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Chapter 141 – Monitoring and Staging Human Sleep

Sharon Keenan,
Max Hirshkowitz

Abstract

Polysomnography involves recording a wide assortment of bioparameters while a person sleeps. The electroencephalogram, electrooculogram, and skeletal muscle electromyogram can be summarized according to specific scoring criteria as sleep stages N1, N2, N3, and R (previously called stage 1, 2, 3, 4, and REM). Scoring criteria depend upon EEG bandwidth activity (delta, theta, alpha, and beta), EEG events (vertex sharp waves, sleep spindles, and K complexes), eye movement activity (slow and rapid eye movements), and the level of muscle tone. Stage N3 is characterized by high-voltage slow-wave activity. Stage N2 contains sleep spindles and K complexes. Stage N1 has low-voltage, mixed-frequency background, possibly slow eye movements, and vertex sharp waves. If rapid eye movements accompany the low-voltage, mixed-frequency EEG and skeletal muscle tone is low, rapid eye movement (REM or R) sleep is present. Central nervous system arousals also can occur from sleep, either spontaneously or resulting from pathophysiology. Quantitative analysis of sleep stages and CNS arousals provide evidence for, contribute to the definition of, and index the severity of some sleep disorders. Similarly, these measures can provide objective outcome measures for assessing therapeutic interventions. This chapter summarizes recording, digital processing, and scoring techniques used for evaluating brain activity during human sleep and its disturbance by CNS arousals.

History

From a behavioral perspective, immobility and reduced environmental responsiveness characterize human sleep. This state stands in contrast to purposeful (presumably) activities and provides the basis for dichotomizing observable living existence as either sleep or wakefulness. Furthermore, sleep and wakefulness cycle in a lawful, orderly fashion. Some rhythms are seasonal, some are daily (circadian), and some occur more than once a day. Changes in sleep cycle duration and composition in response to reduced sleep testify to sleep–wake cycle autoregulation, with a dynamic tension providing overall system homeostasis. Once techniques were developed to transcend observation, electroencephalography (EEG) revealed a complex array of brain activities clustered in a manner strongly suggesting multiple sleep states.

All scientific inquiry begins with observation and description. From there it proceeds to classification based ultimately upon measurement. Thus, when Loomis and colleagues[1] electroencephalographically recorded their first continuous all-night studies, they faced the daunting task of devising a system to describe sleep patterns in normal healthy human subjects. Thus sleep staging was born. In the original studies, amplified activity derived from electrodes that were placed on the scalp's surface at several loci produced ink tracings on paper wrapped around a slowly rotating cylinder. An enormous 8-ft “drum polygraph” enabled all-night sleep recording. One electrode was located near the eye and undoubtedly detected eye movement. However, rapid eye movement (REM) sleep remained unrecognized until Aserinsky published, in part, his University of Chicago doctoral study results 17 years later.[2] Aserinsky actually christened them “jerky eye movements” (JEMs) and in the first paper referred to the phenomenon as *periodic ocular motility.*

Perhaps it was the quirkiness of the original commercially available polygraph systems (e.g., Ofner, Beckman, and Grass) with their tendency to polarize electrodes, problematic rechargeable car battery–like systems, and aperiodic (and difficult to predict) recording interference artifacts. Or perhaps it was Loomis's silence on the matter of eye movements during sleep. In either case, Aserinsky's pilot work reportedly met with considerable skepticism. Ultimately, however, REM sleep's discovery, and particularly its correlation with dreaming, altered the course of sleep research for decades.[2a] The near-exclusive

focus on REM sleep, to the point that all other sleep states were considered simply non-REM (NREM), overshadowed substantial findings (and likely impeded progress) in other sleep research arenas (e.g., neuroendocrinology, physiology, and medicine). The spotlight on REM sleep made electrooculographic (EOG) recording de rigueur when performing sleep studies.

Meanwhile, in Lyon, France, Michel Jouvet noted postural difference during sleep in cats.[3] These differences correlated with sleep state and reduced skeletal electromyographic (EMG) activity. REM sleep (and, by association, dreaming) coincided with marked hypotonia in descending alpha and gamma motor neurons. The hypotonia induced functional paralysis that was quickly ascribed the purpose of keeping the sleeper from enacting dreamed activities. This sleep state–related EMG alteration added the final compulsory recording component to the procedure now known as polysomnography (PSG).

Polysomnography, in addition to brainwave, eye movement, and muscle tone recording, can also assess respiratory, cardiac, and limb movement activity (discussed in detail in other chapters in this volume and elsewhere[3a]). PSG in its simplest form (including EEG, EOG, and EMG), however, provides the basic information requisite for classifying sleep state and examining sleep processes.

Electrode Placement and Application

To make EEG, EOG, and EMG recordings, electrodes are placed on the scalp and skin surfaces. The site must be cleaned and properly prepared to assure good contact and limit electrical impedance to 5000 ohms or less. Scalp electrodes can be affixed with collodion or with electrode paste. Facial electrodes can be applied with double-sided adhesive electrode collars and paper tape. Although prescribed sites for electrode application have changed over the years, the system used to identify location remains the EEG society's international 10-20 system. In this system, the intersection of lines drawn from the left to right preauricular point, with the midpoint along the scalp between the nasion and inion, serves to landmark the vertex, designated Cz. Other loci can be found by measuring 10% and 20% downward along longitudinal and lateral surfaces. Specific locations are designated with a letter indicating the brain area below the electrode (e.g., C for central lobe, O for occipital lobe, F for frontal lobe) and a number ascribing specific points (odd numbers for the left side, even numbers for the right, and z for midline). EEG electrode placements should be precise; consequently, appropriate measurement techniques must be applied to ensure accuracy. Additionally, EEG amplifiers require calibration at the beginning and end of PSG recording to allow actual waveform amplitude measurements.

The classic and amazingly long-lived standardized technique (i.e., the manual produced by the ad hoc committee chaired by Rechtshaffen and Kales) requires a single monopolar central-lobe scalp EEG electrode referenced to a contralateral mastoid electrode (either C3-M2 or C4-M1). This single-channel brainwave recording, when paired with right and left eye EOGs and submentalis EMG, sufficiently reveals brain, eye, and muscle activity for classifying sleep stages.[4] As polysomnography evolved from a psychophysiologic research method to a clinical procedure, an occipital lead has supplemented centrally derived EEG to provide better visualization of waveforms needed to determine sleep onset and central nervous system (CNS) arousals.[5],[6]

EOG recording capitalizes on the eyes' cornea–retina potential difference. Strong positive corneal potential fields affect electrodes placed near the eyes' right and left outer canthi. The recording traces the response to this positive charge moving toward or away from the recording site. Each electrode is referenced to a neutral site, typically over the mastoid behind the ear. Thus, lateral eye movements produce out-of-phase tracings for right and left EOG tracings as the cornea moves toward one electrode and away from the other (provided that two channels are dedicated to tracing eye movements). This arrangement makes eye movements easily differentiable from in-phase frontal lobe EEG activity that is also present when recording from these sites. To discern vertical eye movements, we place the right-side EOG electrode 1 cm above the outer cantus and the left-side electrode 1 cm below (or vice versa). An alternative recording montage devised to enhance vertical eye movement detection entails lowering both recording sites to 1 cm below the outer canthi and referencing each to the middle of the forehead (Fpz).

Skeletal muscle activity level is estimated from a pair of electrodes arranged to record submentalis EMG. An electrode placed midline but 1 cm above the mandible's inferior edge is referenced to another placed 2 cm below and 2 cm to the right (or left). As a precaution, a backup electrode is also attached at the laterally homologous site of the reference electrode. The resulting submentalis EMG recording serves qualitatively (because it is uncalibratable) to provide an overall estimate for muscle activity level.

The American Academy of Sleep Medicine (AASM) has published a standardized manual for conducting clinical polysomnography in their accredited sleep disorders centers.[7] This AASM standards manual makes recommendations for recording, scoring, and summarizing sleep stages, CNS arousals, breathing, various kinds of movement, and electrocardiographic activity. By bringing instructional guidelines for a range of techniques into a single volume, the AASM manual will strongly influence practice, particularly in North America. Researchers, however, should not feel constrained by these clinical guidelines. New discoveries and future techniques need to continue unshackled by even a de facto standard clinical practice cookbook.

AASM specifies recording frontal, central, and occipital monopolar EEG from F4, C4, and O2. The contralateral mastoid (M1) serves as the theoretically neutral reference. Electrodes are placed at F3, C3, and O1 sites (and referenced to M2) to provide redundancy for backup when needed. The AASM manual sanctions the use of midline bipolar recordings for frontal and occipital EEG; however, the AASM frequently asked questions (FAQ) states that frontal bipolar derivations are not appropriate for measuring frontal EEG activity. The FAQ also states that EEG amplitudes can be measured from the C4-M1 derivation. The AASM manual recommends using mastoid-referenced EOG with separate channels for E2 and E1, but it also approves a forehead-referenced alternative montage. Submentalis EMG is recorded in the traditional manner.

Digital Recording Requirements

The first time a polysomnographic signal was digitized, whether it originated from analogue or digital amplifying circuits, an entirely new set of factors required consideration. The two most important questions to resolve involved specifying amplitude and temporal resolution. Selection of voltage per digital unit (bit) and sampling rate likely had more to do with computer hardware limitations than conceptual considerations. Amazingly, no standard was established for digital polysomnography until publication of the AASM standards manual.

The AASM standards manual specifies minimum 12-bit representation for amplitude, providing 4096 units

to represent a 2.5-volt regulated current (IREG) range, or its equivalent (Video 141-1). In this manner, even the smallest signals, exceeding the level of electrical noise, can be detected. Temporal resolution during recording depends on sampling rate and ultimately must allow accurate waveform reconstruction, provide enough data to potentially overcome frequency aliasing, and be appropriate for high- and low-pass digital filter settings. One size does not fit all: The minimum temporal resolution needed during data acquisition to meet these requirements varies for different bioelectrical signals (Table 141-1).

Table 141-1 -- Recording Recommendations for Digital Polysomnography

RECORDING CHANNEL	Sampling Rate (Hz)*		Filter Setting (Hz)	
	DESIRABLE	MINIMAL	LOW *f*	HIGH *f*
Central EEG (C4-M1)	500	200	0.3	35
Occipital EEG (O4-M1 or Cz-Oz)	500	200	0.3	35
Frontal EEG (F4-M1 or Fz-Cz)	500	200	0.3	35
Left EOG (E1-M2 or E1-Fpz)	500	200	0.3	35
Right EOG (E2-M2 or E2-Fpz)	500	200	0.3	35
Muscle tone (submental EMG)	500	200	10	100
ECG (lead II, modified)	500	200	0.3	70
Airflow sensors at nares and mouth	100	25	0.1	15
Oximetry (ear lobe or finger)	25	10	0.1	15
Nasal pressure	100	25	0.1	15
Esophageal pressure	100	25	0.1	15
Body position	1	1		
Respiratory Effort				
Snoring sounds	500	200	10	100
Rib cage and abdominal movement	100	25	0.1	15
Intercostal EMG	500	200	10	100

E1, left eye; E2, right eye; ECG, electrocardiogram; EEG, electroencephalogram; EMG, electromyogram; EOG, electrooculogram; *f* (frequency), Fpz, frontal pole; M, mastoid.

* Higher sampling rates increase file storage requirements but provide increased temporal resolution. The tradeoff between fidelity and practicality is a matter of debate.

Additional digital specifications involve data selection, display pagination, and calibration. Recorded channels must be selectable, and their calibration must be displayable. The viewable data should provide user-selectable time-frame compression and expansion (ranging from 5 seconds to an entire night shown on a page). Display screens definition should be at least 1600 × 1200 pixels. Digital polysomnographs should provide the capability to view data as it appeared when it was first recorded and when staging or when each event was marked and classified manually. Accompanying video at a minimum of one frame per second should be synchronized with the polysomnographic display.

Eeg Bandwidths, Waveforms, and Other Activity

Bandwidths

One approach to differentiating EEG involves separating activity into dominant frequency bandwidths. *Delta activity* includes brain waves with a frequency less than 4 Hz. Sleep-related delta waves occurring at the low end of the frequency spectrum are called *slow waves*. Slow waves have high amplitude (≥75 mV) and low frequency (≤2 Hz). *Theta activity* includes 4- to 7-Hz waves prominent in central and temporal leads. *Alpha activity* consists of an occipitally prominent 8- to 13-Hz rhythm, and *beta waves* include the low-amplitude waves at even higher frequencies.

Waveforms

In addition to ongoing EEG activity oscillating predominantly within one or another of the specific bandwidths, distinct transient waveform events occur. These include vertex sharp waves, K complexes, sleep spindles, and saw-tooth theta waves. *Vertex sharp waves* are sharply contoured, negative-going (upward, as per EEG polarity convention) waves that stand out from the background activity. As the name implies, they appear prominently in EEGs derived from electrodes placed near Cz.

The *K-complex* begins much like a vertex sharp wave but is immediately followed by a large, usually much slower, positive component. Overall, the K-complex is usually clearest in central and frontal regions and has a duration criterion of 0.5 seconds or more. A *sleep spindle* is a readily apparent 0.5-second (or longer) burst of 12- to 14-Hz activity generated by the thalamus and thalamocortical pathways. The name derives from its spindlelike shape. A *sawtooth wave* is a variant of theta activity, with each wave also containing a notch, making it sawtooth-shaped.

Other nonpathologic sleep-related waveforms exist (e.g., benign epileptiform transients of sleep [BETS], sensory motor rhythm [SMR], Wicket rhythm [mu rhythm], and positive occipital sharp transients of sleep [POSTS]. These normal variants do not occur consistently during polysomnography.

Activity Patterns

Sleep EEG also contains dynamic activity patterns not captured by sleep staging schema or identification of individual waveforms. The *cyclic alternating pattern* (CAP) includes waveform bursts (usually high-amplitude slow, sharp, or polymorphic waves) separated by quiescent periods.[8] The pattern's burst component sometimes includes transient alpha bandwidth components that qualify as CNS arousals and

thus can index sleep disturbance. However, a CAP occurring without frank arousals is thought to signify more subtle sleep instability.

Sleep Staging Rules and Central Nervous System Arousals

For more than 40 years, the standardized technique described in *A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects*[4] has provided the unifying methodology for human sleep research. This standardized manual combines elements from various systems that had evolved and provides adequate detail to achieve general use. However, to a large extent, its enormous success stems from the consensus it attained from the multinational, multidiscipline stakeholders composing its development committee. That is, when the committee members returned to their respective laboratories, they used the techniques and taught them to scientists and clinicians in training.

Staging, as a summarizing technique, necessarily must define a period over which the summary applies. The standardized manual endorsed 20- and 30-second time domains. This flexibility deferred to extant technology; that is, generally available polygraph machine paper chart drive speeds. Over time, the 30-second epoch won out because it provided enough detail to see waveforms (EEG standards dictate minimal paper speed of 10 mm/sec to ensure ability to discern individual EEG waveforms); at 10 mm/sec, one epoch fit on a standard 30-cm wide paper fan-fold polygraph page; and one 1000-page box of polygraph paper would hold a complete recording (or two if one also recorded on the back).

Sleep Staging Rules

Wakefulness (stage W) in a relaxed subject with eyes closed is differentiated from sleep by the presence of alpha EEG activity in 50% or more of the epoch (Fig. 141-1). Poorly defined alpha EEG complicates determination of sleep onset.

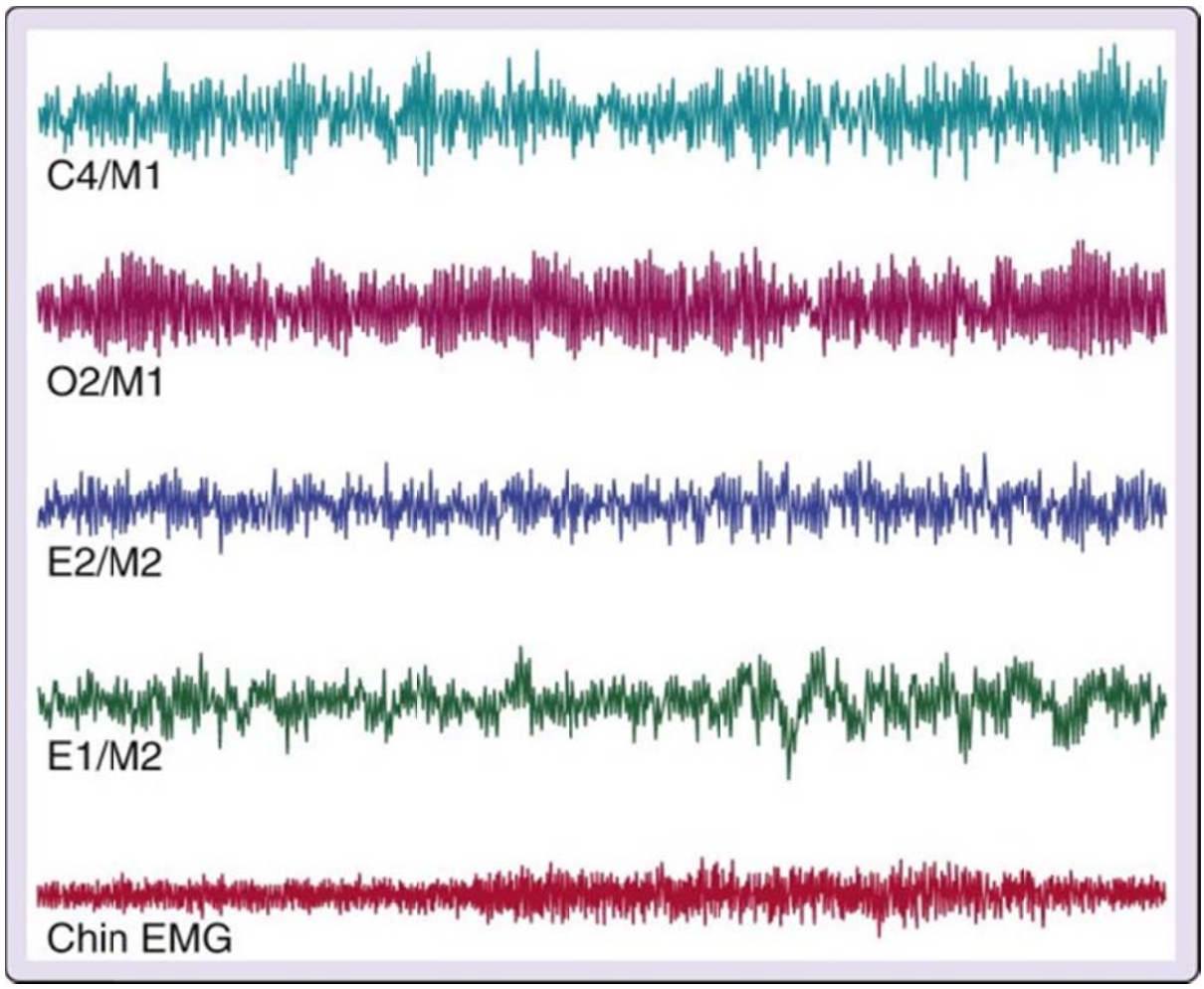

Figure 141-1 Stage wake (W), eyes closed. This example demonstrates a classic wake pattern, with alpha rhythm in the EEG and EOG. Alpha activity is most prominent in the occipital channel. The chin EMG displays normal muscle tone associated with relaxed wakefulness.
(From Butkov N. Atlas of clinical polysomnography, 2nd ed. Medford, Ore: Synapse Media; [in press].)

Stage 1 winds up being largely defined by exclusion; that is, it is a low-voltage, mixed-frequency background EEG devoid of sleep spindles and K-complexes, minimal slow-wave activity, cessation of blinking, absence of saccadic eye movements, and alpha activity less than 50% of the epoch duration (Fig. 141-2). Stage 1 sleep may, but does not necessarily, include vertex sharp waves, background activity slowing, and slow eye movements.

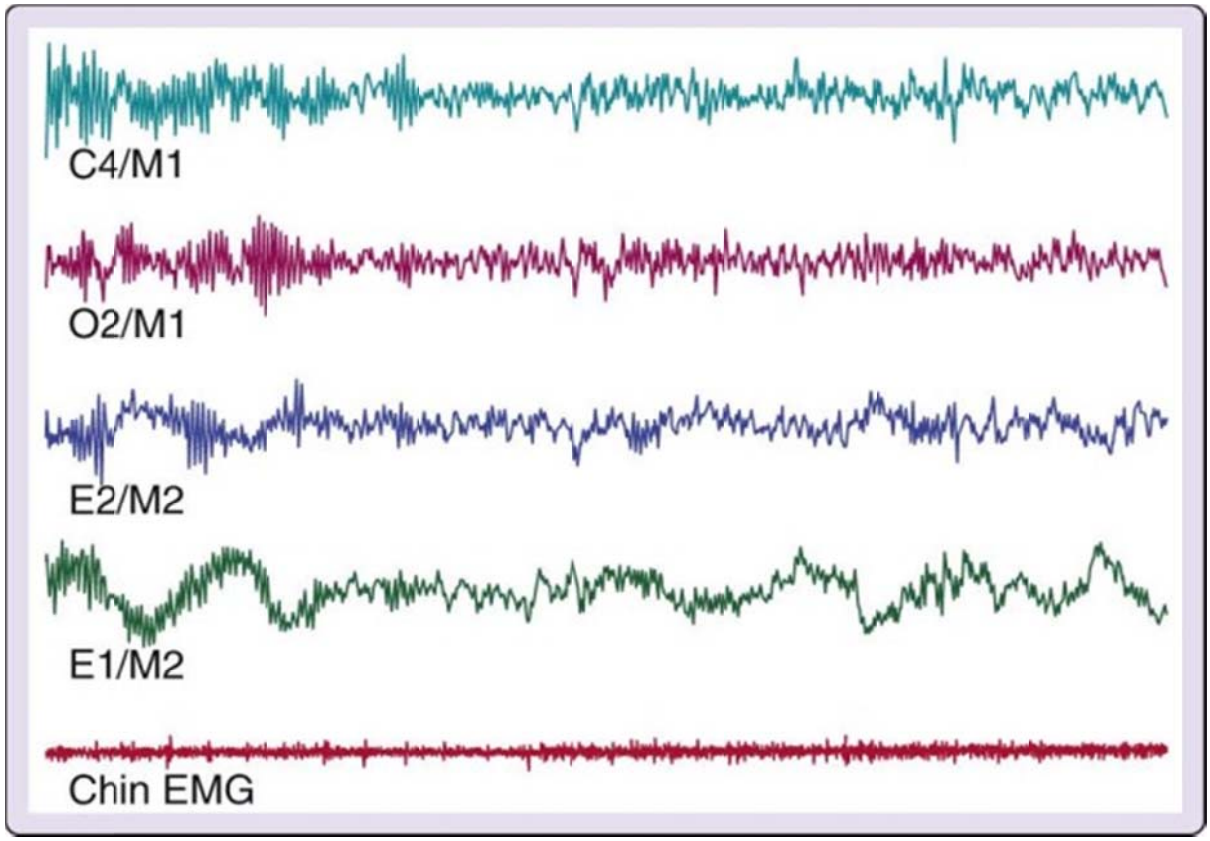

Figure 141-2 Stage 1 sleep (N1). The onset of N1 is identified by the disappearance of alpha rhythm, replaced by relatively low voltage mixed-frequency EEG with a prominence of theta activity in the range of 4 to 7 Hz. The chin EMG remains tonic, although it can attenuate slightly with sleep onset.
(From Butkov N. Atlas of clinical polysomnography, 2nd ed. Medford, Ore: Synapse Media; [in press].)

Stage 2 characteristics include sleep spindles and K-complexes (Fig. 141-3) occurring on a low-voltage, mixed-frequency background EEG and minimal (<20% of the epoch) slow-wave activity.

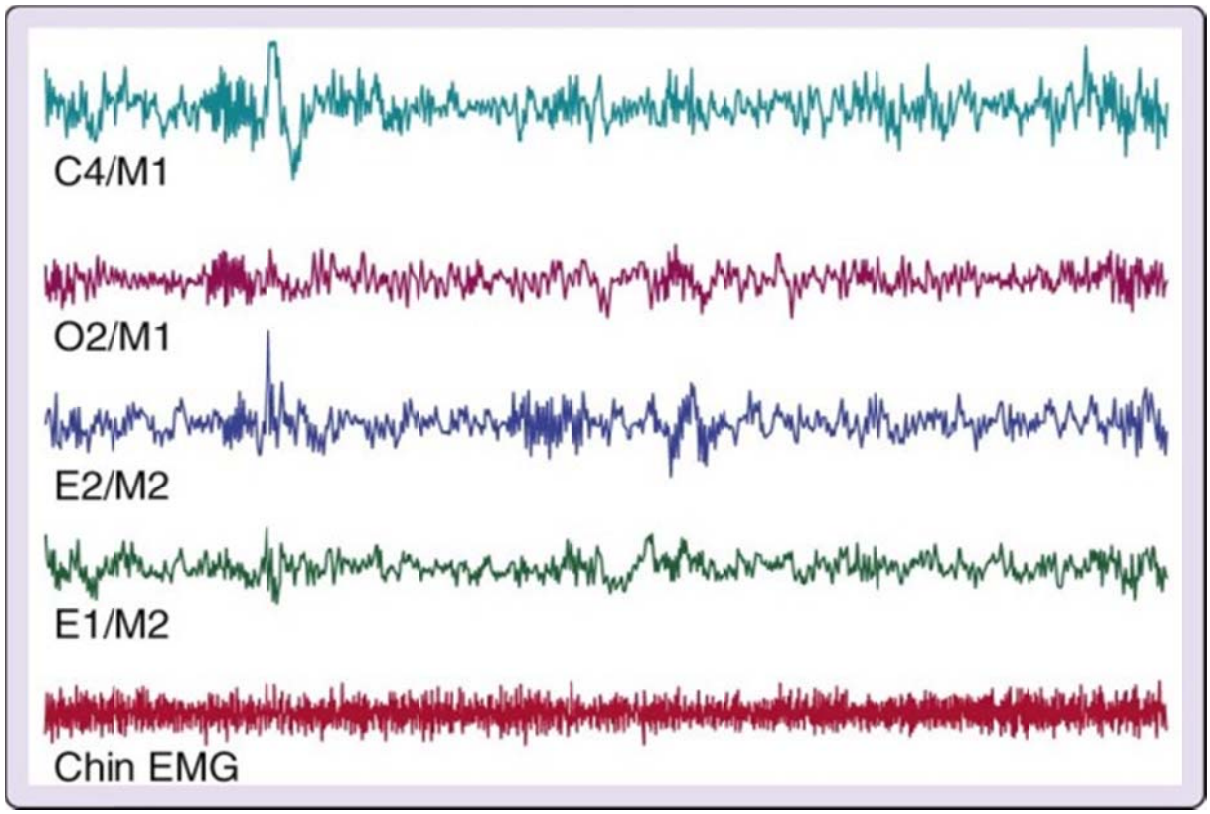

Figure 141-3 Stage 2 sleep (N2). Stage N2 is identified by the presence of K-complexes and/or sleep spindles against a background of mixed-frequency EEG. The chin EMG displays normal muscle tone, as expected during NREM sleep. *(From Butkov N. Atlas of clinical polysomnography, 2nd ed. Medford, Ore: Synapse Media; [in press].)*

Slow-wave sleep (stages 3 and 4 sleep) contains delta EEG activity (recorded from a monopolar central derivation) with a 75-mV or greater amplitude enduring for 20% or more of an epoch (Fig. 141-4). *Stage 3* is scored when the duration of slow waves composes 20% to 50% of the epoch and *stage 4* is scored when duration reaches 50% or more.

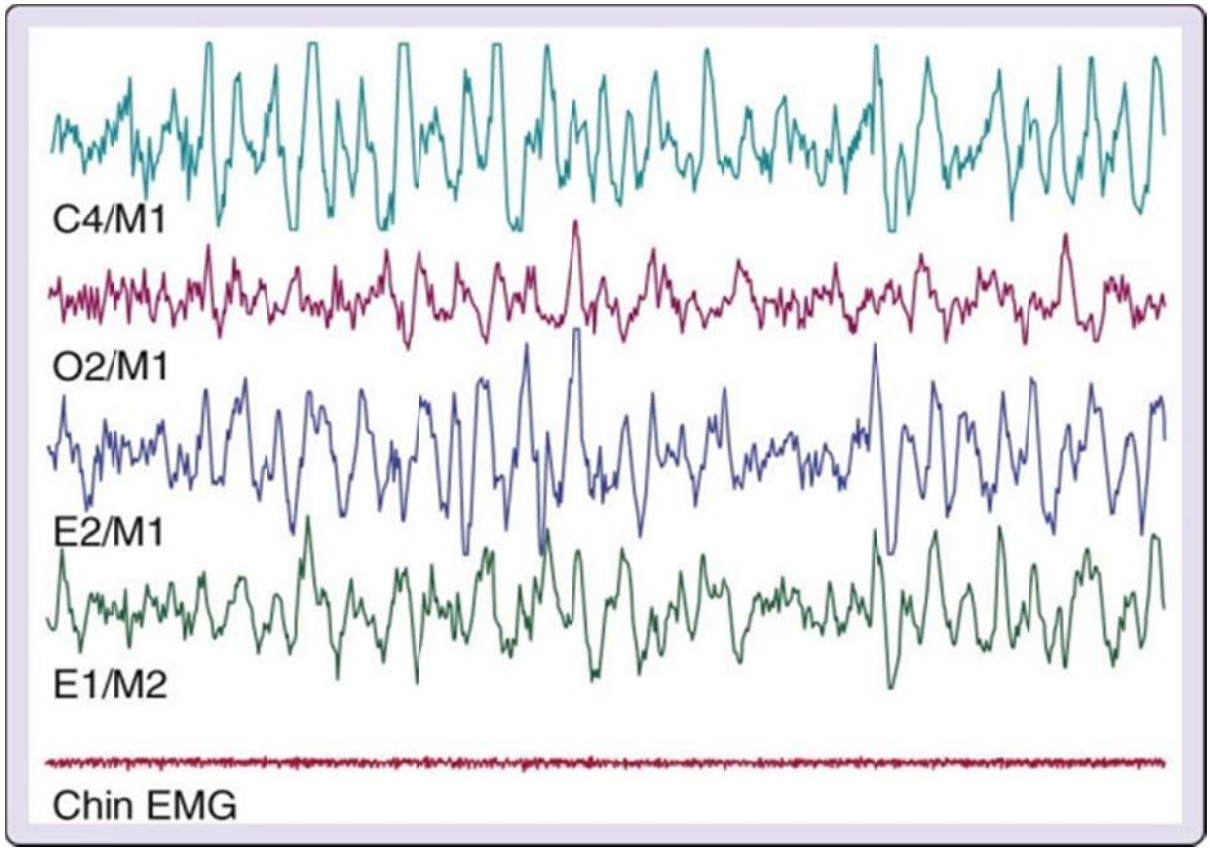

Figure 141-4 Slow-wave sleep (N3). In this example, high-amplitude slow waves occupy greater than 50% of the epoch. By the Rechtchaffen and Kales criteria, this epoch is scored as stage 4. By the revised AASM criteria, this epoch is scored as N3.
(From Butkov N. Atlas of clinical polysomnography, 2nd ed. Medford, Ore: Synapse Media; [in press].)

REM sleep is scored when saccadic eye movements occur during epochs with low-voltage, mixed-frequency EEG in association with a very low level of submentalis EMG activity (Fig. 141-5). Epochs with low-voltage, mixed-frequency EEG and continuing low-level submentalis EMG (without eye movements) falling between epochs of REM sleep (with eye movements) are also scored as REM sleep. Epochs falling before or after (and contiguous with) clear REM sleep that have comparable EEG and EMG features but lack rapid eye movements are scored as REM sleep until an arousal, EMG level increase, or resumption of K-complexes or sleep spindles occurs. These *smoothing rules* gloss over minor transitions on the supposition that REM sleep represents a persistent central nervous system (CNS) organizational state distinct from wakefulness and NREM sleep.

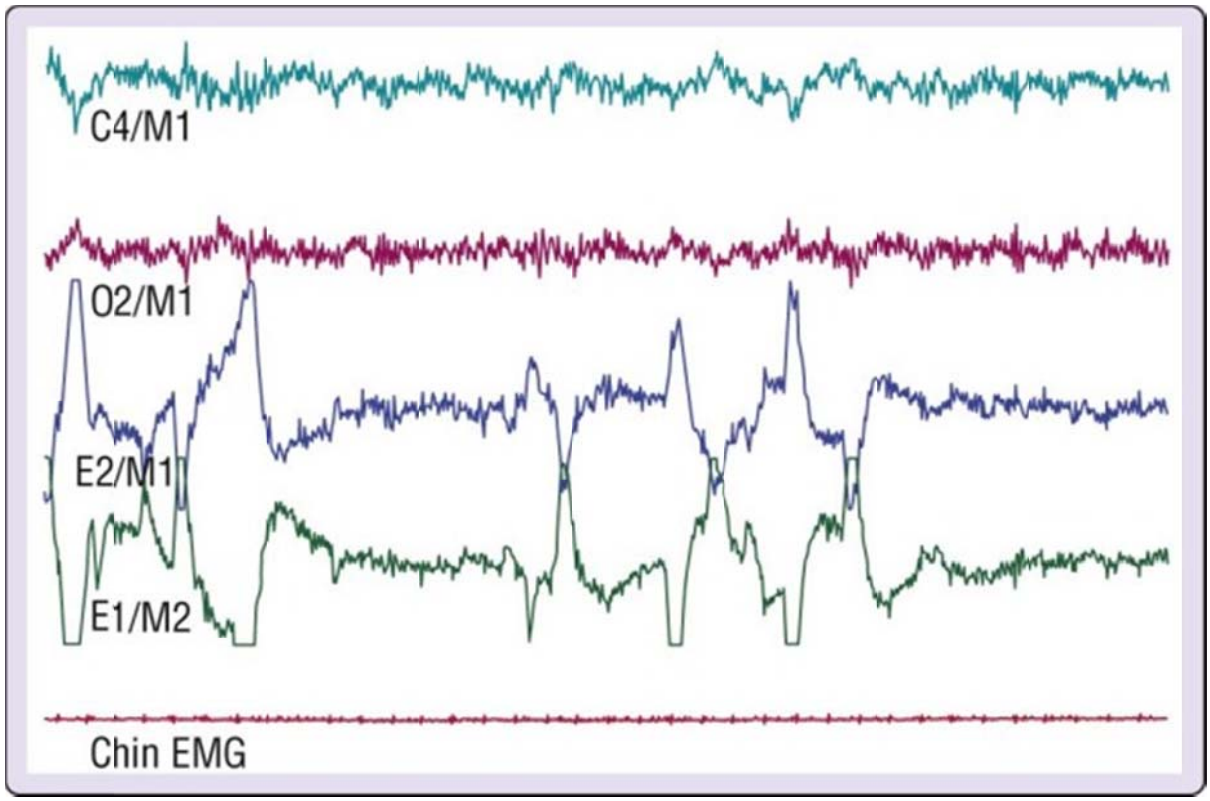

Figure 141-5 REM sleep. During REM sleep, chin muscle tone drops to the lowest level of the recording. REM sleep is identified by the presence of rapid eye movements in combination with relatively low-voltage mixed-frequency EEG and low-chin EMG.
(From Butkov N. Atlas of clinical polysomnography, 2nd ed. Medford, Ore: Synapse Media; [in press].)

In 2007, the AASM standards manual provided revised criteria for scoring sleep stages. Changes are summarized in Table 141-2. Essentially, changes include standardizing epoch length at 30 seconds; combining stages 3 and 4 sleep and applying amplitude criteria for slow waves to frontal EEG activity; revising terminology (R for REM sleep, N1 for NREM stage 1, N2 for NREM stage 2, N3 for NREM stages 3 and 4, and W for wakefulness); and simplifying smoothing rules. Some changes are controversial.[9-14]

Table 141-2 -- Comparison of Traditional and AASM (2007) Sleep Stage Scoring Systems

PARAMETER	R&K CLASSIFICATION CRITERIA	AASM CLASSIFICATION CRITERIA
Epoch length	15 or 30 seconds, user's choice	30 seconds, mandated
Stage nomenclature	Wakefulness, stage 1 sleep, stage 2 sleep, stage 3 sleep, stage 4 sleep, REM sleep, movement time	Stages W, N1, N2, N3, and R
Wakefulness	EEG alpha activity for ≥50% of an epoch	Same
Slow-wave sleep	EEG slow-wave activity for ≥50% of the epoch for stage 4 sleep or ≥20% of the epoch for stage 3 sleep	Same, except that stages 3 and 4 are combined to N3
Stage 2 sleep	Sleep spindles or K-complexes; EEG slow-wave activity for <20% of the epoch	Same
Stage 1 sleep	Low-voltage, mixed-frequency activity; possibly vertex sharp waves; possibly slow eye movements; no sleep spindles or K-complexes; EEG alpha activity for <50% of the epoch	Same
REM sleep	Low-voltage, mixed-frequency EEG activity; very low submental EMG activity; possibly saw tooth EEG theta activity; at least one unequivocal rapid eye movement	Same
Movement time	Polysomnographic activity obscured to the point of not being readable for more than 50% of the epoch; the preceding epoch is scored as stage 1, 2, 3, 4, or REM sleep	This epoch classification is eliminated
Smoothing rules	When an epoch is *classified as a particular stage* but is surrounded by epochs lacking unique features (e.g., a sleep spindle, slow-rolling eye movements, or CNS arousal) and would otherwise have been scored as stage 1 sleep, the *classified epoch* scoring is generalized to the surrounding epochs (but only for 3 minutes). These *smoothing rules* apply to stage 2 and REM sleep.	Same, except that there is no 3-minute limit to the generalization

AASM, American Academy of Sleep Medicine; CNS, central nervous system; EEG, electroencephalogram; EMG, electromyogram; R&K, Rechtchaffen and Kales; REM, rapid eye movement.

Central Nervous System Arousal Scoring

Sleep staging fails to represent brief CNS arousals because it summarizes EEG, EOG, and EMG activity over a 30-second time domain. Increasing clinical application of polysomnographic technique heightened the need to appreciate sleep fragmentation; consequently, a scoring system for arousals was developed[6] under the auspices of the American Sleep Disorders Association (later to become the AASM). Abrupt 3-second (or longer) EEG frequency increases to theta, alpha, or beta (but not to sleep spindles) are considered biomarkers for CNS activation. The arousals most often entail emergent occipital EEG alpha activity. To qualify as an arousal, 10 seconds of sleep must precede the event. In REM sleep, activity must increase in submentalis EMG leads for at least 1 second (Fig. 141-6). The 3-second duration represents the minimum duration that could be reliably scored by visual inspection (among the task force members). Events of shorter duration likely also have clinical significance. The AASM standards manual endorsed this scoring technique and simplified the original 11 rules to a single statement with two explanatory notes.

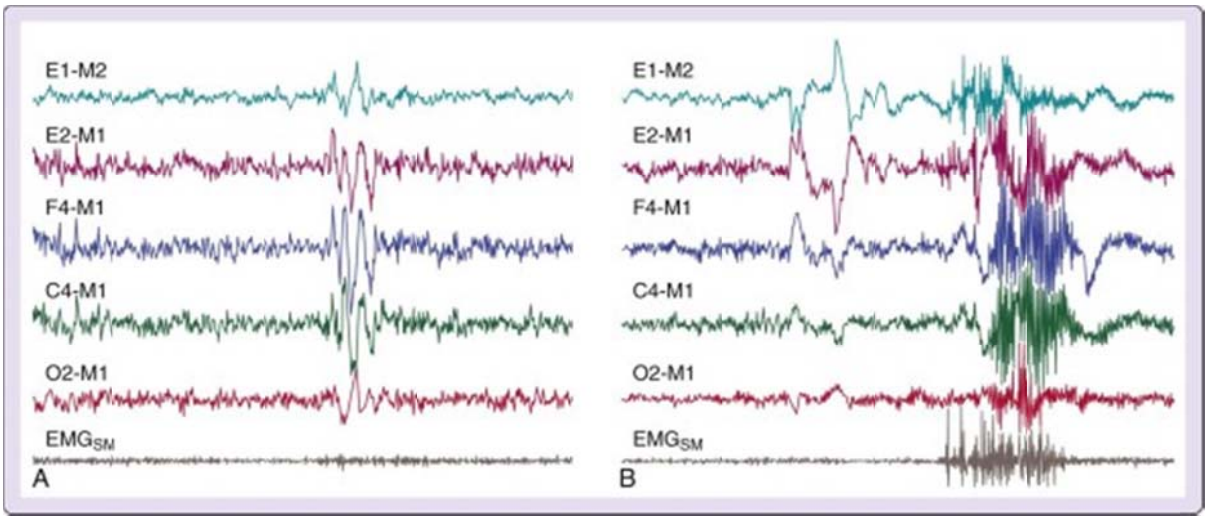

Figure 141-6 Arousals from NREM(A) and REM(B) sleep. **A,** A paroxysmal burst of high-amplitude slow activity appears near the center of the epoch. The distribution of the electrical field changes associated with this event can be seen reflected in the other EEG channels but with (expected) decreased amplitude. There is little or no change in the EMG channel in association with this event. It is common to see K-complex activity evoked by auditory stimuli. **B,** An increase in EMG activity is noted on the EMG and almost simultaneously in the E2-M1 channel. This is followed by a brief generalized presentation of EMG artifact throughout the EEG and EOG channels. Prior to the event there is evidence of REM sleep: low-voltage, mixed-frequency EEG, rapid eye movements, and very low EMG. After the event, the EMG channel shows an increased tone, and the EEG background activity is low voltage and fast. There is a continuation of EMG artifact on the EEG channels after the short burst. These data, especially the burst of alpha activity seen in the O2-M1 channel, are consistent with a possible transition to wake from REM sleep
(Courtesy of Max Hirshkowitz, PhD, DABSM).

Summarizing Normal Sleep

The sleep stage pattern across the night can be represented diagrammatically (Fig. 141-7). In healthy young adults, stage R accounts for approximately 20% to 25% of total sleep time, stage N2 accounts for 50%, N3 accounts for 12.5% to 20%, and N1 accounts for the remainder. In normal sleepers, wakefulness might account for 5% to 10% of the time in bed. Stage R typically does not appear until approximately 90 minutes after sleep onset, after which it reoccurs every 90 to 120 minutes in distinct episodes. These episodes increase in duration as the night progresses; therefore, the first half of the sleep session contains less REM sleep than the second half. By contrast, slow-wave activity (stage N3) predominates in the first third of the night. Age-matched sleep bears great similarity in men and women;

however, women might have slightly better preserved stage N3 with advancing age. Sleep can be quantitatively summarized, and Table 141-3 provides definitions for commonly used parameters.

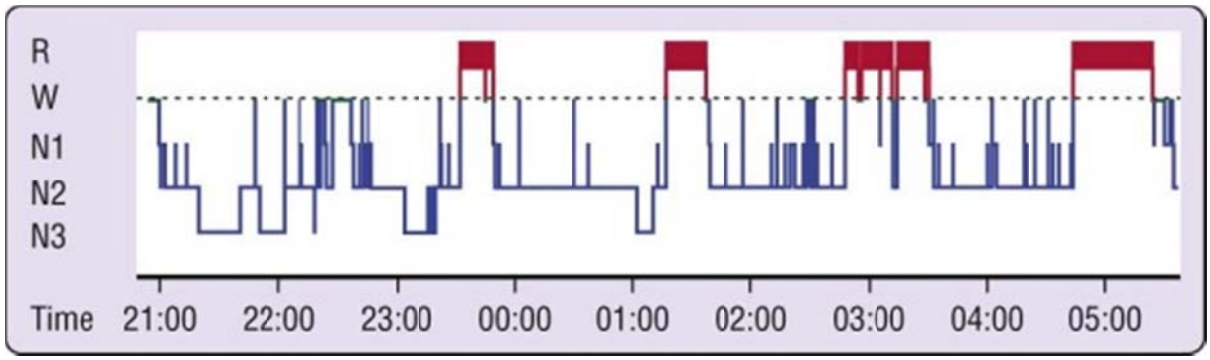

Figure 141-7 Normal sleep histogram illustrating sleep macroarchitecture (stages) for a young adult.

Table 141-3 -- Parameters Derived from Sleep Staging and CNS Arousal Scoring

PARAMETER	NOTATION	EXPLANATION
AASM Recommended Parameters		
Lights out clock time	L-out	The clock time (in hh:mm) that the subject was instructed to allow himself or herself to fall asleep
Lights on clock time	L-on	The clock time (in hh:mm) that the subject was awakened
Total sleep time	TST	Minutes scored as stage N1, N2, N3, or R
Total recording time	TRT	Elapsed time from L-out to L-on (in minutes)
Sleep latency	SLAT	Elapsed time from L-out to first epoch of stage N1, N2, N3, or R (in minutes)
REM sleep latency	RLAT	Elapsed time in minutes from SLAT to first epoch of stage R
Wake after sleep onset	WASO	Minutes scored as stage W from first sleep epoch to L-on

PARAMETER	NOTATION	EXPLANATION
Sleep efficiency	SEI	TST as a percentage of TRT
Time in each stage	MW, M1, M2, M3, MR	Minutes scored as W, N1, N2, N3, and R (individually)
Sleep stage percentages	P1, P2, P3, PR	Time scored as N1, N2, N3, and REM as a percentage of TST (individually)
Number of CNS arousals	NArsls	The number of CNS arousals
CNS arousal	CNS AI	The number of CNS arousals scored per hour of TST
Other Useful Parameters		
Latency to persistent sleep	LTPS	Elapsed time (in minutes) from L-out to first of 10 consecutive minutes of sleep
Latency to unequivocal sleep	LUS	Elapsed time (in minutes) from L-out to first epoch of N2, N3, or R or to three consecutive (or more) epochs of N1 If N1 is followed by an epoch of N2, N3, or R, LUS is calculated from L-out to the first epoch of N1
Sleep-period time	SPT	Minutes from first to last epoch scored as N1, N2, N3, or R
Number of REM episodes	NREME	Number of stage R occurrences
Number of awakenings	NWake	Number of stage W occurrences
Wake index	WI	Number of awakenings per hour of TST
Sleep fragmentation index	SFI	Number of awakenings and CNS arousals per hour of TST
Number of stage	NShifts	Number of stage transitions during TRT

PARAMETER	NOTATION	EXPLANATION
shifts		
Stage shift index	SSI	Number of stage transitions per hour of TRT
Latency to arising	LTA	Duration of final stage W if it was ongoing when L-on occurred

CNS, central nervous system; REM, rapid eye movement [sleep].

Ambiguous Sleep Stages and Sleep Quality

Sleep stage scoring was developed to summarize EEG, EOG, and EMG correlates of *normal sleep*. Under normal circumstances, particular events cluster the vast majority of the time. By contrast, this tight coupling tends to loosen when patients rebound from sleep deprivation; sustain brain injury; are afflicted with sleep, medical, neurologic, psychiatric, or sleep disorders; or ingest psychoactive substances. The resulting intrusion, translocation, or migration of specific EEG, EOG, or EMG activity, characteristic of one stage into another, produces ambiguous epochs that are difficult to classify according to the usual scoring rules. This departure from normal processes can provide qualitative evidence of an underlying sleep dysfunction.

Perhaps the most common ambiguities accompany pharmacotherapy. Gamma-aminobutyric acid A ($GABA_A$) and benzodiazepine receptor agonists generally increase spindle activity in the EEG. These pharmacologically induced spindles typically are of higher frequency (16 to 18 Hz), often of longer duration, occur more frequently (higher density), and can appear not only in N2 but also in other stages of sleep and even in wakefulness.

Another commonly noted drug effect involves serotonin agonist augmentation of eye movement activity. In some persons, rapid eye movements occur at sleep onset, in stage N2, and stage N3, making the scoring of REM sleep a challenge. The phenomenon is so common that many sleep specialists refer to it as *Prozac eyes* (referring to fluoxetine, the prototypical selective serotonin reuptake inhibitor).

Another serotonin agonist–provoked sleep alteration involves elevated muscle activity during REM sleep. In some cases, these medications produce a loss of atonia, permitting attempted dream enactments (i.e., iatrogenic REM Sleep behavior disorder [RBD]). Individual PSG epochs during these events do not meet usual stage classification criteria. Similar REM sleep ambiguities occur in idiopathic, Parkinson's disease–related, and posttraumatic stress disorder–related RBD.

Patients suffering from neurodegenerative diseases or brain insult can manifest an overall erosion of EEG sleep events. This includes reduced sleep spindles, K-complexes, and slow-wave activity. We also sometimes observe this in patients with sleep apnea, heart failure, and metabolic disorders. The resulting nearly featureless sleep EEG can be difficult to score according to normal staging rules. By contrast, another very different scoring problem can occur in patients with severely fragmented sleep produced by obstructive apnea. In these patients, a continual cycle of falling asleep, airway collapse, struggle to breathe, awakening, and falling asleep occurs. Thus, the patient remains in a *t*ransition state that does not fit well into any sleep stage category. It was once proposed that this pattern be scored as *t-sleep.*

In some persons, copious EEG alpha activity permeates ongoing background activity. In sleep states marked by low-amplitude, mixed-frequency activity, alpha bursts meeting criteria for CNS arousal can be scored as such (alpha intrusion). However, when slow waves characterize the dominant ongoing

background EEG activity and the alpha coincides with delta, arousals are not scored. This *alpha-delta* sleep sometimes accompanies pain syndromes, but it appears to lack specificity. A related phenomenon, also ascribed to pain, involves K-complex bursts followed by EEG alpha activity. Many sleep specialists consider *K-alpha* a variety of the CAP.

Clinical Pearl
Sleep staging and CNS arousal scoring provide important clinical information about sleep-related brain process. Ultimately, persons who awaken sleepy or unrefreshed or who have difficulty initiating or maintaining sleep can be assayed for sleep integrity, quantity, and quality using polysomnography. Human sleep is a brain process. Pathophysiologies such as increased airway resistance and leg movements produce CNS arousals that fragment and destroy the fabric of sleep. Disorders often alter sleep patterns and overall architecture. Treatments may promote return to normal. Quantitative analysis through staging and arousal scoring objectively documents sleep disruption and provides a severity index for sleep disorders.

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