physiologic recording techniques are reviewed in detail. Recent advances include sleep studies transmitted over the Internet for scoring and final interpretation, wireless PSG systems, and studies validating alternative technologies in comparison to PSG.[39] Technological advances have enabled increased possibility of monitoring sleep and enhanced ability to deliver sleep health care. PSG continues to be held as the gold standard for diagnosis of sleep disorders.

Clinical Indications for PSG

According to the 2005 AASM proposed guidelines,[15] an attended PSG is considered the standard of practice for

- Diagnosis of sleep-related breathing disorders (SRBD)
- Positive airway pressure titration
- Preoperative assessment before snoring or obstructive sleep apnea (OSA) surgery
- Evaluating results of the following treatments:
  - Oral appliances for moderate to severe OSA
  - Surgical procedures for moderate to severe OSA
  - Surgical or dental procedures in SRBD for return of symptoms

- Treatment results requiring follow-up PSG:
  - Substantial weight loss or gain (10% of body weight)
  - When clinical response is insufficient or when symptoms return

- Patients with systolic or diastolic heart failure and nocturnal symptoms of SRBD
- Patients whose symptoms continue despite optimal management of congestive heart failure
- Neuromuscular disorders with sleep-related symptoms

- Narcolepsy (Multiple Sleep Latency Test [MSLT] after PSG)
- Periodic limb movement disorder in cases secondary to complaints by patient or observer (movements during sleep, frequent awakenings, excessive daytime sleepiness)

PSG is not required to diagnose

- Parasomnias
- Seizure disorders
- Restless legs syndrome
- Common, uncomplicated, noninjurious events (arousals, nightmares, enuresis, sleeptalking, bruxism)
- Circadian rhythm disorders

Diagnosis with clinical evaluation alone is the standard in these cases. Standard evaluation includes history, details of behavior, age of onset, time, frequency, regularity, and duration.

PATIENT CONTACT

A number of factors need to be kept in mind when a PSG is scheduled. Issues such as shift work, time zone change, or suspected advanced or delayed sleep phase syndrome should be taken into consideration. The study should be conducted during the patient's usual, major sleep period, to avoid confounding circadian rhythm factors.

When the PSG is scheduled, the patient is sent a questionnaire about his or her sleep-wake history and a sleep diary that solicits information about major sleep periods and naps for 2 weeks prior to the study (Appendix 11-1). Information is provided for the patient about the purpose and procedures of the sleep study. The goal is to make the patient's experience of the sleep study as uncomplicated and comfortable as possible.

In sleep laboratory settings, the technologist should ensure that patients are familiar with the surroundings and that they receive explicit information about the process. Patients should be shown to a bedroom and through the laboratory. They are made aware that someone will be monitoring their sleep throughout the entire study and told how to contact the technologist if necessary.

Before the study is undertaken, a full medical and psychiatric history should be completed and made available to the technologist performing the study. This information is necessary for correct interpretation of the data, and it allows the technologist to anticipate difficulties that may arise during the study. Technologists must also understand what questions the study seeks to answer. This enhances their ability to make protocol adjustments when necessary, and ensures that the most pertinent information is recorded.

Prestudy Questionnaire

It is not uncommon for patients, particularly those with excessive sleepiness, to have a diminished capacity to evaluate their level of alertness.[28] In addition, patients with difficulty initiating and maintaining sleep often report a subjective evaluation of their total sleep time and quality that is at odds with the objective data collected in the laboratory. For these reasons, it is recommended that subjective data be collected systematically as part of the sleep laboratory evaluation.

The Stanford Sleepiness Scale (SSS)[40,][41] (Appendix 11-2) is an instrument used to assess a patient's subjective evaluation of sleepiness prior to the PSG. The SSS is presented to the patient immediately before the beginning of the study. Patients respond to a series of phrases by selecting the set of adjectives that most closely corresponds to their current state of sleepiness or alertness. The scale is used extensively in both clinical and research environments. However, it has two noteworthy limitations: it is not suitable for children who have a limited vocabulary or for adults whose primary language is not English. In these situations, a linear analog scale is recommended to provide an introspective measure of sleepiness (see Appendix 11-2). One end of the scale represents extreme sleepiness and the other end alertness. Patients mark the scale to describe their state just prior to testing.

Another instrument, the Epworth Sleepiness Scale,[42] lends information about chronic sleepiness. Patients are asked to report the likelihood of dozing in situations such as riding as a passenger in a car, watching television, and the like.

Patients are also asked about their medication history, smoking history, any unusual events during the course of the day, their last meal prior to the study, alcohol intake, and a sleep history for the last 24 hours, including naps. Involvement of the patient in providing this information usually translates into increased cooperation for the study. A technologist's complete awareness of specific patient idiosyncrasies, in the context of the questions to be addressed by the study, ensures a good foundation for the collection of high-quality data.

Nap Studies

A proposed alternative to nocturnal PSG has been the nap study (to be distinguished from the MSLT). The rationale is that, if a patient has a sleep disorder, it will be expressed during an afternoon nap, not just during a more extensive PSG. The nap study approach has been used most frequently for the diagnosis of SRBDs and was proposed in an effort to reduce the cost of the sleep laboratory evaluation. The short study in the afternoon avoids the necessity of having a technologist present for an overnight study. There are serious limitations to the use of nap studies, however, including the possibility of false-negative results or the misinterpretation of the severity of SRBDs if the patient is sedated or sleep deprived prior to the study. When a nap study is performed, it should follow the guidelines published by the American Thoracic Society[43]:

> *Although minimal systematic data exist on the value of nap recordings, nap studies of 2 to 4 hours' duration may be used to confirm the diagnosis of sleep apnea, provided that all routine polysomnographic variables are recorded, that both non-REM and REM sleep are sampled, and that the patient spends at least part of the time in the supine posture. Sleep deprivation or the use of drugs to induce a nap are contraindicated. Nap studies are*

inadequate to definitively exclude a diagnosis of sleep apnea.

Preparation of the Equipment

This chapter describes the polygraph, an instrument in which the main component is a series of amplifiers (see also Chapter 12). Usually there is a combination of alternating current (AC) channels and direct current (DC) channels; some amplifiers may be able to function in either AC or DC mode. Typically, at least 12 to 16 channels are available for recording, though many systems offer more channels. The data from the amplifiers were historically written to a moving chart. In modern digital systems, the analog signal is converted to a digital signal, which is stored by the computer for subsequent manipulation and analysis. A complete discussion of digital systems appears in Chapter 18, and a brief discussion appears near the end of this chapter. Currently, the data are reduced via a human visual pattern recognition process. However, some aspects of PSG data readily lend themselves to automatic analysis, and the use of sophisticated frequency analysis, such as fast Fourier transform analysis.[44]

Equipment for recording polysomnograms is produced by a number of manufacturers. Each may have a distinctive appearance and some idiosyncratic features, but there is a remarkable similarity when the basic functioning of the instrument is examined.

Equipment preparation includes an understanding of how the filters and sensitivity of the amplifiers affect the data collected. Decisions regarding sensitivity, filters, and channel selection are often predetermined by default software settings. Inasmuch as the major difference between classic analog PSG and computer-based systems lies principally in data storage and display, it is important that all technologists, regardless of the system used, have adequate knowledge of the operation of the equipment.

The amplifiers used to record physiologic data are very sensitive, so it is essential to eliminate unwanted signals from the recording. By using a combination of high- and low-frequency filters, and appropriate sensitivity settings, it is possible to maximize the likelihood of recording and displaying the signals of interest and decrease the possibility of recording extraneous signals. When using the filters, however, care must be taken to ensure that an appropriate window for recording specific frequencies is established and that the filters do not eliminate important data.

Alternating Current Amplifiers

Differential AC amplifiers are used to record physiologic parameters of high frequency, such as the electroencephalogram (EEG), the electro-oculogram (EOG), the electromyogram (EMG), and the electrocardiogram (ECG). The AC amplifier has both high- and low-frequency filters. The presence of the low-frequency filter makes it possible to attenuate slow potentials not associated with the physiology of interest; these include galvanic skin response, DC electrode imbalance, and breathing, any of which may be reflected in an EMG, EEG, or EOG channel. Combinations of specific settings of the high- and low-frequency filters make it possible to focus on specific bandwidths associated with the signal of interest. For example, respiration is a very slow signal (roughly 12–18 breaths/min) in comparison with the EMG signal, which has a much higher frequency (~20–200 Hz or cycles/sec). In the sleep lab, the bandwidth of interest for EEG data is 0.5–25 Hz.

Direct Current Amplifiers

In contrast to the AC amplifier, the DC amplifier does not have a low-frequency filter. DC amplifiers are typically used to record slower moving potentials, such as output from the oximeter or pH meter, changes in pressure in positive airway pressure treatment, or output from transducers that record endoesophageal pressure changes or body temperature. Airflow and effort of breathing can be successfully recorded with either AC or DC amplifiers.

An understanding of the appropriate use of filters in clinical PSG is essential to proper recording technique.[45] Table 11-1 provides recommendations for filter settings for various physiologic parameters.

TABLE 11-1 -- Recommendations for Filter Settings and Sensitivity for Various Physiologic Parameters

Channel*	Low-Frequency Filter (Hz)	Time Constant (sec)	High-Frequency Filter (Hz)	Sensitivity
EEG	0.3	0.4	35	50 (μV/cm)
EOG	0.3	0.4	35	50 (μV/cm)
EMG	5[†]	0.03	90–120	20–50 (μV/cm)
ECG	1.0	0.12	15	1 MV/cm
Index of airflow	0.15[‡]	5[‡]	15	[§]
Index of effort	0.15[‡]	5[†]	15	[§]

Modified from Keenan SA. Polysomnography: technical aspects in adolescents and adults. In C Guilleminault (ed), Clinical Neurophysiology of Sleep Disorders (Handbook of Clinical Neurophysiology Series). Amsterdam: Elsevier, 2005:33.

ECG, electrocardiography; EEG, electroencephalography; EMG, electromyography; EOG, electro-oculography

* EEG includes C3/A2, C4/A1, O1/A2, and O2/A1 (or any other EEG derivation). EOG includes right outer canthus and left outer canthus referred to opposite reference (or any other EOG derivation).

If shorter time constant or higher low-frequency filter is available, it should be used. This includes settings for all EMG channels, including mentalis,

† submentalis, masseter, anterior tibialis, intercostal, and extensor digitorum.

† Because breathing has such a slow frequency (as compared to the other physiologic parameters), the longest time constant available, or the lowest setting on the low-frequency filter options, would provide the best signal. It is also possible to use a DC amplifier (with no low-frequency filter, time constant = infinity) to record these signals.

§ It is common in clinical practice to index changes in airflow and effort to breathe by displaying qualitative changes in oral/nasal pressure, temperature, and chest and abdominal movement. It is well recognized that quantitative methods (such as endoesophageal pressure changes) provide a more sensitive and accurate measure of work of breathing. Ideally, a multimethod approach is used to increase confidence in detecting events of sleep-related breathing anomalies.

Calibration of the Equipment

Ideally, any recording instrument is calibrated prior to a test. The calibration ensures adequate functioning of amplifiers and appropriate settings for the specific protocol. Historically, in analog systems, a series of calibrations was performed and documented. The first calibration is an all-channel calibration (Fig. 11-1). During this calibration, all amplifiers are set to the same sensitivity, high-frequency filter, and low-frequency filter settings, and a known signal is sent through all amplifiers simultaneously. The proper functioning of all amplifiers is thus demonstrated, ensuring that all are functioning in an identical fashion.

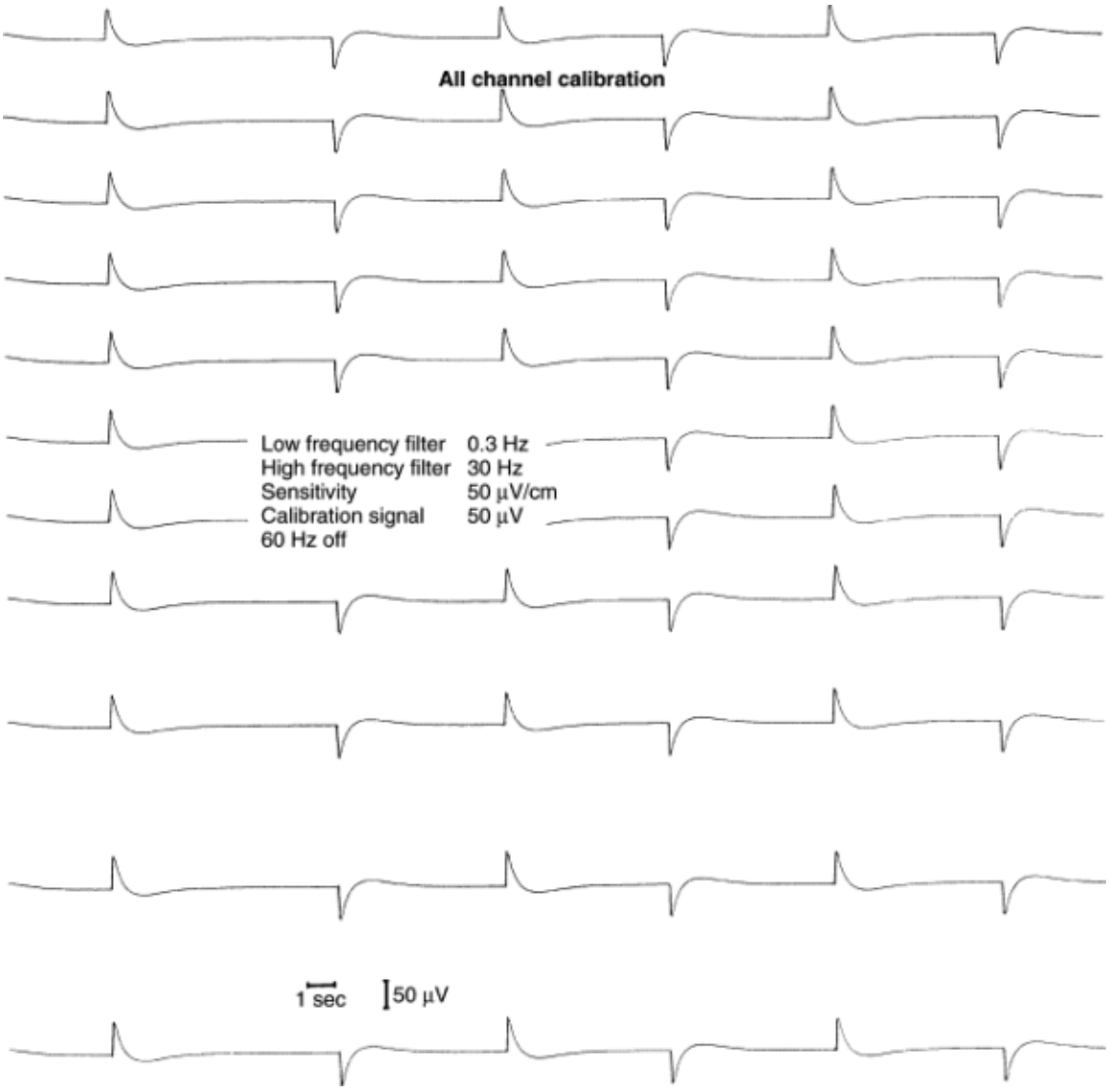

FIGURE 11-1 All-channel calibration. All amplifiers have the same sensitivity and high- and low-frequency filter settings.

A second calibration is performed for the specific study protocol. During this calibration, amplifiers are set with the high-frequency filter, low-frequency filter, and sensitivity settings appropriate for each channel; the settings are dictated by the requirements of the specific physiologic parameter recorded on each channel (Fig. 11-2; see also Table 11-1). The protocol calibration ensures that all amplifiers are set to ideal conditions for recording the parameter of interest. Filter and sensitivity settings should be clearly documented for each channel. Epoch lengths and clock times should be verified.

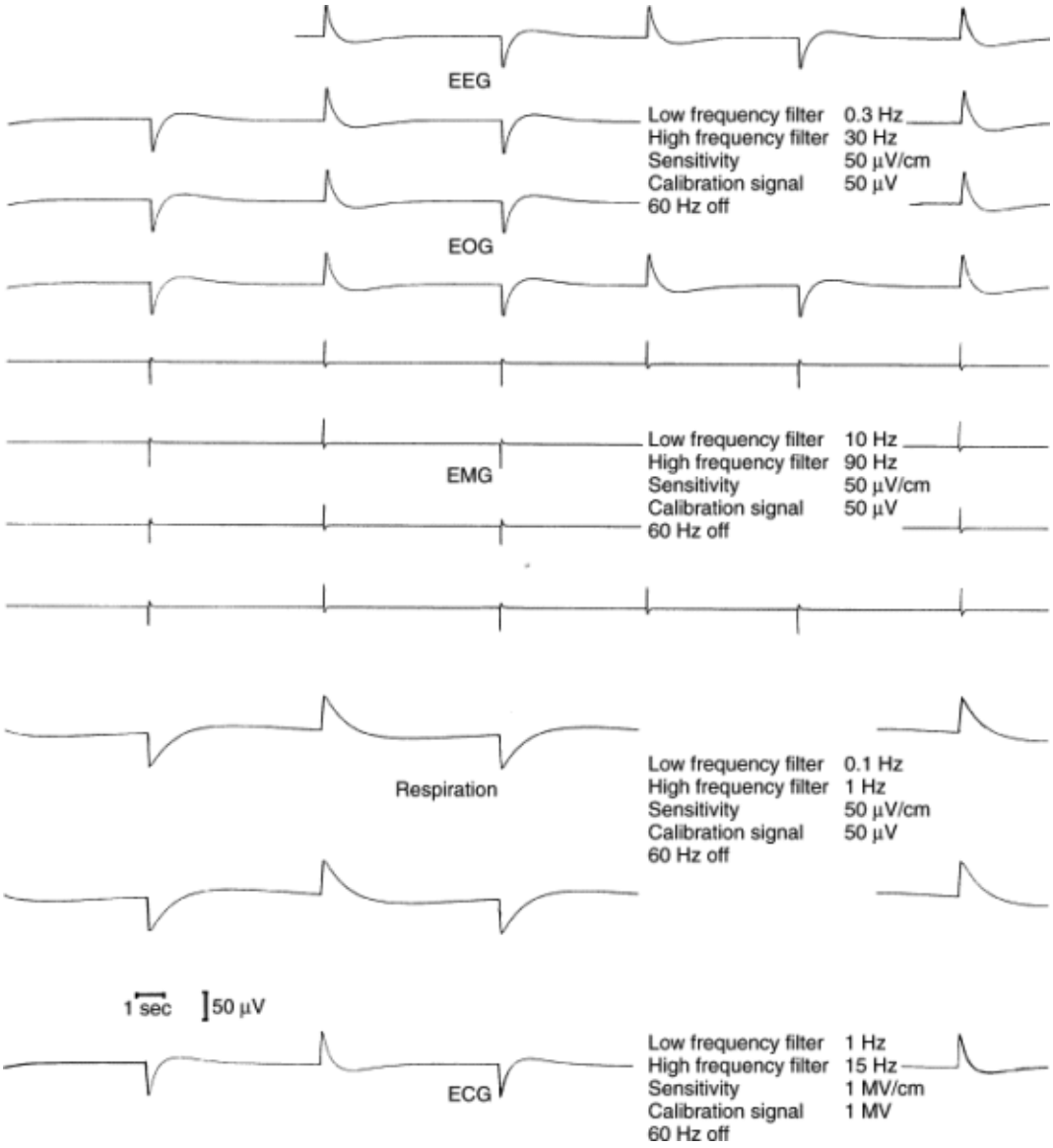

FIGURE 11-2 The montage calibration shows changes in high- and low-frequency filter settings from the all-channel calibration to accommodate the display of a variety of physiologic signals for the polysomnograph. (ECG, electrocardiogram; EEG, electroencephalogram; EMG, electromyogram; EOG, electro-oculogram.)

Digital systems generally do not require day-to-day adjustments; however, the calibration procedures should be performed before each study to document the selected filter and sensitivity settings and to confirm appropriate signal response for each channel.

"Paper Speed"

Historically, the speed of the chart drive for the recording instrument established the epoch length (amount of time per page) of the recording. A common paper speed for traditional polysomnography was 10 mm/sec, providing a 30-second epoch. Another widely accepted paper speed was 15 mm/sec, a 20-second epoch length. For patients with suspected sleep-related seizure activity, a paper speed of 30 or 60 mm/sec enhanced the ability to visualize EEG data. Data such as oxygen saturation, respiratory signals, or changes in penile circumference, however, were more easily visualized with slower paper speeds. The issue of selecting the appropriate paper speed became moot when digital systems became the norm. The ability to manipulate the display of data after collection is a major advantage of the digital systems.

Sleep stage scoring requires epoch-by-epoch review of the data. The AASM Task Force[46] recommends a 30-second epoch as the standard unit of time for analysis of sleep stages. Analysis of anomalies in movement or cardiac rhythms are counted and described in terms of their relation to stage of sleep.

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THE STUDY

Electrode/Monitor Application Process

The quality of the tracing generated in the sleep laboratory depends on the quality of the electrode application.[47] Before any electrode or monitor is applied, the patient should be instructed about the procedure and given an opportunity to ask questions. The first step in the electrode application process involves measurement of the patient's head. The International 10–20 System[48] of electrode placement is used to localize specific electrode sites (Fig. 11-3). The following sections address the application process for EEG, EOG, EMG, and ECG electrodes.

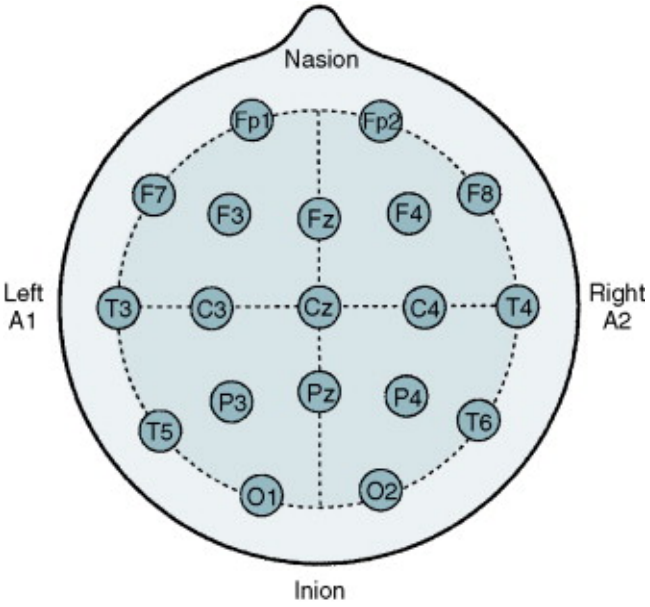

FIGURE 11-3 The complete International 10-20 System of electrode placement.

Electroencephalography

As noted in the Rechtschaffen and Kales manual,[49] standard electrode derivations for monitoring EEG activity during sleep are C3/A2 or C4/A1 for central EEG activity, and O1/A2 or O2/A1 for occipital EEG activity. The AASM Task Force terminology includes the terms “M1” and “M2” instead of “A1” and “A2” for the reference electrodes placed on the mastoid process.[46] In this case, the derivations would be C3/M2 or C4/M1, and O1/M2 or O2/M1. In some situations there may be a need for additional electrodes. For example, to rule out the possibility of epileptic seizures during sleep, or to detect the presence of other sleep-related EEG abnormalities, it may be necessary to apply the full complement of EEG electrodes according to the International 10–20 System (see Fig. 11-3). An abbreviated montage to screen for EEG abnormalities during PSG is discussed in Appendix 11-3. Also, the AASM Task Force pointed to the importance of frontal derivations (Fp1/M2, Fp2/M1) when considering decisions regarding K complexes and/or slow-wave activity.

For recording an EEG, a gold cup electrode with a hole in the center is commonly used. Silver–silver chloride electrodes are also useful to record an EEG, though they may have limitations such as increased maintenance (evidenced by the need for repeated chloriding) and the inability to attach these electrodes to the scalp.

The International 10-20 System of electrode placement determines the placement of EEG electrodes. Reference electrodes are placed on the bony surface of the mastoid process. A description of the measurement procedure appears in Appendix 11-4.

The collodion technique[47] has long been an accepted and preferred method of application for EEG scalp and reference electrodes. This technique ensures a long-term placement and allows for correction of high impedances (>5000 ohms) after application. Other methods using electrode paste and a conductive medium are acceptable and often preferred in certain conditions.

Electro-oculography

The EOG is a recording of the movement of the corneoretinal potential difference that exists in the eye. It is the movement of this dipole with respect to the eye movement electrodes that is recorded. Gold cup electrodes or silver–silver chloride electrodes can be used to monitor the EOG. An electrode is typically applied at the outer canthus of the right eye (ROC) and is offset 1 cm above the horizontal. Another electrode is applied to the outer canthus of the left eye (LOC) and is offset by 1 cm below the horizontal. The previously mentioned A1 and A2 (M1, M2) reference electrodes are used as follows: ROC/A1 (or M1) and LOC/A2 (or M2). Additional infraorbital and supraorbital electrodes enhance the ability to detect eye movements that occur in the vertical plane, and can be particularly useful in the MSLT[50,][51] (Fig. 11-4). It should be noted that many variations of electrode placement and recording derivations have been used in a variety of clinical and research settings. In an attempt to standardize procedure, the AASM Task Force has recently made recommendations[46] regarding eye movement recording, naming of references (M1, M2 vs. A1, A2), and the use of frontal derivations to enhance detection of EEG waveforms such as K complexes and slow-wave activity.

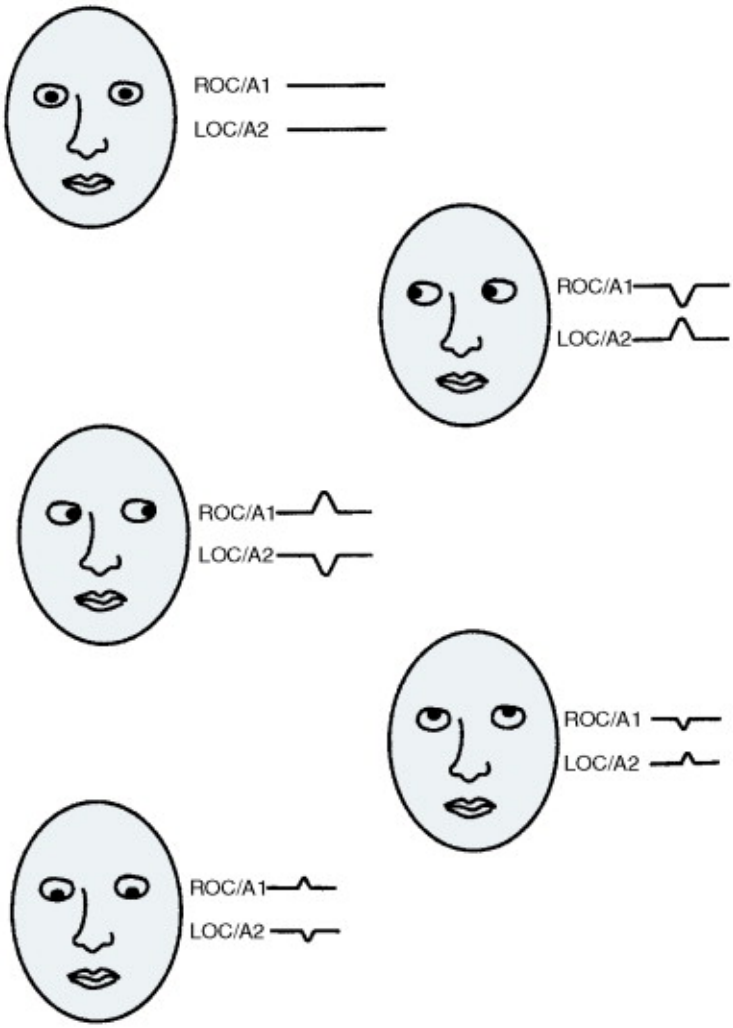

FIGURE 11-4 The recording montage for a 2-channel EOG demonstrates out-of-phase pen deflection in association with conjugate eye movements.

EOG electrodes are typically applied to the surface of the skin with an adhesive collar; this method avoids the risk of collodion contacting the patient's eyes.

Given the existing variations in methodology within the clinical and research environments, it is important to know exact electrode placement and inputs to EOG channels when interpretation of EOG activity has significant impact on diagnosis or treatment outcome.

Electromyography

A gold cup or a silver–silver chloride electrode attached with an adhesive collar is used to record EMG activity from the mentalis and submentalis muscles. Two of the electrodes are used to create a bipolar EMG recording. At least three EMG electrodes are applied to allow for an alternative electrode to be used in the event that artifact develops in one of them. The additional electrode can be placed over the masseter muscle to allow for detection of bursts of EMG activity associated with bruxism (Fig. 11-5).

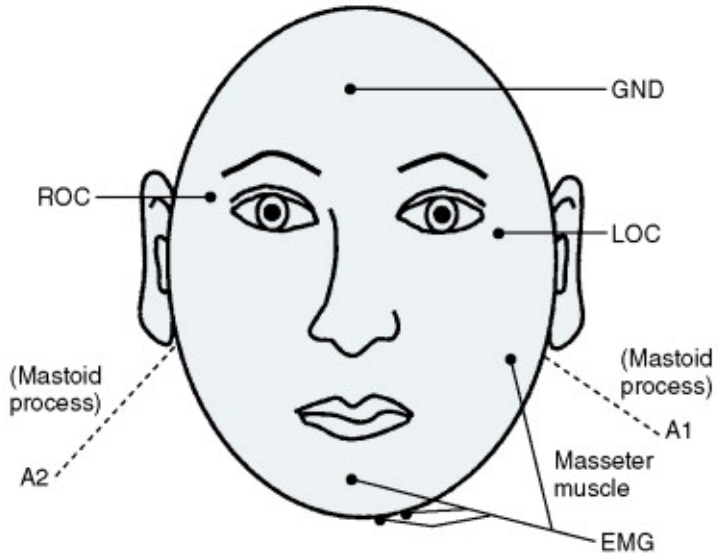

FIGURE 11-5 Schematic diagram showing placement of the electromyography (EMG) electrodes to record activity from the mental, submental, and masseter muscles. (GND, ground [earth]; LOC, left outer canthus [of the eye]; ROC, right outer canthus.)

Electrocardiography

There are a variety of approaches for recording the ECG during PSG. The simplest approach involves use of standard gold cup electrodes. However, disposable electrodes are also available to record ECG.

ECG electrodes are applied with an adhesive collar to the surface of the skin just beneath the right clavicle and on the left side at the level of the seventh rib (“modified lead II”). A stress loop is incorporated into the lead wire to ensure long-term placement.

Impedances

Before recording, electrodes should be visually inspected to check the security of their placement and an impedance check should be performed and documented. An impedance meter is ideally part of the recording system. Alternatively, a separate device can be used. Adjustment should be made to any EEG, EOG, or chin EMG electrode with an impedance greater than 5000 ohms. Higher impedances (20–30 kohm) are tolerated for ECG electrodes and for other EMG (anterior tibialis, extensor digitorum) derivations.

Physiologic Calibrations

Physiologic calibrations are performed after the electrode and monitor application is complete. This calibration allows for documentation of proper functioning of the electrodes and other monitoring devices, and provides baseline data for review and comparison when scoring the PSG. The specific instructions given to the patient for this calibration include

- Eyes open, look straight ahead for 30 seconds.
- Eyes closed, look straight ahead for 30 seconds.
- Hold head still, look to left and right, up and down. Repeat.
- Hold head still, blink eyes slowly, five times.
- Grit teeth, clench jaw, or smile.
- Inhale and exhale slowly, three times.
- Hold breath for 10 seconds.
- Flex right foot, flex left foot.
- Flex right hand, flex left hand.

As these instructions are given to the patient, the technologist examines the tracing and documents the patient's responses. When the patient stares straight ahead for 30 seconds with eyes open, the background EEG activity is examined. As the patient looks right and left, the tracing is examined for out-of-phase deflections of the signals associated with recording the EOG. Out-of-phase deflection occurs if the inputs to consecutive channels of the polygraph are ROC/M1 for the first EOG channel and LOC/M2 for the second. It is also important, when the patient closes his or her eyes, to observe the reactivity of the alpha rhythm seen most prominently in the occipital EEG; alpha rhythm is usually best visualized when the patient's eyes are closed.

The mentalis/submentalis EMG signal is checked by asking the patient to grit the teeth, clench the jaws, or yawn. The technologist documents proper functioning of the electrodes and amplifiers used to monitor anterior tibialis EMG activity by asking the patient to dorsiflex the right foot and the left foot in turn. If rapid eye movement (REM) sleep behavior disorder

is suspected, additional electrodes should be applied to the surface of the skin above the extensor digitorum muscles of each arm. Patients are asked to extend their wrists while the technologist examines the recording for the associated increase in amplitude in the corresponding EMG channel.

Inhalation and exhalation allow for examination of the channels monitoring airflow and breathing.[52,][53] The reader is referred to Chapter 14 in this volume for a more detailed discussion of this topic. A suggested convention is that inhalation causes an upward deflection of the signal and exhalation a downward deflection. It is most important that the signals on all the channels monitoring breathing are in phase with each other to avoid confusion with paradoxical breathing. The technologist should observe a flattening of the trace for the duration of a voluntary apnea. (Note: It is strongly recommended to include end-tidal or transcutaneous CO_2 monitoring when studying children,[24] or adult patients with underlying lung disease. The addition of CO_2 monitoring increases the sensitivity of the study of hypoventilation [see Fig. 11-7 later].)

If the 60- or 50-Hz notch filter (also called “line filter” or “AC filter”) is in use, a brief examination (2–4 seconds) of portions of the tracing with the filter in the “out” position is essential. This allows for identification of any 60- or 50-Hz interference that may be masked by the filter. Care should be taken to eliminate any source of interference and to ensure that the 60- or 50-Hz notch filter is used only as a last resort. This is most important when recording patients suspected of having seizure activity, because the notch filter attenuates the amplitude of the spike activity seen in association with epileptogenic activity. If other monitors are used, the technologist should incorporate the necessary calibrations.

The physiologic calibrations enable the technologist to determine the quality of data before the PSG begins. If artifact is noted during the physiologic calibrations, it is imperative that every effort be made to correct the problem, as the condition is likely to get worse through the remaining portions of the recording. The functioning of alternative (spare) electrodes should also be examined during this calibration.

When a satisfactory calibration procedure and all other aspects of patient and equipment preparation are completed, the patient is told to assume a comfortable sleeping position and to try to fall asleep. Then the lights are turned out in the patient's room and the “lights-out” time is noted clearly on the tracing or in the recording log.

Monitoring and Recording

Complete documentation for the PSG is essential. This includes patient identification (patient's full name and medical record number), date of recording, and a full description of the study. The name of the technologist performing the recording, as well as those of any technologists who prepared the patient or the equipment, should be noted. In laboratories that use multiple pieces of equipment, the specific instrument used to generate the recording should be identified. This is particularly useful in the event that artifact is noted during the analysis portion (scoring) of the sleep study.

Specific parameters recorded on each channel should be clearly noted, as should a full description of sensitivity, filter, and calibration settings for each channel. Information regarding epoch length should be clearly visible. The time of the beginning and end of the recording must be recorded, as well as specific events that occur during the night. Any changes made to filter, sensitivity, or paper speed settings should be clearly noted in the study.

The technologist is also responsible for providing a clinical description of unusual events. For example, if a patient experiences an epileptic seizure during the study, the clinical manifestations of the seizure must be detailed: deviation of eyes or head to one side or the other, movement of extremities, presence of vomiting or incontinence, duration of the seizure, and postictal status. Similar information should be reported on any clinical event observed in the laboratory, such as somnambulism or clinical features of REM sleep behavior disorder. Physical complaints reported by the patient are also noteworthy.

Troubleshooting and Artifact Recognition

In general, when difficulties arise during recording, the troubleshooting inquiry begins at the patient and follows the path of the signal to the recording device. More often than not, the problem can be identified as a difficulty with an electrode or other monitoring device. It is less likely that artifact is the result of a problem with an amplifier. If the artifact is generalized (i.e., on most channels), then the integrity of the ground electrode and the instrument cable should be checked. If the artifact is localized (i.e., on a limited number of channels), then the question should be: which channels have this artifact in common and what is common to the channels involved? The artifact is probably the result of a problem located in an electrode or monitoring device that is common to both channels. If the artifact is isolated to a single channel, the source of artifact is limited to the inputs to the specific amplifier, the amplifier itself, or to display of the channel.

Figures 11-6 through 11-15 depict some frequently encountered artifacts seen during PSG.

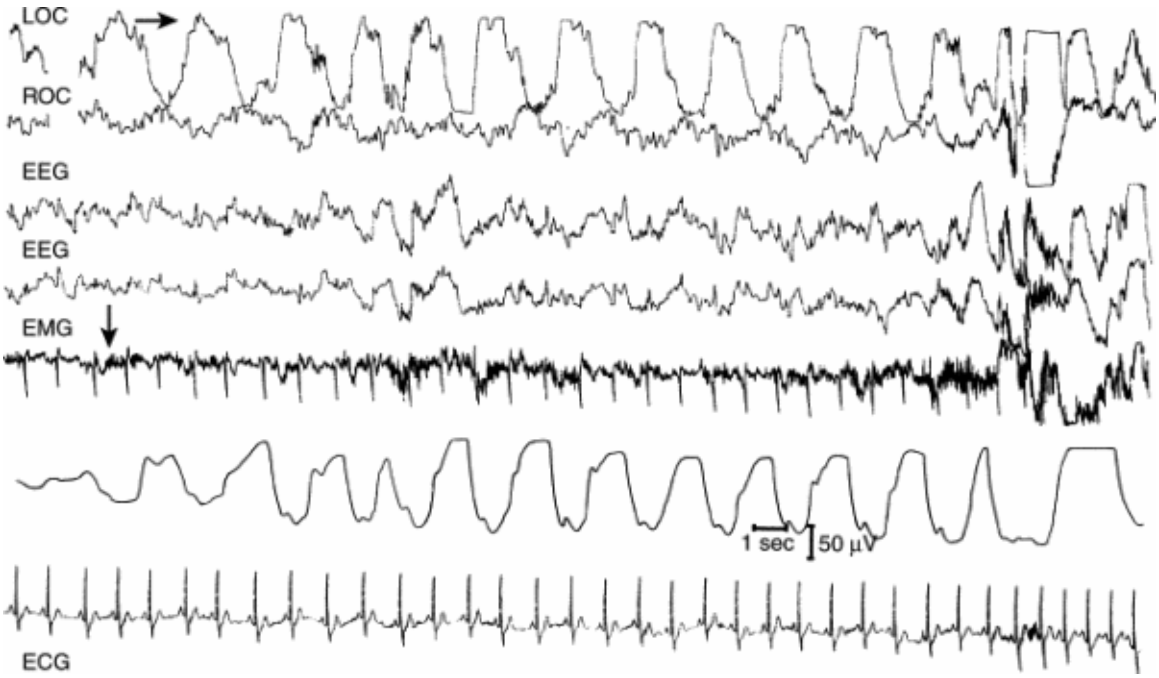

FIGURE 11-6 Artifact in left outer canthus (LOC) channel (LOC/A1) can be localized to the LOC electrode. The EEG channels in the trace are C3/A2 and O2/A1. Since the artifact does not appear in the O2/A1 channel, it is localized to the LOC electrode. The electrode placement may be insecure or the patien may be lying on the electrode and producing movement of the LOC electrode in association with breathing. Additional artifact is noted in the EMG channel. This signal is contaminated with ECG artifact, and the intermittent slower activity as well as the wandering baseline are most likely due to a loose lead. The ECG channel also shows a pattern consistent with a loose electrode wire.

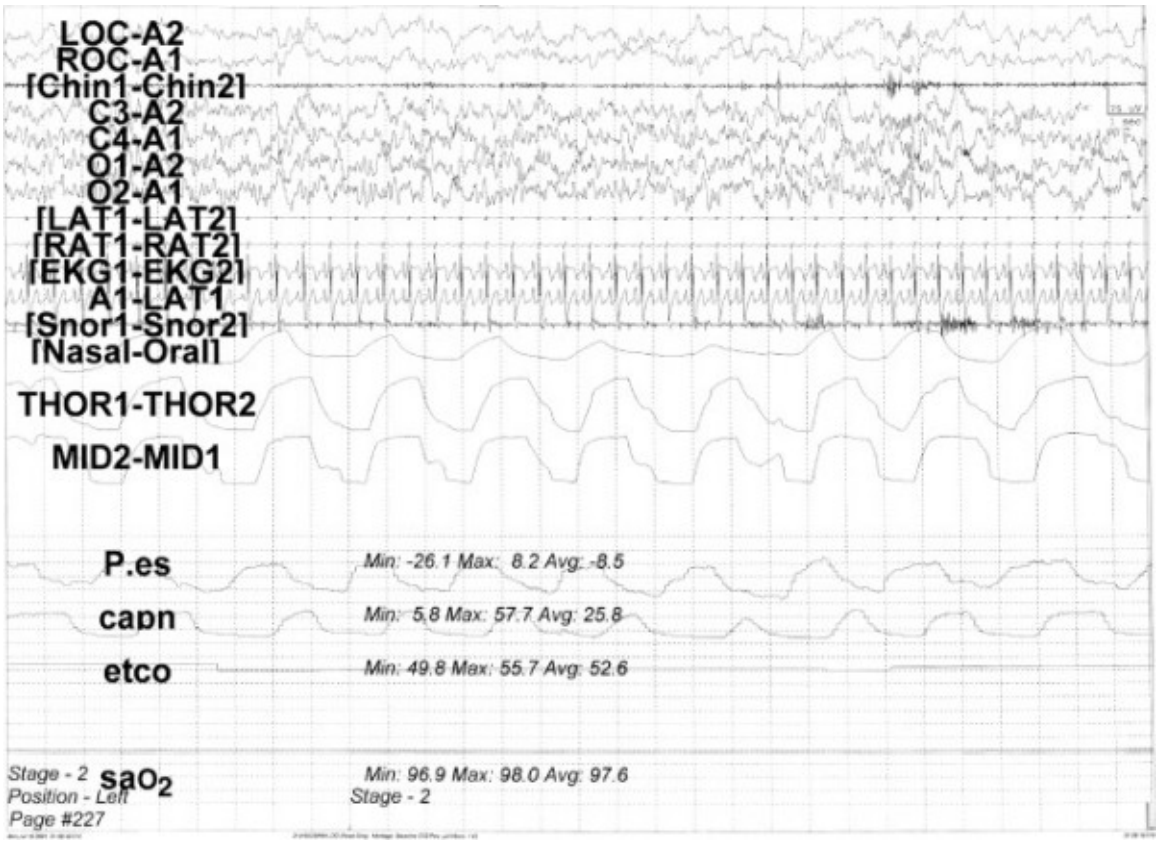

FIGURE 11-7 Sleep-disordered breathing: hypopnea. Note that end-tidal carbon dioxide (etco2) channel shows CO_2 retention while arterial oxygen saturation (SaO_2) channel shows normal values.

(Reproduced with permission from Chokroverty S, Thomas RJ, Bhatt M. The Atlas of Sleep Medicine. Philadelphia:Elsevier Butterworth-Heinemann, 2005:338.)

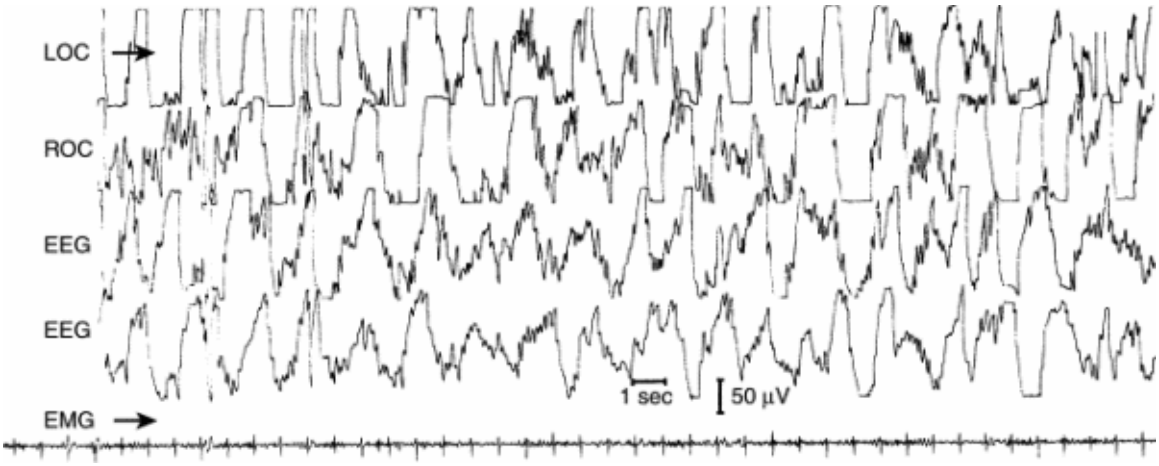

FIGURE 11-8 The blocking artifact seen with inappropriate sensitivity settings can be alleviated by decreasing sensitivity. If adjustments to sensitivity are made, they should be clearly noted, and the same adjustments should be made on all channels displaying EEG data. It is common procedure to calibrate th equipment with decreased sensitivity (i.e., 100 µV/cm) for children's studies or increased sensitivity (i.e., 30 µV/cm) for older patients. Typically, sensitivity settings are not changed frequently during the recording (as they may be in routine EEG). As a result, it is not uncommon to see this artifact when the patier enters slow wave sleep. This is not a common problem with digital systems because of the user's ability to manipulate sensitivity after data collection.

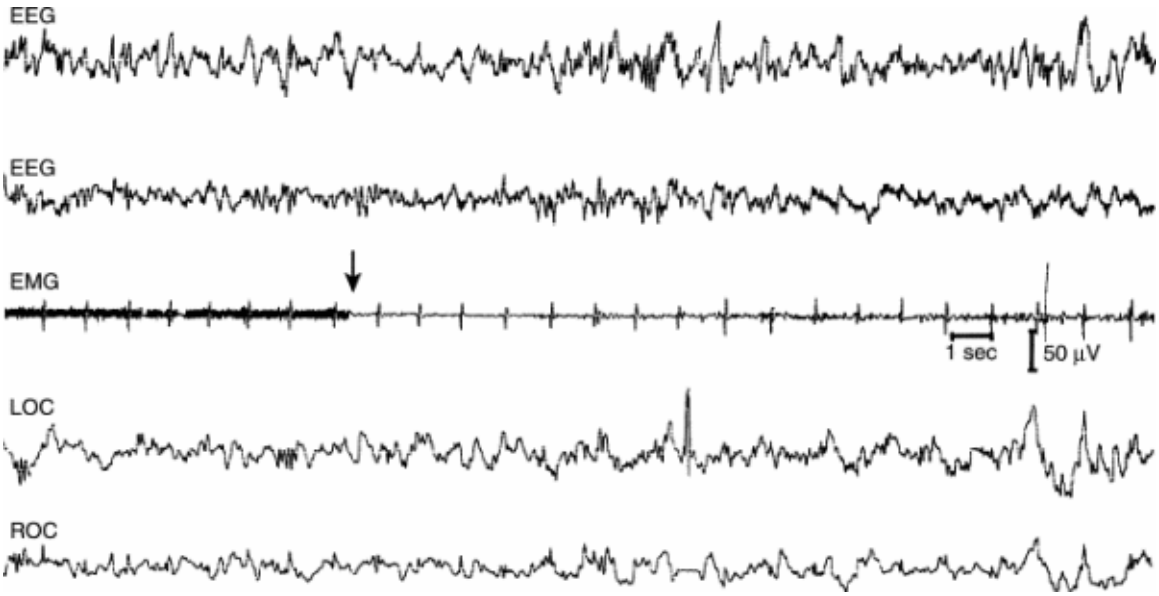

FIGURE 11-9 A 60-Hz artifact exists in the EMG channel. At the *arrow,* the 60-Hz filter is turned on. However, there is continued evidence of difficulty witl electrodes on this channel, as evidenced by the ECG artifact and occasional spike-like activity. Turning on the 60-Hz filter is not the correct response to eliminate the artifact. If possible, the technologist should switch to an alternative electrode or fix the one involved.

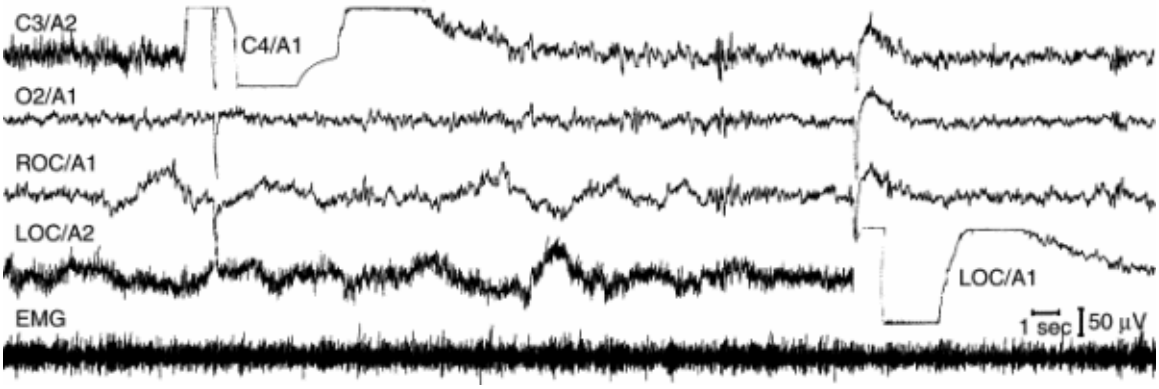

FIGURE 11-10 The high-frequency (probably EMG) artifact noted in the C3/A2 and LOC/A2 channels can be localized to the A2 electrode. This problem can be solved by switching to the alternative reference (A1) electrode. A high-amplitude discharge is noted during the switch from C3/A2 to C4/A1 and LOC/A2 to LOC/A1. This can be avoided by placing the amplifier in standby mode, if possible, while making the change.

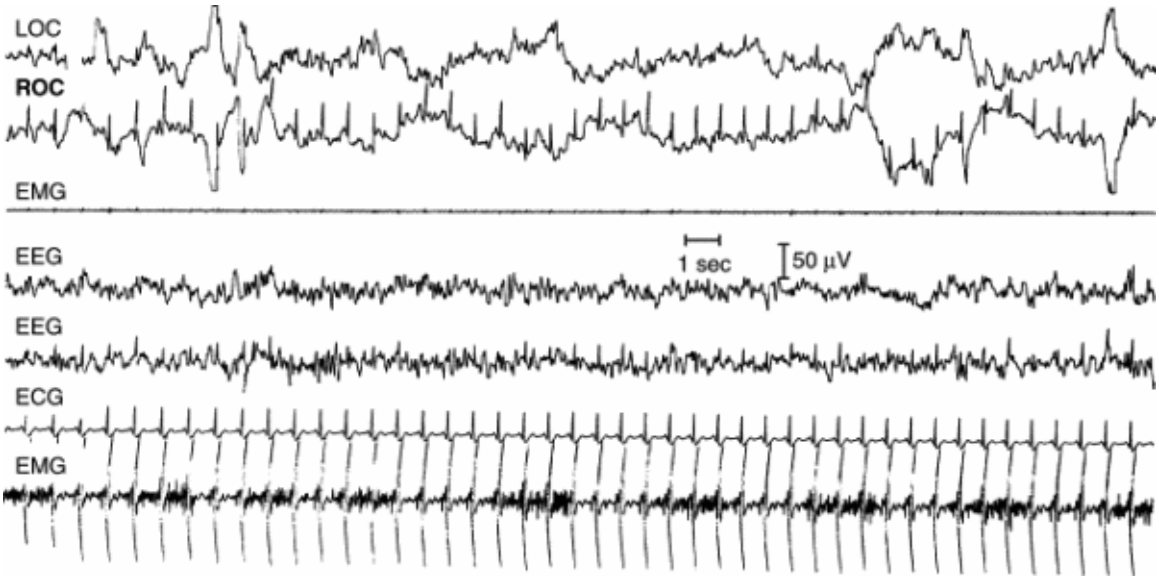

FIGURE 11-11 The ROC channel (ROC/A1) and the second EEG (O2/A1) channels are contaminated with ECG artifact. The artifact can be identified by aligning the spike-like activity noted in these channels with the R wave on the ECG channel. Because it is seen in both ROC/A1 and O2/A1, and A1 is common to both channels, it must be localized to the A1 electrode. It should be noted that the high-amplitude ECG artifact, seen in the EMG channel below the ECG channel, is unavoidable. This artifact is due to the proximity of EMG electrodes to the heart, which creates a robust signal superimposed on the intercostal EMG signal.

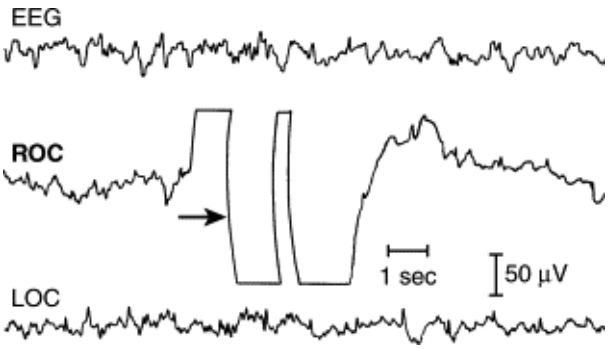

FIGURE 11-12 The high-amplitude deflection in the ROC (ROC/A1) channel is associated with an electrode artifact commonly referred to as an “electrod pop.” This can be the result of a compromised electrode placement or insufficient electroconductive gel under the electrode. When this artifact is observed, the electrode involved should not be trusted to give reliable data.

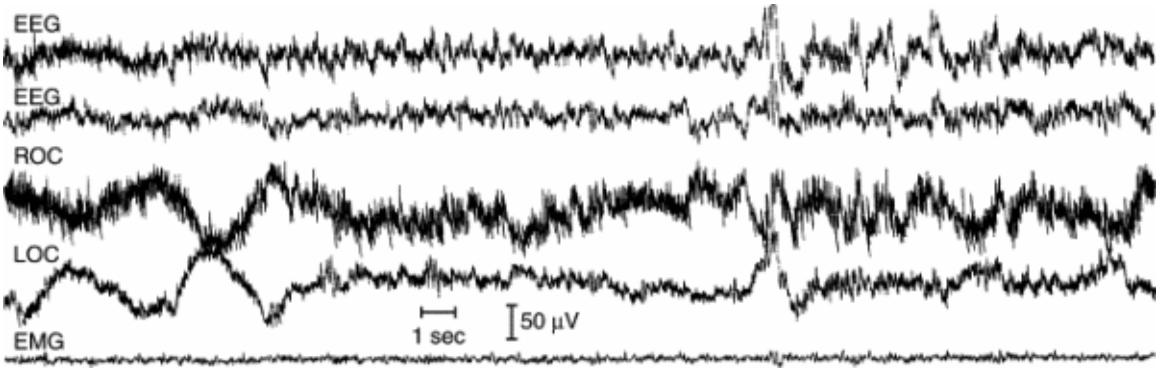

FIGURE 11-13 The generalized, high-frequency activity superimposed upon the EEG and EOG channels is most likely secondary to muscle activity. The EMG channel shows only artifact. In addition, there appears to be a slant to the left, particularly in channels 1 through 4, which is probably secondary to difficulty with the mechanical baseline of the pens.

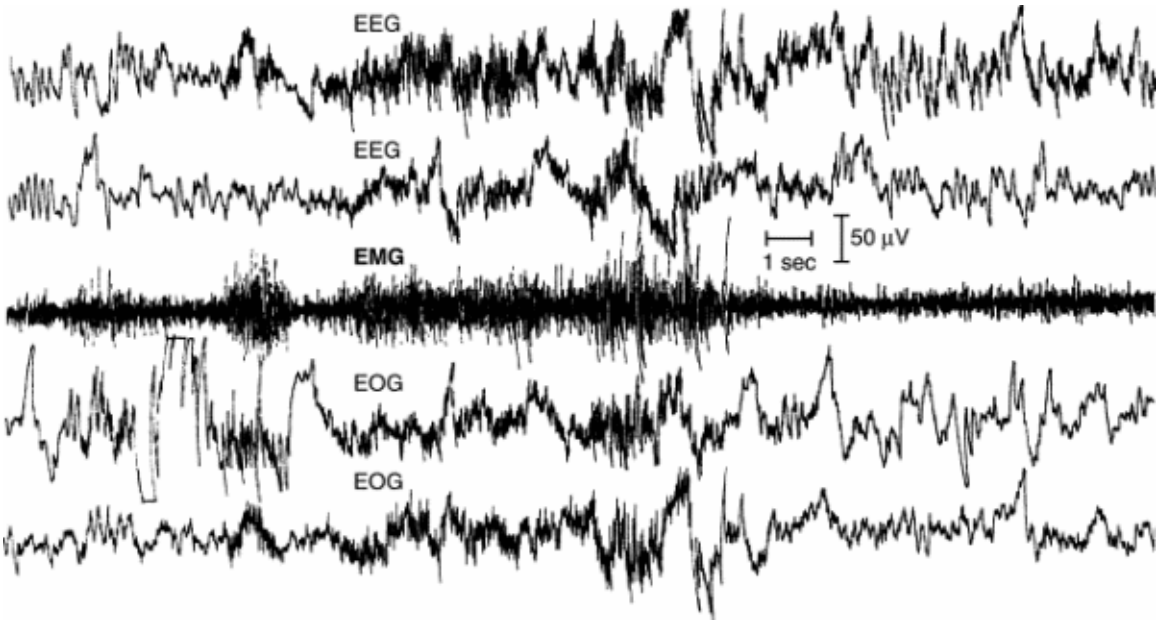

FIGURE 11-14 This burst of high-frequency artifact, superimposed on the EEG and EOG channels, is due to a brief movement by the subject. As in Figure 11-13 this is a superimposition of EMG activity on the EEG and EOG channels. It should also be noted that there is an electrode pop in the first EOG channel. The EMG channel in this tracing is of good quality and should be compared to Figure 11-13.

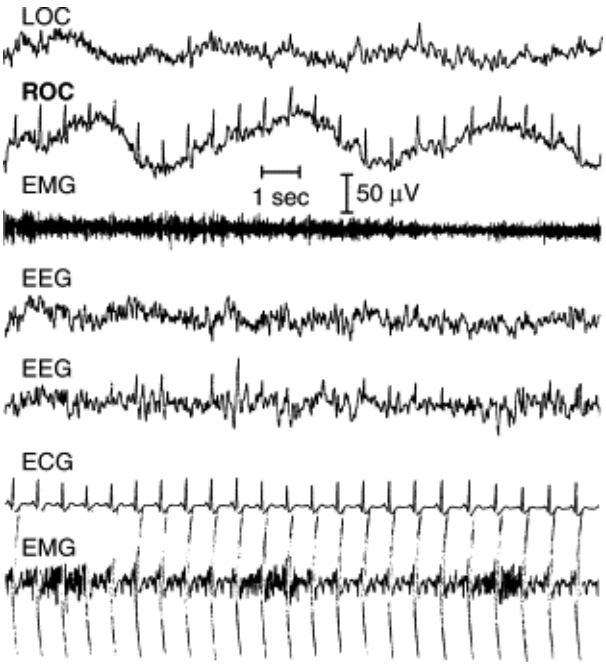

FIGURE 11-15 A high-amplitude, slow artifact is noted in the ROC (ROC/A1) channel. This is most likely associated with the patient's breathing and is secondary to a loose electrode or the patient lying on the right side and disturbing the electrode in synchrony with breathing. A relatively high-amplitude EC(artifact is also seen. The artifact can be localized to the ROC electrode. The EMG tracing noted at the bottom of this example is an intercostal EMG. The high-amplitude ECG spike in this channel is impossible to eliminate; however, brief bursts of EMG activity can be noted in association with the artifact seen in the ROC/A1 channel. This suggests that the artifact noted in the ROC electrode is associated with breathing, since the bursts of intercostal EMG activity are seen in association with the effort of breathing.

Ending The Study

Often, clinical circumstances and laboratory protocol dictate whether the patient is awakened at a specific time or allowed to awaken spontaneously. Deviations from the patient's usual sleep period must be clearly noted. After awakening at the end of the study, the patient should be asked to perform the physiologic calibrations to ensure that the electrodes and other monitoring devices are still functioning properly. Ideally, the equipment should be calibrated at the settings used for the study. Last, the amplifiers should be set to identical settings for high- and low-frequency filters and sensitivity and an all-channel calibration should be performed. This is essentially the reverse of the calibration procedures outlined for the beginning of the study.

A subjective evaluation is made by the patient. The patient is asked to estimate how long it took to fall asleep, the amount

of time spent asleep, and if there were any disruptions during the sleep period. Patients should also report on quality of sleep and the level of alertness upon arousal.

For patient safety, a plan needs to be made for patients leaving the laboratory after a study. A patient who has a severe sleep disorder should avoid driving. An arranged ride or public transportation should be used, particularly if the patient has withdrawn from stimulant medications for the purpose of the study.

Expert CONSULT

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DIGITAL SYSTEMS

The first digital EEG systems,[20,][44] which became available in the late 1980s, revolutionized EEG and PSG by increasing the flexibility and sensitivity of data analysis. Significant advantages of digital systems include autocorrection of amplifier gains, self-diagnostic tests of amplifier functions, and software-controlled in-line impedance testing. The use of the computer has facilitated storage of data, manipulation of data after collection, and the presentation of different views of the data. Despite these changes, however, users of digital systems must still adhere to the rigorous standards that ensure high-quality data in analog recordings. Both analog and digital systems require electrodes and other sensors to be applied with the greatest of care. Ideally, calibration procedures should be performed to document and ensure the collection of high-quality data at the beginning and end of the recording. Knowledge of the specifics of the equipment and of the physiology of interest are important to ensure accurate signal processing.

Some of the main differences noted between analog and digital systems include the following:

- The size of the display of the data is a function of the size of the computer monitor.
- The ability to view data in retrospect may not be available during collection in digital systems.
- Annotation of the recording requires the use of the mouse or a keyboard, which can be more difficult than using a pen.
- Pen noise is absent, which prevents auditory perception of movement, entry into REM sleep, or other events.

In digital systems, it is rare to encounter breakdown of any mechanical component; the most frequently encountered problems have to do with disk drives or cables. To ensure trouble-free operation, it is important to avoid mechanical shock, dust, or static electricity.

An important factor for understanding the digital systems is the concept of sampling rate. Sampling rate can be understood as the frequency with which the signal is reviewed for conversion to the digital signal. Currently, 100 Hz is regarded as the minimum acceptable sampling rate for EEG, EOG, and EMG with high-frequency filters set at 35 Hz. A sampling rate of 200 Hz would be required if the high-frequency filter were set at 70 Hz.[54]

Another issue unique to digital systems is the precision of recordings. The resolution of the signal is a function of the number of binary bits used to represent the digital values. Readers will recall that a bit is a value of 1 or 0. Thus, in binary, 8 bits is equal to 2^8 (2 to the eighth power), or 256. For example, if we assume an EEG voltage change of 256 μV (from -128 μV to +128 μV) this would result in a resolution (using an 8-bit system) of 1 μV difference being represented by 1 bit. Among the digital systems that are currently available, 8-bit systems provide the lowest degree of precision. Usually, a 10- or 12-bit system is preferred to give increased resolution. For example, at 12 bits, successive digital values represent a 0.0625-μV change. Obviously, the 12-bit representation is far more precise and can reflect a smaller change in the signal. Additionally, the 8-bit resolution may appear jagged on the display screen when compared to the 12-bit waveform. The 12-bit representation is likely to appear smoother and less jagged than the 8-bit signal, and offers a signal that has greater fidelity to the original waveform. (It is interesting to note that the equivalent precision of paper tracings is approximately 6 bits, and 64-bit systems are now available at low cost!)

Also to be considered is the display resolution, which is determined by the resolution of the monitor. The computer screen for review of the recording should have a sufficiently high resolution. Ideally, the screen should be at least 20 inches with a resolution of 1280 × 1024 pixels, and flicker free (i.e., 75-Hz monitor scan rate).[44]

Figures 11-16 through 11-19 are examples of digital recordings during PSG.[17]

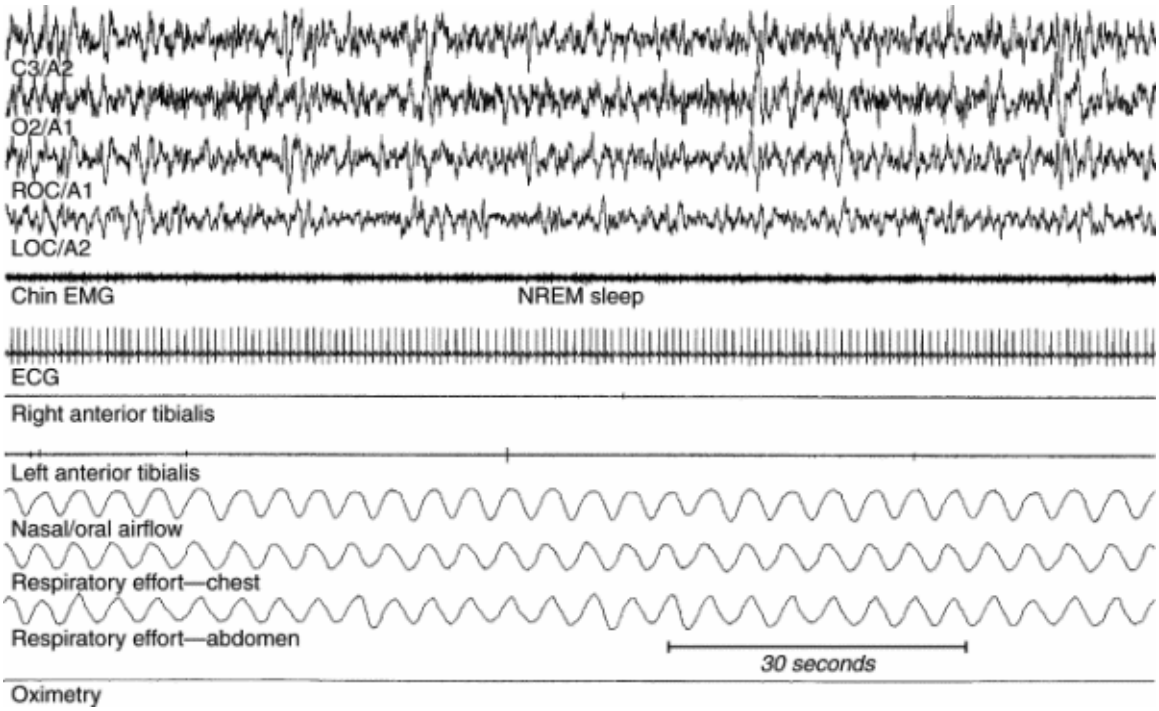

FIGURE 11-16 Digital recording sample of non–rapid eye movement (NREM) sleep using time-scale compression. Digital data can be further compresse to display several epochs on a screen simultaneously. This sample, and the recordings shown in Figures 11-17 through 11-19, have been compressed to accommodate 4 epochs of data (2 minutes) to a page. This type of display offers the scorer or interpreter a general overview of the sleep recording, as well as a practical method of counting any prominent sleep-related events such as obstructive apneas, hypopneas, or body movements. The resolution of the data is inadequate, however, for precise EEG evaluation or sleep-stage scoring. This sample shows a normal respiratory pattern during NREM sleep, witho any apparent evidence of arousal, movement, or other form of sleep disturbance.
(Reprinted with permission from Butkov N. Atlas of Clinical Polysomnography. Ashland, OR: Synapse Media, 1996.)

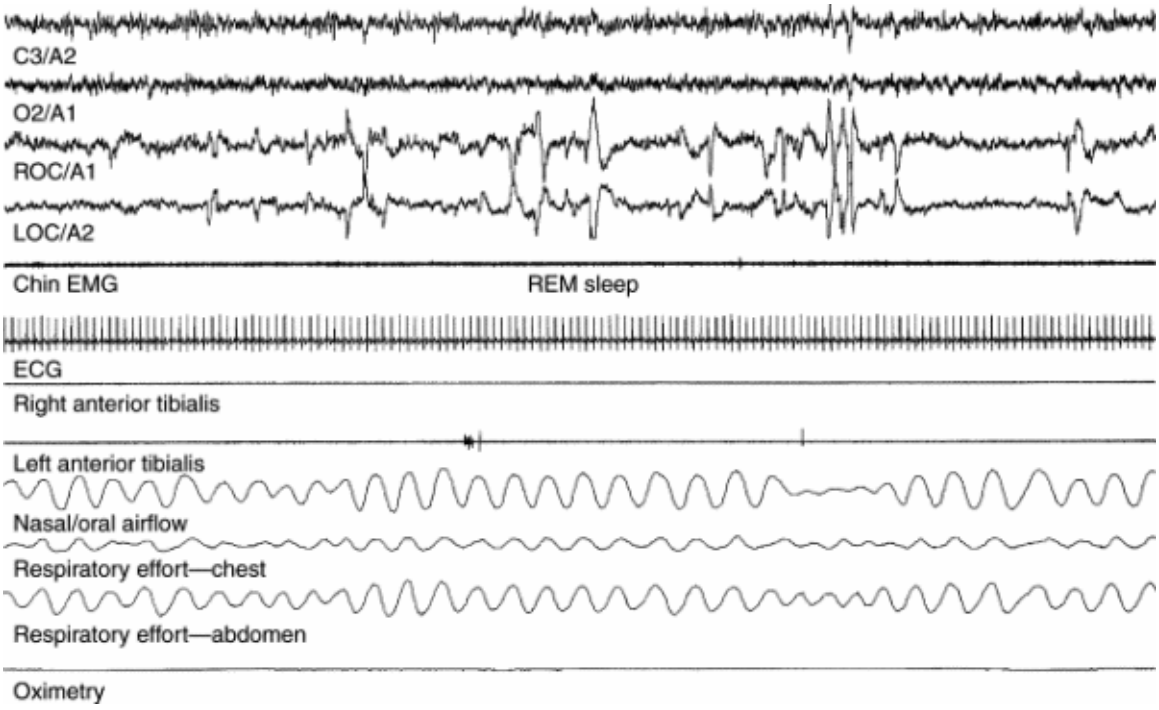

FIGURE 11-17 Digital recording sample of REM sleep. Although altered by time-scale compression, the sleep-stage pattern can readily be identified as REM. Note the mild respiratory irregularity, which is a normal variant of REM sleep physiology.
(Reprinted with permission from Butkov N. Atlas of Clinical Polysomnography. Ashland, OR: Synapse Media, 1996.)

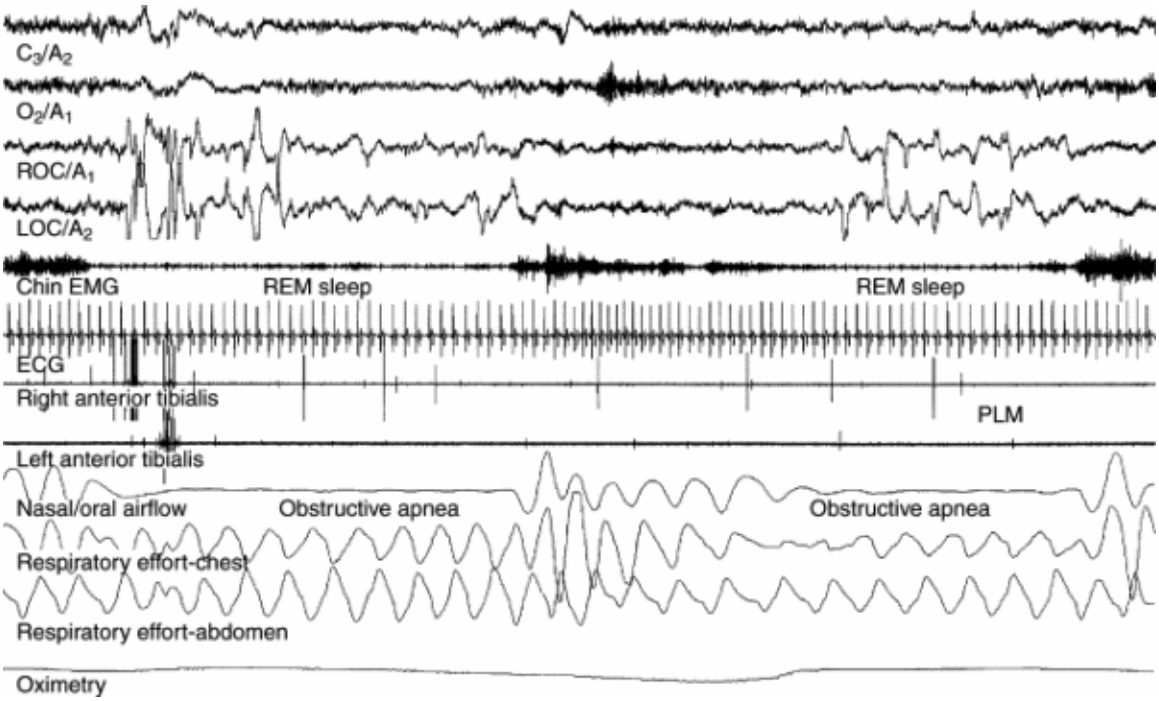

FIGURE 11-18 Digital recording sample showing a compressed display of repetitive obstructive apneas occurring during REM sleep. These represent the extreme end of the sleep-disordered breathing continuum. In this example, all the features of classic obstructive sleep apnea are present, including distinct paradoxic (out-of-phase) respiratory effort, instances of complete cessation of airflow, subsequent EEG arousals, and cyclic oxygen desaturations.
(Reprinted with permission from Butkov N. Atlas of Clinical Polysomnography. Ashland, OR: Synapse Media, 1996.)

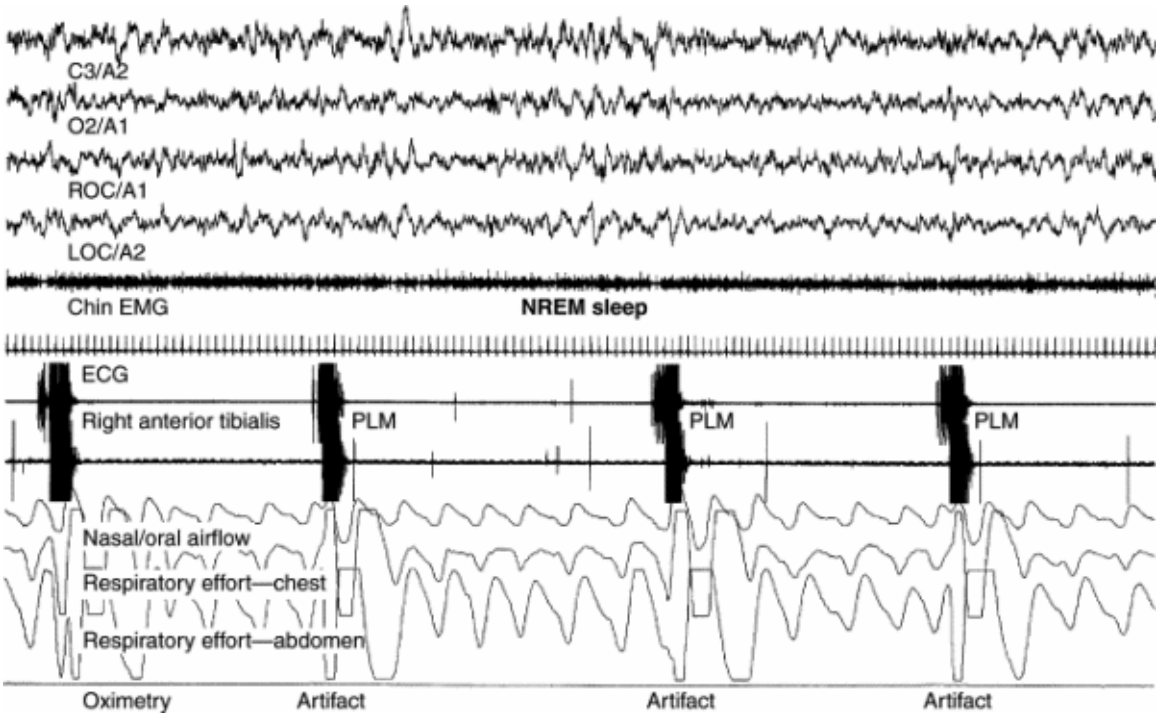

FIGURE 11-19 Digital recording sample of periodic limb movements, which often generate artifacts in the respiratory channels that appear similar to cycli hypopneas. This sample shows a compressed version of the characteristic pattern of periodic limb movement (PLM), recorded by the right and left anterior tibialis EMG. Note that the respiratory channel artifact appears almost identical to the cyclic hypopneas seen in Figure 11-18.
(Reprinted with permission from Butkov N. Atlas of Clinical Polysomnography. Ashland, OR: Synapse Media, 1996.)

PERSPECTIVE ON POLYSOMNOGRAPHY

Technical advances and increases in clinical knowledge provide great potential for our ability to monitor physiologic changes in our quest to understand sleep and its disorders. The recently published *Atlas of Sleep Medicine*[18] provides an excellent review of PSG and hypnogram analysis. Specialized techniques, including pulse transit time, peripheral arterial tonometry, and cyclic alternating patterns, are illustrated and discussed. Special attention is given to motor disorders, sleep and epilepsy, and a variety of other neurologic disorders.

Also recently published is an excellent review of the critical differences between children and adults[24] who have SRBD and restless leg syndrome. It is imperative that we identify sleep disorders as early as possible in order to prevent needless suffering. In order to achieve this goal, it is crucial for clinicians and technologists to understand that the clinical presentation of sleep disorders may be different in children than in adults. For example, as mentioned previously, it is important to record CO_2 changes in children as they may show retention of CO_2 more commonly than dramatic changes in arterial O_2 saturation (as compared to adults with SRBD).

Throughout its evolution, PSG has proven a robust tool for enhancing understanding of sleep and its disorders. It is an essential diagnostic procedure. Increased public awareness of sleep disorders as a major public health concern will drive the need for diagnosis and treatment. We must be effective and efficient in providing the highest quality of patient care. It is well recognized that questionnaires[55] have proven to be excellent tools in helping to triage patients in need of further evaluation. Polysomnography remains the “gold standard” for diagnosis when indicated.

PSG is complex and labor intensive. It requires specialized technical skills and knowledge of normal sleep and sleep disorders. Technologists need to be experts with equipment, competent in dealing with medically ill patients, and capable of dealing with emergencies that may be encountered. The establishment of accredited training programs and licensure are tangible signs of the growth and development of the field of PSG technology. New Jersey became the second state after Louisiana to license an independent profession of PSG technology. This legislation, known as the PSG Practice Act, became effective as of as of December 15, 2005.

Recent publications[56–58] and changes in reimbursement policies are clear demonstration that PSG is moving in the direction of increased access. It is our responsibility to millions of patients awaiting optimal sleep health care to demand that all studies performed during sleep meet the highest standards of practice. With this commitment, we maximize our ability to facilitate improved patient health outcomes for all those suffering from sleep disorders.

APPENDIX 11-1 Template for 24-Hour Sleep-Wake Log

This log should be completed by the patient for a period of 2 weeks prior to the study.

Date	Date	Date						
Time	Awake	Asleep	Time	Awake	Asleep	Time	Awake	Asleep
12:00			12:00			12:00		
13:00			13:00			13:00		
14:00			14:00			14:00		
15:00			15:00			15:00		
16:00			16:00			16:00		
17:00			17:00			17:00		
18:00			18:00			18:00		
19:00			19:00			19:00		
20:00			20:00			20:00		
21:00			21:00			21:00		
22:00			22:00			22:00		
23:00			23:00			23:00		
24:00			24:00			24:00		
01:00			01:00			01:00		
02:00			02:00			02:00		
03:00			03:00			03:00		
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05:00			05:00			05:00		
06:00			06:00			06:00		
07:00			07:00			07:00		
08:00			08:00			08:00		
09:00			09:00			09:00		
10:00			10:00			10:00		
11:00			11:00			11:00		
Exercise	Exercise	Exercise						
Treatment	Treatment	Treatment						
Sleep Quality	Sleep Quality	Sleep Quality						
Medications	Medications	Medications						
Comments	Comments	Comments						

For each hour of the day:

- *indicate sleep or wake time with an (X) in the appropriate box(es)*
- *indicate naps with an (N) in the appropriate box(es)*
- *indicate periods of extreme sleepiness with an (S) in the appropriate box(es)*

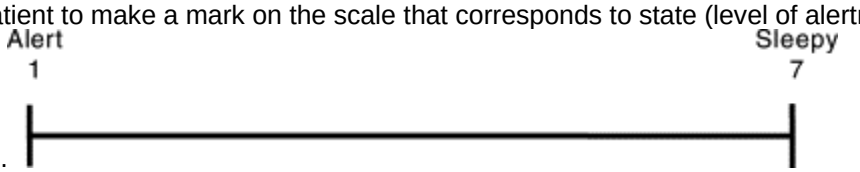
APPENDIX 11-2 Subjective Evaluation of Sleepiness

Stanford Sleepiness Scale

1. Feeling active and vital; alert; wide awake.
2. Functioning at a high level, but not at peak; able to concentrate.
3. Relaxed; awake; not at full alertness; responsive.
4. A little foggy; not at peak; let down.
5. Fogginess; beginning to lose interest in remaining awake; slowed down.
6. Sleepiness; prefer to be lying down; fighting sleep; woozy.
7. Almost in reverie; sleep onset soon; lost struggle to remain awake.

Linear Analog Scale/Introspective Measure of Sleepiness

Ask patient to make a mark on the scale that corresponds to state (level of alertness versus sleepiness) prior to testing.



Adapted from Hoddes E, Dement WC, Zarcone V. The development and use of the Stanford Sleepiness Scale (SSS). Psychophysiology 1972;9:150.

APPENDIX 11-3 Suggested Montages for Recording Sleep-Related Seizure Activity

Montage for a 12-Channel Study

1 Fp1–C3
2 C3–O1
3 Fp1–T3
4 T3–O1
5 Fp2–C4
6 C4–O2
7 Fp2–T4
8 T4–O2
9 EMG: submentalis–mentalis
10 Right outer canthus–left outer canthus
11 Nasal/oral airflow
12 ECG

Montage for a 21-Channel Study

1 Fp1–F3
2 F3–C3
3 C3–P3
4 P3–O1
5 Fp2–F4
6 F4–C4
7 C4–P4
8 P4–O2
9 Fp1–F7
10 F7–T3
11 T3–T5
12 T5–O1
13 Fp2–F8
14 F8–T4
15 T4–T6
16 T6–O2
17 EMG: mentalis–submentalis
18 Right outer canthus–A1
19 Left outer canthus–A2
20 Nasal/oral airflow
21 ECG

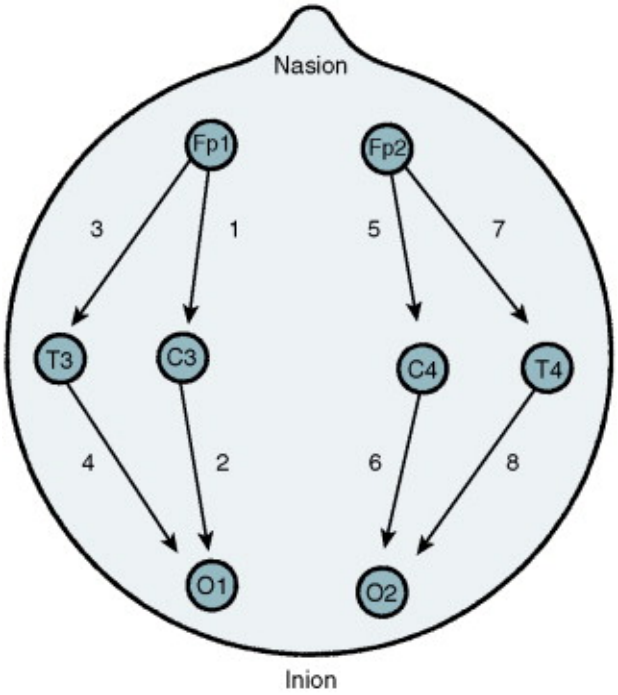


FIGURE 11-A1 Suggested montage to be used to screen for possible seizure activity during sleep. Use of wide interelectrode distance affords for a globa view of EEG activity and conserves the channels. To more adequately localize epileptogenic activity, a full complement of electrodes should be used. For a more comprehensive review of montages, the reader is referred to Standard EEG Montages as proposed by American EEG Society Guidelines No. 7, Gras Instruments (1980).

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APPENDIX 11-4 Measuring the Head for C3, C4, O1, and O2

Before measuring the head, it is helpful to make an initial mark at the inion, the nasion, and the two preauricular points.

1. Measure the distance from the nasion to inion along the midline through the vertex. Make a preliminary mark at the midpoint (Cz). An electrode will not be placed on this spot, but it will be used as a landmark.
2. Center this point in the transverse plane by marking the halfway point between the left and right preauricular points. The intersection of marks from steps 1 and 2 gives the precise location of Cz.
3. Reposition the measuring tape at the midline through Cz and mark the points 10% up from the inion (Oz) and nasion (Fpz).
4. Reposition the measuring tape in the transverse plane, through Cz, and mark 10% (T3) and 30% (C3) up from the left preauricular point and 10% (T4) and 30% (C4) up from the right preauricular point.
5. Position the tape around the head through Fpz, T3, Oz, and T4. Ten percent of this circumference distance is the distance between Fp1 and Fp2 and between O1 and O2. Mark these four locations on either side of the midline.
6. The second marks for O1 and O2 are made by continuing the horizontal mark for Oz. Do this by holding the tape at T3 and T4 through Oz, and extend the horizontal mark to intersect the previous O1 and O2 marks.
7. To establish the final mark for C3, place the tape from O1 to Fp1 and make a mark at the midpoint of this line. When extended, this mark will intersect the previous C3 mark. Repeat on the right side for C4

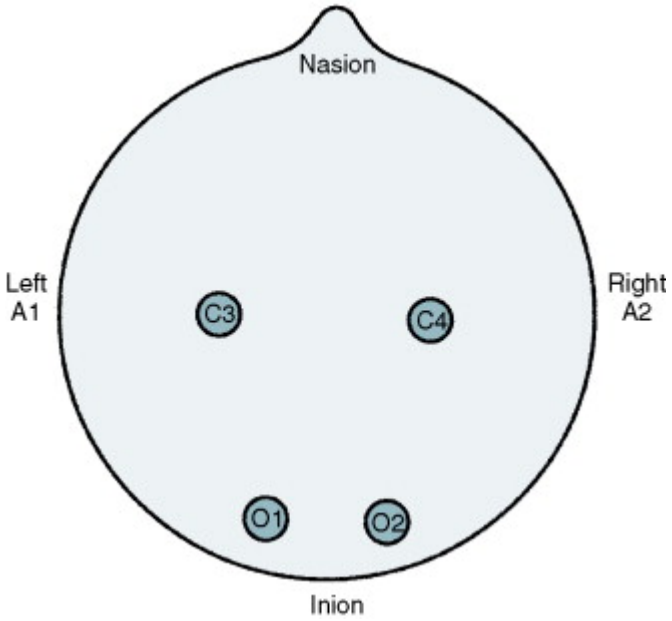

FIGURE 11-A2 The International 10-20 System of EEG electrode placement for sleep recordings.

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