

Sleep Stages and Scoring Technique

Raman K. Malhotra
Alon Y. Avidan

Introduction to Sleep Stage Scoring

The original Rechtschaffen and Kales sleep scoring manual of 1968, commonly known as the *R and K* rules, was used until 2007, at which point the American Academy of Sleep Medicine (AASM) updated the scoring manual in what is commonly known as the *AASM scoring manual*. The Rechtschaffen and Kales method divides sleep into five distinct stages: non-rapid eye movement (non-REM [NREM]) stages 1, 2, 3, and 4 and stage REM sleep. The AASM scoring manual recognizes four sleep stages: Stage N1 (formerly stage 1 sleep), stage N2 (formerly stage 2 sleep), stage N3 (formerly stages 3 and 4 sleep), and stage R sleep (formerly stage REM sleep). The reader is reminded that sleep stages should not be viewed as distinct entities, but rather as a gradual transition of a waveform. The scoring rules were devised to allow uniformity between sleep laboratories and to offer a conceptual simplicity rather than a rigid framework.

Particular signals of interest for sleep scoring include those generated from the cerebral cortex (electroencephalogram [EEG]), eye movements (electro-oculogram [EOG]), and the muscles of the face (picked up by chin electromyographic activity). Electrode placement for EEG scoring rules follows the international 10-20 system, which assigns a number to each EEG electrode to specify the location in the left or right hemisphere (Table 3.1).

Figures 3.1 and 3.2 depict the updated AASM-recommended derivations for recording the EEG.

This chapter will include a discussion of the specific parameters required for staging sleep and a summary of the various EEG activity needed to score sleep. This discussion will be followed by a discussion of the stages of sleep using specific polysomnographic (PSG) records.

The following abbreviations are used in the PSG samples provided in this chapter:

Electro-oculogram electrodes (EOG): Left outer canthus: LOC-A2; right outer canthus: ROC-A1; LOC-A2, ROC-A1, left and right electro-oculogram referred to right and left mastoid leads; M2, right mastoid electrode location; M1, left mastoid electrode location; L/ROC-AVG, left and right electro-oculogram referred to an average reference electrode; E1, left outer canthus eye electrode; E2, right outer canthus eye electrode.

Electroencephalogram electrodes (EEG): C3-A2, C4-A1, O1-A2, O2-A1, left central, right central, left occipital,

right occipital; electrode location: ground (FPZ), reference (CZ), A1 or M1 and A2 or M2; C3 and O1, left central and occipital, respectively, EEG electrodes; C4 and O2, right central and occipital, respectively, EEG electrodes. The exploring reference electrode (F3, F4, C3, C4, O1, and O2) is chosen on the opposite side of the head from the mastoid electrode (M1, M2) or average (AVG).

Electromyogram electrodes (EMG): LtTib1-LtTib2 and RtTib1-RtTib2, left and right tibialis anterior EMG electrodes; Chin1-Chin2, submental EMG signal; chin EMG, Chin1-Chin2; limb EMG (left leg, right leg), LtTib1-LtTib2, RtTib1-RtTib2.

Electrocardiogram electrodes (ECG): ECG1-ECG2, ECG2-ECG3.

Respiratory electrodes: SNORE, snore sensor sound; OroNs, oronasal airflow or oronasal thermistor; PFLOW, nasal pressure transducer; THOR/CHEST and ABD, chest and abdominal walls motion effort; THOR1-THOR2, thoracic effort channel; ABD1-ABD2, abdominal effort channel; CFLOW, continuous positive airway pressure (CPAP) airflow channel; Pco₂, mm Hg of carbon dioxide; Spo₂, oxygen saturation by pulse oximetry by finger probe; Pleth, plethysmography; Pt Position, patient position (supine, left, right, prone).

Figures are provided with a 1-second ruler.

Parameters for Staging Human Sleep

Common to all PSG monitoring is the measure of the following three physiological parameters:

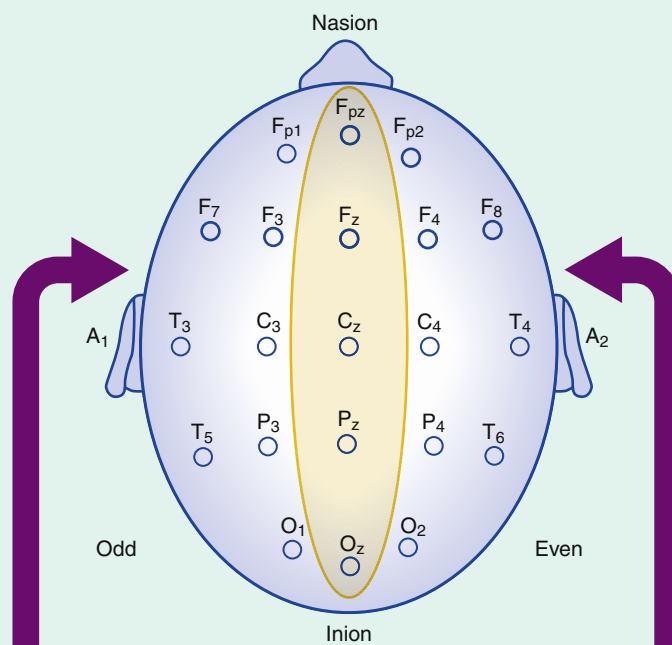
1. EOG leads: left eye and right eye
2. EEG leads: one occipital, one central, and one frontal lead
3. EMG lead: one submental EMG channel

Eye Movements (Electro-oculogram Activity)

The EOG signals measure changes in the electrical potential of the positive anterior aspect of the eye, the cornea, relative to the negative posterior aspect, the retina. Horizontal axis electrodes are placed near the outer canthi and vertical axis electrodes 1 cm below (LOC) and 1 cm above (ROC) the eye to measure transient changes in potential during the

Table 3.1 10-20 Electrode Placement

The 10-20 system assigns a number to further specify the location in the left or right hemisphere. Location *z* is used to indicate that the location of the electrode is in the midline or “zero,” meaning that it is neither left hemisphere nor right hemisphere. The electrode placed at *C_z* is said to be the *vertex*, meaning that it is the midcentral or at the top of the head. *F_{pz}* and *O_z* are used in achieving the other measurements and can be used as additional electrode placements for localization of activity. *F_{pz}* may be used as the location of the common or ground electrode placement.



Brain area	Left	Midline	Right
Frontal pole	Fp1	Fpz	Fp2
Frontal	F3	Fz	F4
Inferior frontal	F7		F8
Anterior temporal	T1 or F9		T2 or F10
Midtemporal	T3		T4
Posterior temporal	T5		T6
Central	C3	Cz	C4
Parietal	P3	Pz	P4
Occipital	O1	(Oz)	O2

actual eye movement (Fig. 3.3). During any eye movement the cornea moves toward one electrode, while the retina moves away. When the eye is not moving, the change in relative position is zero, and the eye leads do not record a signal.

Slow rolling eye movements (SREMs) occur during drowsiness and light sleep and are recorded as long gentle waves, whereas rapid jerking movements are represented by sharply contoured fast waves. Blinking of the eyes produces rapid vertical movements. During REM sleep, eye movements again become active and jerky. The intensity of the bursts of activity is used to describe the density of REM sleep.

Electro-oculographic Recording

- EOG voltages are higher than EEG signal. Because the eye is outside of the skull structure, there is no bone to attenuate signal.

- The cornea (front) has a positive polarity. The retina (back) has a negative polarity.
- EOG placement (LOC and ROC) is on the outer canthus of the eye, offset 1 cm below (LOC) and 1 cm above (ROC) the horizon.
- Electro-oculography picks up the inherent voltage of the eye. During eyes-open wakefulness, sharp deflections in the EOG tracing may indicate the presence of eye blinks.

Electroencephalographic Recording

Wakefulness and sleep are determined by the characteristic patterns of the scalp EEG signals and are of fundamental importance in interpreting PSG studies. EEG records electrical potentials generated by the cortex but can reflect

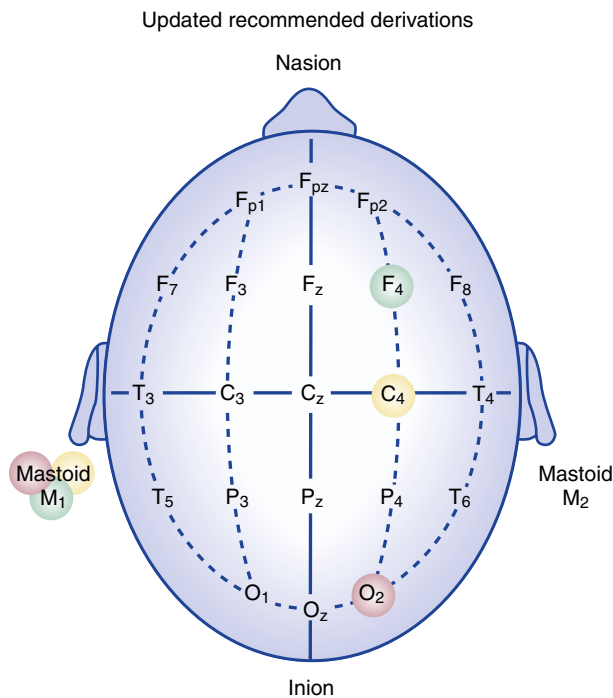


FIGURE 3.1 Updated American Academy of Sleep Medicine (AASM) recommended derivations for recording the electroencephalogram. Electrode locations as recommended in 2007 by the AASM. (Modified from Kryger MH. *Atlas of Clinical Sleep Medicine*. Philadelphia: Saunders/Elsevier; 2010.)

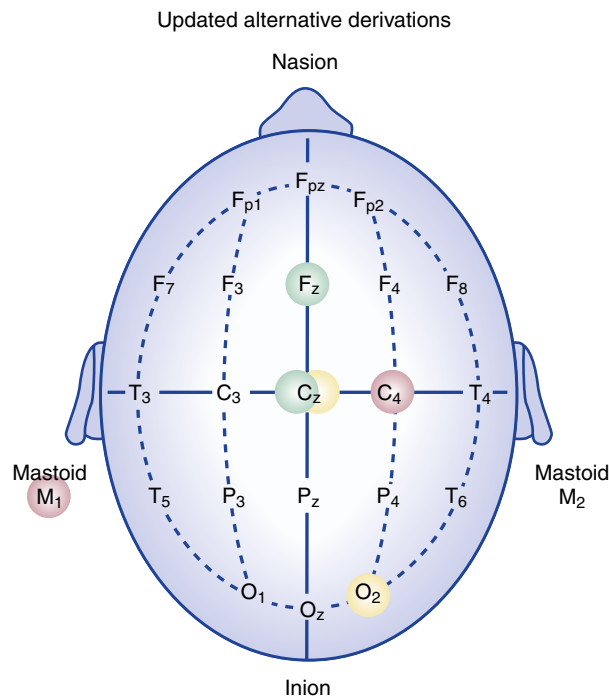


FIGURE 3.2 Updated American Academy of Sleep Medicine alternative derivations for recording the electroencephalogram. Alternative electrode locations as recommended in 2007. Backup electrode substitutions: O₁ for O₂, F_{pz} for F_z, and C₃ for C_z. F_{pr}, Frontopolar or prefrontal; F, frontal; C, central; T, temporal; P, parietal; O, occipital; A, ear or mastoid; F₃, left midfrontal; P₃, left parietal; T₄, right temporal; A₁, right ear; C_z, vertex. (Modified from Kryger MH. *Atlas of Clinical Sleep Medicine*. Philadelphia: Saunders/Elsevier; 2010.)

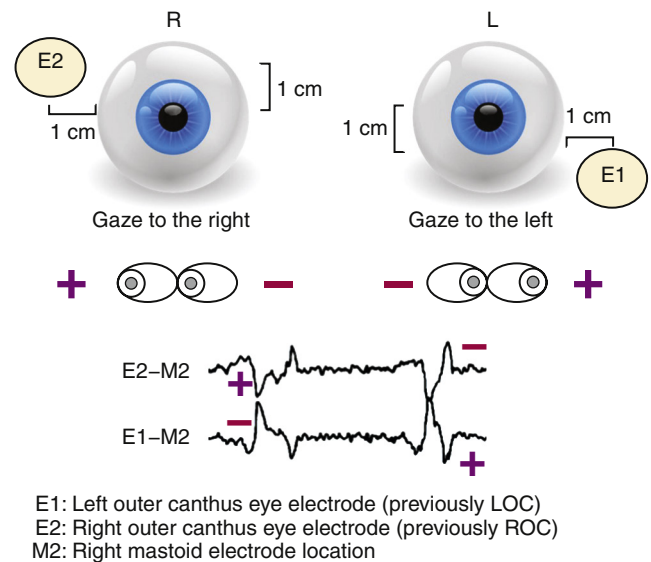


FIGURE 3.3 The eye can be envisioned as a battery with the positive pole at the cornea and the negative pole at the retina. The electro-oculogram (EOG) consists of a bipolar linkage from the right electro-oculogram (ROC) electrode 1 cm lateral and 1 cm superior to one outer canthus to the left electro-oculogram (LOC) electrode 1 cm lateral and 1 cm inferior to the other outer canthus. The electrode toward which the eyes move becomes relatively positive, the other relatively negative. As the eyes move during sleep, they produce corresponding changes in the electrical field, producing a correlating potential change in the electroencephalogram electrodes. This can be verified by noting corresponding movements in the EOG channels. (From Avidan AY, Barkoukis T, eds. *Review of Sleep Medicine*. 3rd ed. Philadelphia: Elsevier; 2011.)

the influence of deeper brain structures, such as the thalamus. Measurement of the EEG signal is possible because of the relative difference in potential between two recording electrodes in grid 1 and grid 2 of the channel. A negative discharge in grid 1 relative to grid 2, by convention, is represented by an upwardly deflecting wave in grid 1 of the channel. The PSG references the left or right electrodes to electrodes on the opposite right and left ears (A2, A1) or mastoids (M2, M1). The general rule is to read only from the right cortical channel. However, when this channel develops artifact or the validity of the signal is suspected, comparison is made with the left channel.

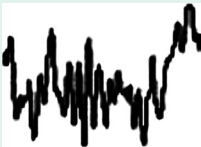




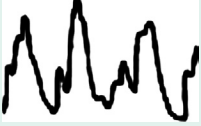
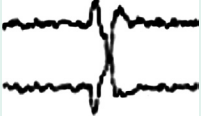

Electroencephalographic Recording Criteria:

- Minimum paper speed of 10 mm/sec. One page equals 30 seconds and is defined as one epoch.
- Time constant of 0.3 seconds or low-frequency filter of 0.3 Hz.
- Pen deflections of 7.5 to 10 mm for 50 μ V are recommended.
- Electrode impedances should not exceed 5000 Ω .

Electromyographic Recording

The EMG signals are muscle twitch potentials, which are used in PSG to distinguish between sleep stages based on the fact that EMG activity diminishes during sleep. Specifically, during REM sleep, muscle activity is minimal. Compounding the problem of interpreting EMG channels is occasional intrusion of EMG artifact into the record. Some

Table 3.2 Sleep Electroencephalographic Waveforms

Sample	Definition	Label
	Alpha activity	8- to 13-Hz rhythm, usually most prominent in occipital leads. Thought to be generated by cortex, possibly via dipole located in layers 4 and 5. Used as a marker for relaxed wakefulness and CNS arousals.
	Theta activity	4- to 8-Hz waves, typically prominent in central and temporal leads. Sawtooth activity (shown in figure) is a unique variant of theta activity (containing waveforms with a notched or sawtooth-shaped appearance) frequently seen during REM sleep.
	Vertex sharp waves	Sharply contoured, negative-going bursts that stand out from the background activity and appear most often in central leads placed near the midline.
	Steep spindle	A phasic burst of 11- to 16-Hz activity, prominent in central scalp leads; typically last for 0.5-1.5 seconds. Spindles are a scalp representation of thalamocortical discharges; the name derives from their shape (which is spindlelike).
	K complex	Recently redefined in the AASM manual as <i>an EEG event consisting of a well-delineated negative sharp wave immediately followed by a positive component standing out from the background EEG with total duration ≥ 0.5 seconds, usually maximal in amplitude over the frontal regions.</i>
	Slow waves	High-amplitude ($\geq 75 \mu\text{V}$) and low-frequency ($\leq 2 \text{ Hz}$) variants of delta (1-4 Hz) activity. Slow waves are the defining characteristics of stage N3 sleep.
	REM	Rapid eye movements are conjugate saccades occurring during REM sleep correlated with the dreamer's attempt to look at the dream sensorium. They are sharply peaked with an initial deflection usually < 0.5 second in duration.
	SEM	Slow eye movements are conjugate, usually rhythmical, rolling eye movements with an initial deflection usually ≥ 0.5 second in duration.

Modified from Kryger MH. *Atlas of Clinical Sleep Medicine*. Philadelphia: Saunders/Elsevier; 2010.

AASM, American Academy of Sleep Medicine; CNS, central nervous system; EEG, electroencephalogram; REM, rapid eye movement; SEM, slow eye movement.

of these intrusions are in the form of yawns, swallows, and teeth grinding (bruxism).

Submental Electromyographic Recording Criteria

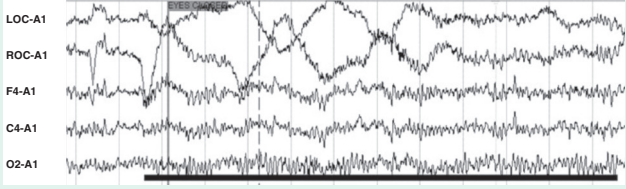
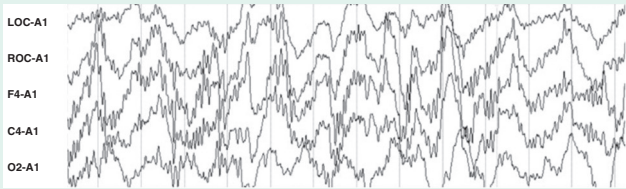
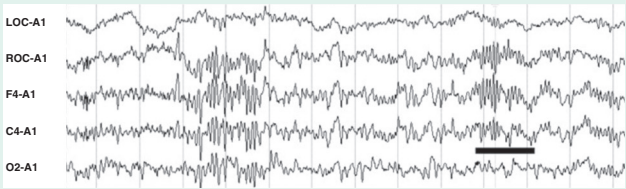
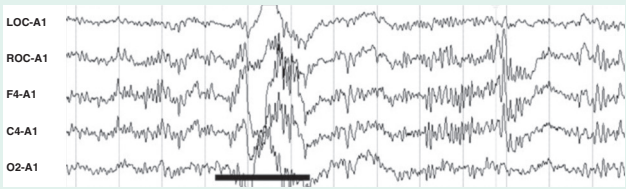
- Mental (mentalis muscle) and submental (mylohyoid and anterior belly of the digastrics muscle) placements are acceptable.
- These are used to detect muscle tone changes for scoring REM versus NREM sleep.
- Muscle tone is high during wakefulness and NREM sleep. It is lower in NREM sleep than in wakefulness. It is generally lower in slow wave sleep than in stage N1 or N2.
- Muscle tone is lowest during stage REM.

Electroencephalographic Activity During Wakefulness and Sleep

Six EEG wave patterns are used to differentiate wake and sleep states and classify sleep stages: (1) alpha activity, (2) theta activity, (3) vertex sharp waves, (4) sleep spindles, (5) K complexes, and (6) slow wave activity. These are summarized in [Tables 3.2 and 3.3](#).

Cortical activity can be characterized by specific frequencies. Frequency is defined as the number of times a repetitive wave recurs in a specific time period (typically 1 second). Frequency is noted as cycles per second (i.e., Hertz [Hz]). EEG activity has been divided into four bands based on the frequency and amplitude of the waveform, and

Table 3.3 Definitions and Examples of Sleep Figures Encountered on an Electroencephalogram**Please note that although all slow waves are in the delta frequency range, not all delta waves are slow waves.**

EEG Rhythm	Characteristics	Best Seen	Examples
Posterior dominant rhythm	8.5-13 Hz	Occipital	
Slow waves	0.5-2 Hz; amplitude $\geq 75 \mu\text{V}$	Frontal	
Spindle	11-16 Hz; duration ≥ 0.5 sec	Central	
K complex	Diphasic; large amplitude, duration ≥ 0.5 sec	Frontal	

Modified from Vaughn BV, Giallanza P. Technical review of polysomnography. *Chest*. 2008;134:1310-1319.
 EEG, Electroencephalogram.

the bands are assigned Greek letters (alpha, beta, theta, and delta). The EEG frequencies are defined slightly differently according to the reference used. The following convention is used to define EEG frequencies: beta is greater than 13 Hz; alpha is between 8 and 13 Hz; theta is between 4 and less than 8 Hz, and delta is the slowest activity at less than 4 Hz. Another EEG activity is gamma, which ranges from 30 to 45 Hz.

Beta Activity

- Beta EEG is defined as a waveform between 14 and 30 Hz but is usually between 18 and 25 Hz.
- It originates in the frontal and central regions but can also occur more diffusely.
- It is present during wakefulness and drowsiness.
- It may be more persistent during drowsiness, diminish during deeper sleep, and reemerge during REM sleep.
- The amplitude over the two hemispheres should not vary by more than 50%.
- Enhanced or persistent activity suggests use of sedative-hypnotic medications.

Alpha Activity (see Table 3.3)

- It is also known as *posterior dominant rhythm*.
- Alpha EEG is 8 to 13 Hz.
- It originates in the parietooccipital regions bilaterally.
- A normal alpha rhythm is synchronous and symmetrical over the cerebral hemispheres.
- It is seen during quiet alertness with eyes closed.
- Eye opening causes the alpha waves to “react” or decrease in amplitude.
- It has a sinusoidal appearance.
- Decrease in frequency occurs with aging.

Theta Activity

- Theta activity has a frequency of 4 to less than 8 Hz.
- It originates in the central vertex region.
- There is no amplitude criteria for theta.
- It is the most common EEG sleep frequency.

Sleep Spindles

- Sleep spindles are 11 to 16 Hz.
- They originate in the central vertex region.

Table 3.4 Major Differences Between Rechtschaffen and Kales Manual and the AASM Scoring Manual from 2007

Differences	R and K Manual	AASM Scoring Manual
EEG electrodes	Score sleep stages using central (C3, C4) leads	Score using frontal, central, and occipital leads
Major body movements	Movement time can be scored if more than half the epoch is obscured	No movement time staging exists
Slow wave sleep	Consists of both stage 3 and stage 4 sleep with delta wave amplitude measured using central leads	Only recognizes stage N3 sleep with delta wave amplitude measured using frontal leads
Terminology of stages	Stage 1, stage 2, stage 3, stage 4, and stage REM sleep	Stage N1, stage N2, stage N3, and stage R sleep
Reference electrode	Left and right ear or mastoid, termed A1 or A2	Left and right mastoid, termed M1 or M2
Scoring stage 2 (or N2) sleep	3-minute rule that states if greater than 3 minutes pass between spindles or K complexes, then score stage 1 sleep	No 3-minute rule exists

AASM, American Academy of Sleep Medicine; EEG, electroencephalogram; R and K, Rechtschaffen and Kales; REM, rapid eye movement.

- They have a duration criterion of at least 0.5 seconds for the purpose of sleep stage scoring.
- They characterize stage N2 sleep but can be seen in other stages.

K Complexes (see Table 3.3)

- They are sharp, slow waves, with a biphasic morphologic structure (negative then positive deflection).
- They are predominantly central vertex in origin.
- Duration must be at least 0.5 seconds.
- They do not have an amplitude criteria.
- They are indicative of stage N2 sleep.

Delta Activity (see Table 3.3)

- Delta activity has a frequency of 0.5 to 2 Hz for the purpose of sleep scoring.
- It is seen predominantly in the frontal region.
- Delta activity has an amplitude criterion of 75 μ V or greater.
- There is no duration criterion.

Stages of Sleep

When scoring a record for stage of sleep, the reader should initially scroll through the entire record quickly to evaluate the quality of the recording and the usefulness of specific channels. He or she should observe the specific shape of the features that represent the stages in that particular individual and gain an overall picture of the cycles for that record. Specifically observe for sleep spindles, K complexes, slow waves, and rapid eye movements.

Table 3.4 illustrates the major differences between the R and K manual and the AASM scoring manual from 2007.

Stage Wake (Figs. 3.4 and 3.5)

Typically the first several minutes of the record will consist of wake (W) stage. Stage W is recorded when more than 50% of the epoch has scorable alpha EEG activity. The EEG will show mixed beta and alpha activities as the eyes open and close, and predominantly alpha activity when the eyes remain closed. Submental EMG is relatively high tone and will reflect the high-amplitude muscle contractions and movement artifacts. The EOG channels will show eye blinking and rapid movements. As the patient becomes

drowsy, with the eyes closed, the EEG will show predominant alpha activity, whereas the EMG activity will become less prominent. The EOG channels may show SREMs. If the patient moves in bed or rolls, the record will reflect this as a paroxysmal event characterized by high-amplitude activity with sustained increased artifact. The patient may enter stage N1 sleep for one or two epochs and then reawaken. Transitions may be difficult to score. From stage W, patients typically proceed to stage N1, but infrequently they may enter REM sleep or stage N2 sleep directly if the pressure to do so is high (reflecting a state of pathological sleep deprivation).

Stage N1 NREM Sleep (Fig. 3.6)

Stage N1 NREM sleep may also be termed *transitional sleep* or *light sleep*. Transition into sleep occurs following stage W sleep. Stage N1 NREM sleep is a transitional state characterized by low-voltage, fast EEG activity. The EEG patterns may be quite variable and may shift rapidly, making it sometimes difficult to interpret. Stage N1 sleep is scored when more than 15 seconds ($\geq 50\%$) of the epoch is made up of theta activity (4 to 7 Hz), sometimes intermixed with low-amplitude beta activity replacing the alpha activity of wakefulness. Amplitudes of EEG activity are less than 50 to 75 μ V. Paroxysms of 4 to 7 Hz less than 75 μ V may occur. The alpha activity in the EEG drops to less than 50%. Stage N1 is of very short duration, lasting for 1 to 7 minutes.

Vertex sharp waves may occur toward the end of stage N1, but sleep spindles or K complexes are never a part of stage N1 sleep and neither are rapid eye movements. Vertex waves have a characteristic high-voltage sharp surface negative followed by surface positive component and are maximal over the Cz electrode. The EMG shows less activity than in wake stage, but the transition is gradual and of little assistance in scoring. Arousals are paroxysms of activity lasting 3 seconds but less than 15 seconds. If an arousal occurs in stage N1 sleep, and if the burst results in alpha activity for greater than 50% of the record, then the epoch is scored as stage W.

During drowsiness and stage N1 sleep, the eyes begin to slowly roll—SREMs. Sometimes eye movements during drowsiness and stage N1 NREM sleep may be jerky, irregular, or gently rolling. Theta activity may start to enter into the EOG tracing as an artifact. The submental EMG tone is relatively high.

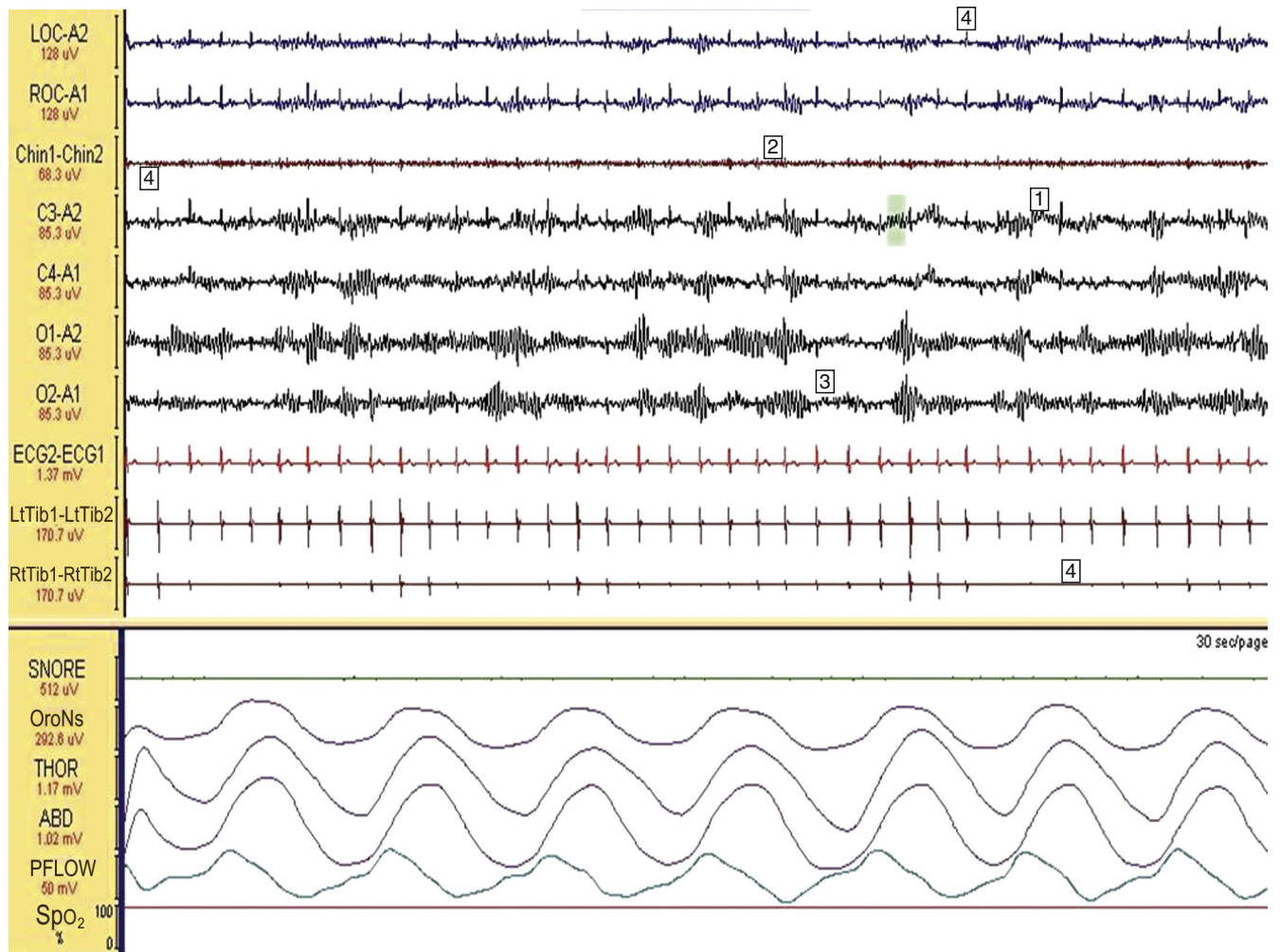


FIGURE 3.4 Stage wake (30-second epoch). Wakefulness, eyes open. More than 50% of the epoch has scorable alpha electroencephalogram (EEG) activity (1). Electromyogram (EMG) activity is reduced, consistent with relaxed wakefulness (2). Note the posterior dominant alpha frequency in the O1-A2 and O2-A1 leads (3). An electrocardiogram (ECG) artifact is noted in the electro-oculogram (EOG), EEG, and EMG leads (4). *OroNs*, Oronasal airflow; *PFLOW*, nasal pressure transducer; *SpO₂*, pulse oximetry.

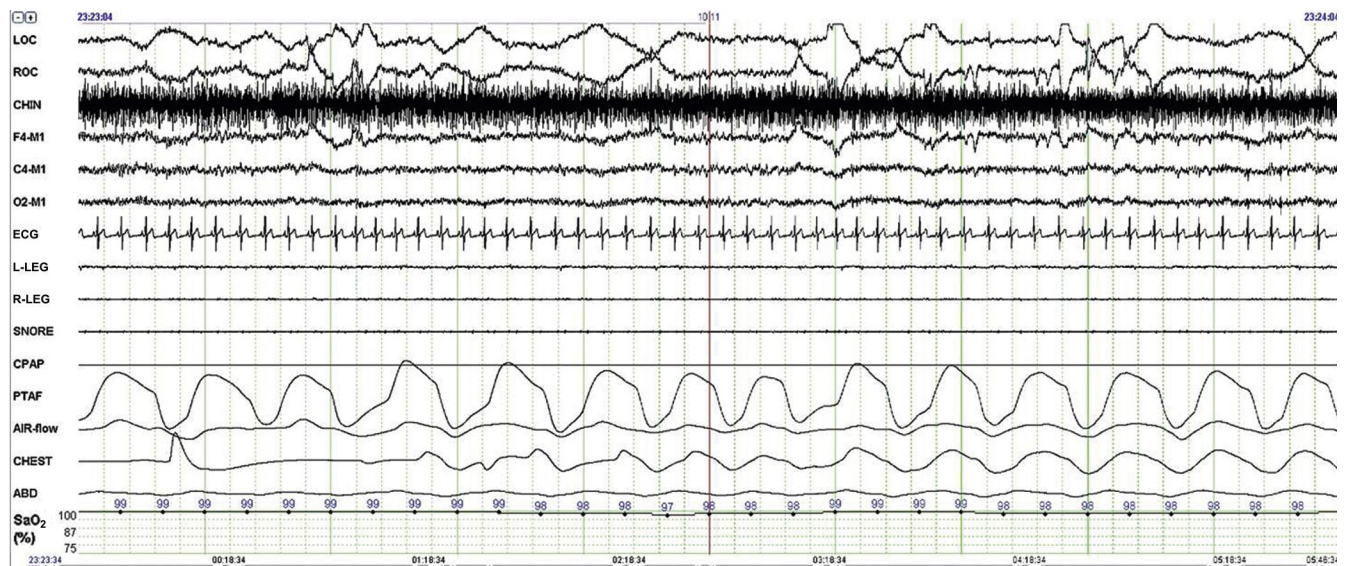


FIGURE 3.5 Stage wake (60-second epoch). Wakefulness with faster rolling eye movements. The electromyogram activity is elevated consistent with wakefulness.

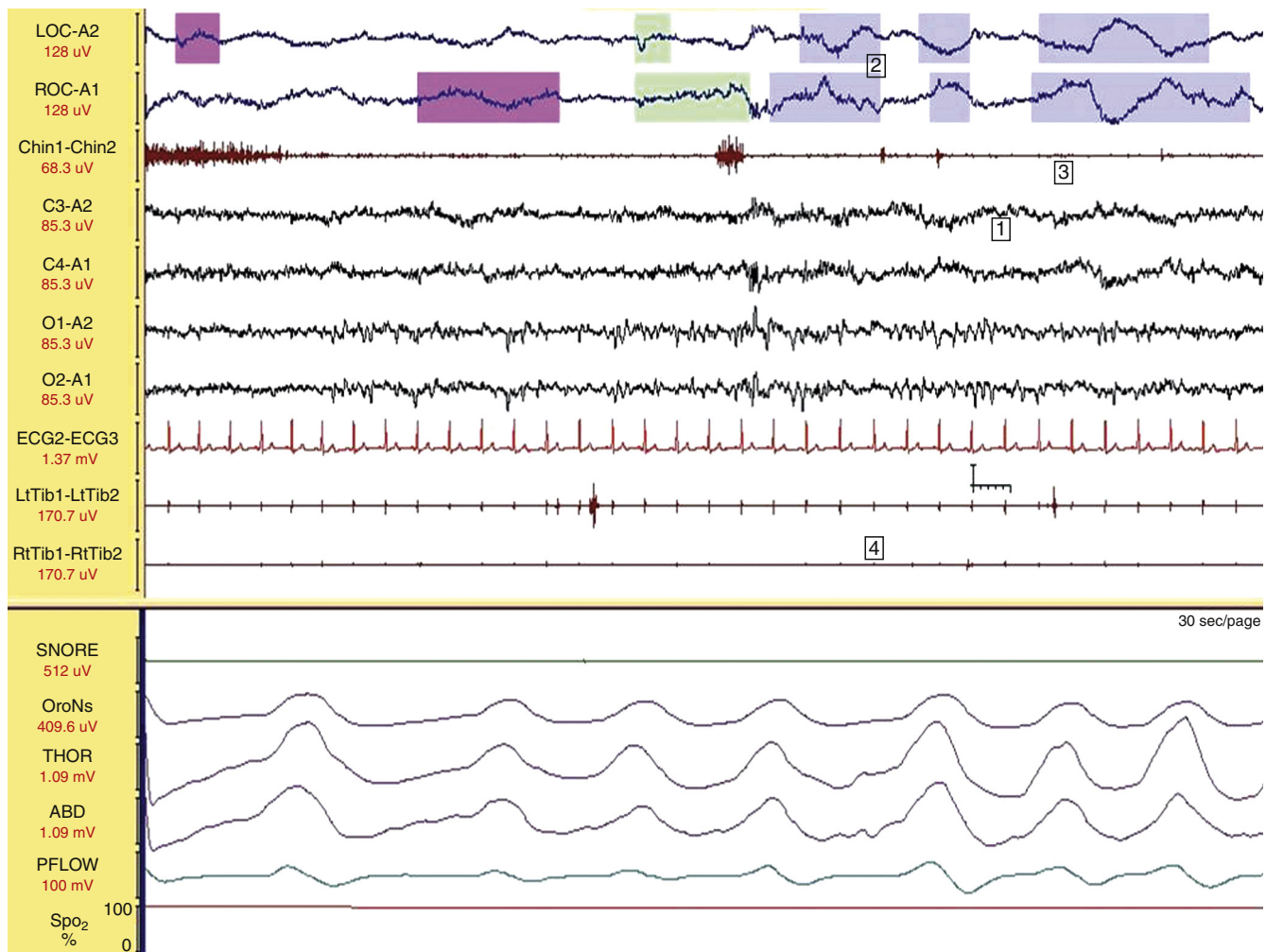


FIGURE 3.6 Stage N1 sleep (30-second epoch). There is presence of low-voltage, mixed-frequency theta activity demarcated by the arrows (1). Slow rolling eye movements are evident (2) and so is a more substantial reduction in chin electromyogram tone (3), which happens to capture activity from the electrocardiogram (ECG) leads in the form of an ECG artifact (4).

Physiologically the patient's breathing becomes shallow, heart rate becomes regular, blood pressure falls, and the patient exhibits little or no body movement. This portion of sleep is distinguished by drifting thoughts and dreams that move from the real to the fantastic, along with a kind of floating feeling. The sleeper is still easily awakened and might even deny having slept. In general the time spent in Stage N1 increases with age.

Stage N2 NREM (Figs. 3.7 to 3.9)

Stage N2 NREM sleep may also be termed *sigma*, *spindle*, or *intermediate sleep* (see Fig. 3.7). It is an intermediate stage of sleep, but it also accounts for the bulk of a typical PSG recording (up to 50% in adult patients). It follows stage N1 NREM sleep and initially lasts about 20 minutes. It is characterized by predominant theta activity (4- to 7-Hz EEG activity) and occasional quick bursts of faster activity. The EEG may show minimal alpha activity. Amplitude may increase from that seen in stage N1 sleep. Delta activity is only allowed to occur for less than 20% of the epoch. The threshold triggering slow wave sleep scoring is reached if 20% of the epoch consists of delta activity.

K complexes and sleep spindles occur for the first time and are typically episodic. The EOG leads mirror EEG activity. Submental EMG activity is tonically low. Excessive spindle activity may indicate the presence of medications (such as benzodiazepines). K complexes (see Fig. 3.8) are sharp, monophasic or polyphasic slow waves, with a sharply negative (upward) deflection followed by a slower positive (downward) deflection. They characteristically stand out from the rest of the background. K complexes have a duration criterion and must persist for at least 0.5 seconds. No minimum amplitude criterion exists for K complexes. K complexes, even without the presence of sleep spindles, are sufficient for scoring stage N2 sleep. They are predominantly central vertex in origin.

K complexes may occur with or without stimuli such as a sudden sound, and in this respect they may represent a form of cortical evoked potential in a brain still minimally responsive to external stimuli. K complexes may be labeled *spontaneous* if they arise from an unknown reason, indicating that their origin is of an endogenous brain activity. They may be labeled *evoked* if they are clearly triggered by an external stimulus such as sound/noise. K-alpha complexes may be triggered by other entities such as periodic limb movements

Sleep spindles are short rhythmical waveform clusters of 12 to 14 Hz assuming a waxing and waning appearance.

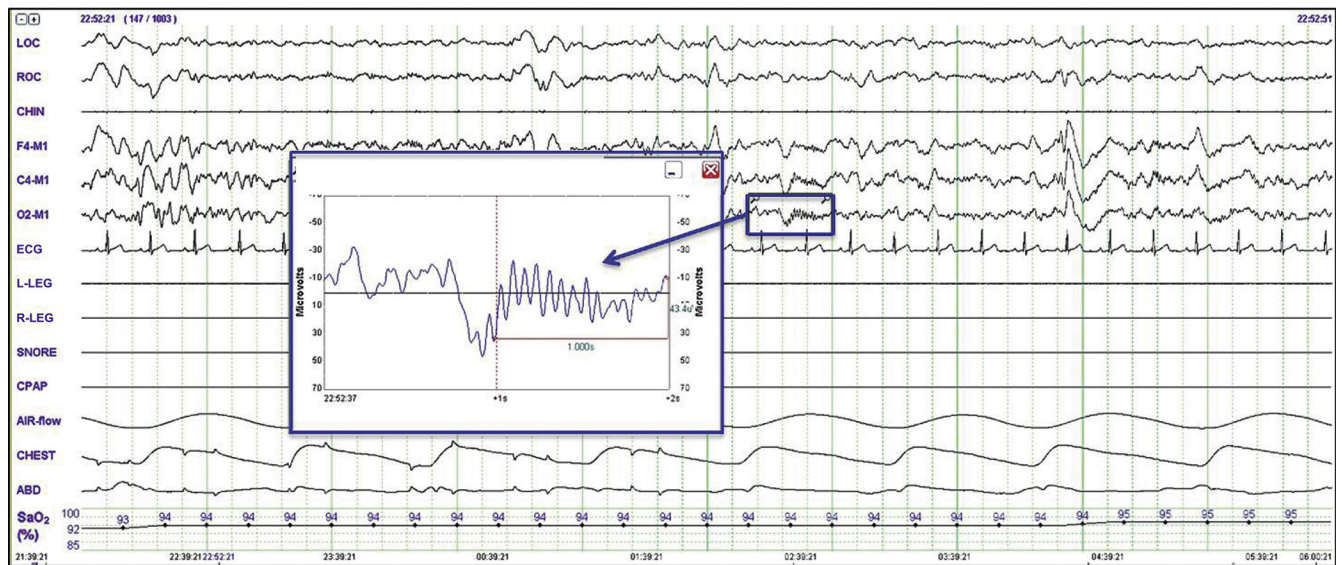


FIGURE 3.7 Stage N2: the morphological structure and characteristics of sleep spindles (30-second epoch). The illustrated montage is according to American Academy of Sleep Medicine scoring criteria.

K complexes are represented by a sharp negative wave followed by a slower positive component, a unique feature of stage N2 sleep.

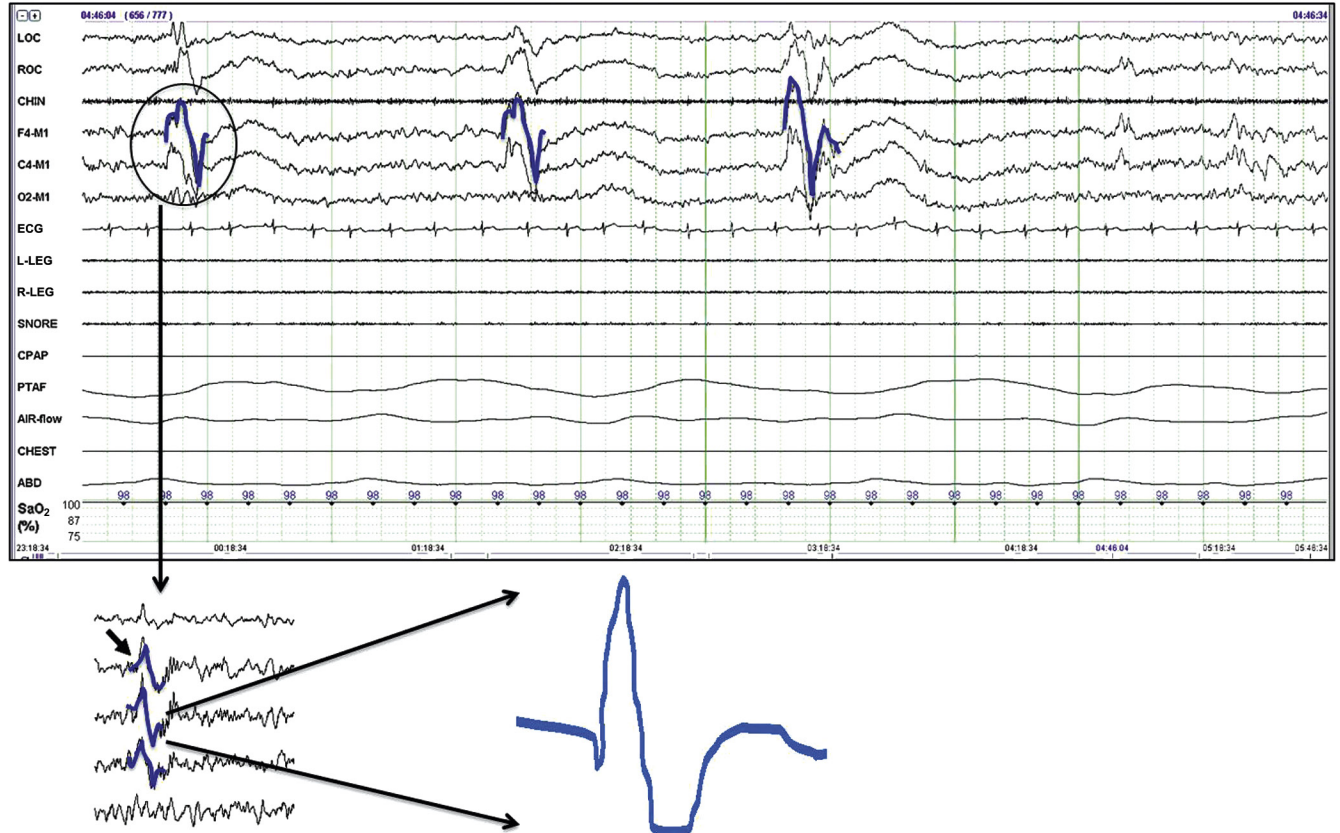


FIGURE 3.8 Stage N2: the morphological structure and characteristics of K complexes (30-second epoch). The illustrated montage is according to American Academy of Sleep Medicine scoring criteria.

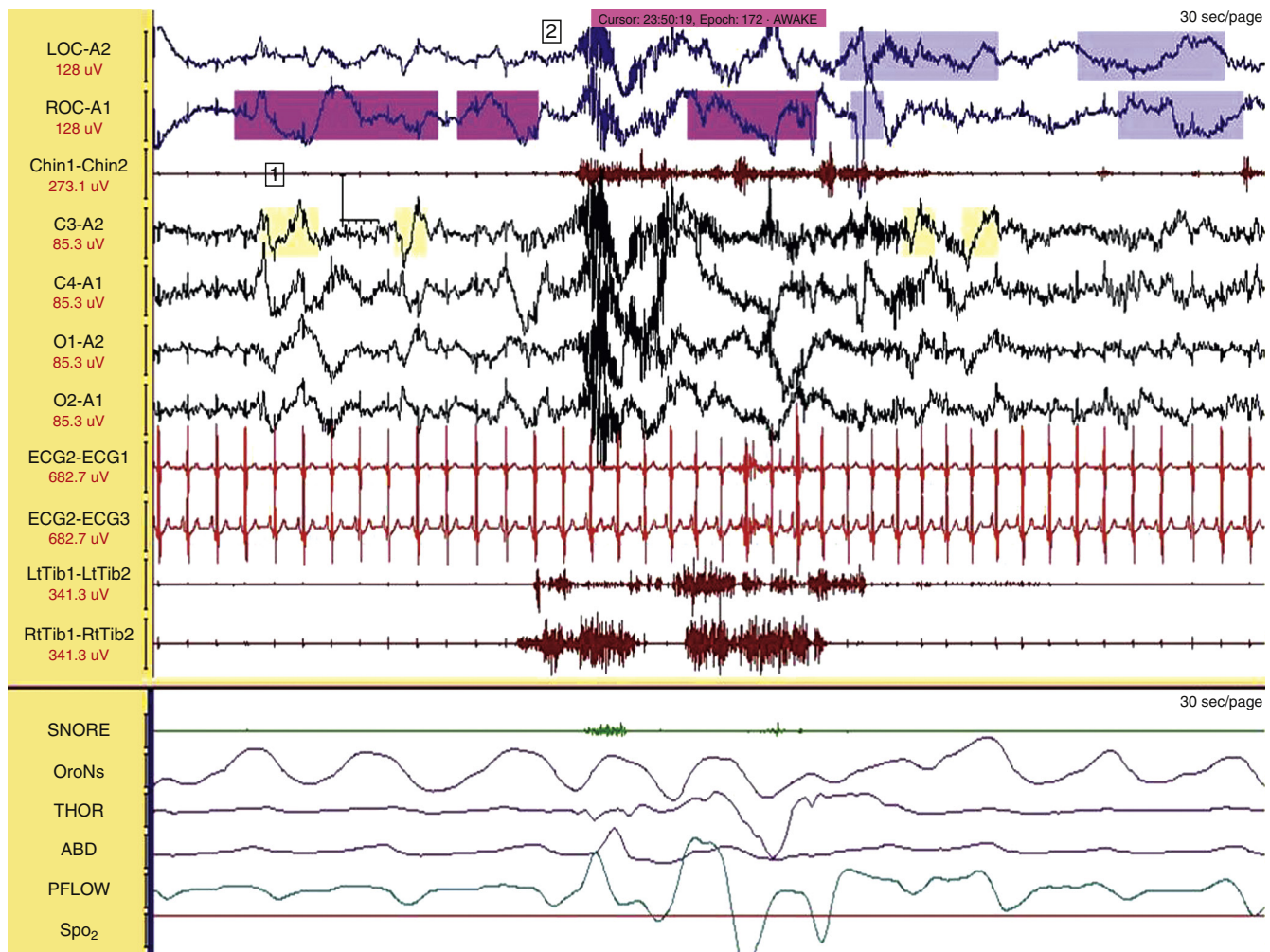


FIGURE 3.9 Transition of stage N2 sleep into wakefulness (30-second epoch). This epoch depicts transition of stage N2 into stage W. K complexes and sleep spindles are noted earlier in the record (1). An arousal (2) is 3 seconds or longer in duration, and the resulting alpha electroencephalogram activity persists for more than 50% of the record. The epoch is therefore scored as stage W sleep.

in sleep, an apneic event, or in association with an arousal (alpha EEG activity) immediately following the complex.

Sleep spindles (see Fig. 3.7), which are also termed *sigma waveforms*, may appear here. They are generated in and controlled by activity within the midline thalamic nuclei (reticular thalamic nucleus) and represent an inhibitory activity. Sleep spindles are characterized by 12- to 14-Hz sinusoidal EEG activity in the central vertex region and must persist for at least 0.5 seconds (i.e., six to seven small waves in 0.5 seconds), but are rarely longer than 1 second. Sleep spindles possess a high degree of synchrony and symmetry between the two hemispheres in patients older than 1 year. Although classically described as spindle shaped, they may be polymorphic and may attach as a tail to a K complex. Normal variant for scoring human sleep is the appearance in stage N2 sleep of low K complex quantity and high-amplitude spindle activity. Central nervous system (CNS) depressant drugs (such as benzodiazepines) often increase the frequency of the spindle activity, whereas advancing age often diminishes their frequency. No specific criteria exist for EOG and EMG in this stage.

Arousal from stage N2 may default the scoring into stage N1 or into wakefulness (W) as seen in Figure 3.9. If EEG

alpha activity persists for less than 50% of the record, then the epoch is scored as stage N1 sleep. If the alpha activity persists for greater than 50% of the record, the epoch is scored as stage W. If the first half of the following epoch demonstrates stage N2 characteristics (i.e., sleep spindles, K complexes, high-amplitude theta/delta activity), then that epoch is scored as stage N2 sleep.

Stage N2 sleep is associated with a relative diminution of physiological bodily functions. Blood pressure, brain metabolism, gastrointestinal secretions, and cardiac activity decrease. The patient descends deeper into sleep, becoming more and more detached from the outside world and progressively more difficult to arouse.

Stage N3 NREM Sleep (Fig. 3.10)

Stage N3 NREM sleep may also be termed *deep sleep*, *slow wave sleep (SWS)*, or *delta sleep*. The new AASM stage N3 includes R and K stages 3 and 4 together and does not make a distinction between them because such distinction probably does not have clear clinical significance. SWS is marked by high-amplitude slow waves. No specific criteria for EOG and EMG exist for SWS, but in general, muscle

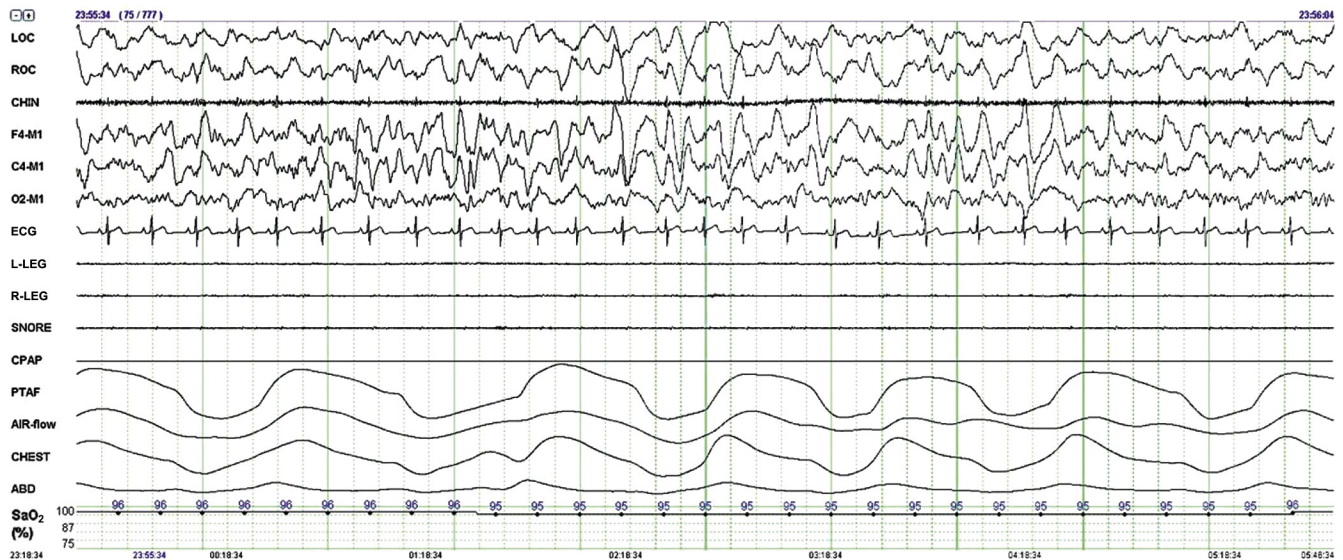


FIGURE 3.10 Stage N3 (30-second epoch). Demonstrated in this figure is the highly synchronized low-frequency activity characterizing stage N3 according to the new American Academy of Sleep Medicine guidelines.

tone is further decreased. SWS constitutes the deepest, most refreshing and restorative sleep type, which tends to diminish with age.

Physiologically a patient going through SWS has the highest threshold for arousal. SWS may be associated with diffuse dreams (20% of dreams), and many parasomnias (sleep terrors, sleepwalking) manifest themselves here. Eye movements may cease altogether in this stage of sleep. Physiologically SWS is often linked with a peak in growth hormone secretion.

The arousal threshold of this stage of sleep is far greater than in stage N1 or N2 sleep. Both K complexes and sleep spindles may be seen in stage N3 sleep, but no specific criteria exist for EOG and EMG. If the patient wakes up from slow wave sleep, he or she may appear confused or disoriented. The patient may experience “sleep inertia” or “sleep drunkenness,” seeming unable to function normally for several minutes. The duration of sleep inertia depends on prior sleep deprivation and CNS-active medications.

Stage REM Sleep (Figs. 3.11 to 3.18)

Stage R or REM sleep may also be termed *paradoxical sleep* or *active sleep*. REM sleep typically occurs about 90 to 120 minutes after sleep onset in adults. The first REM period is typically brief with subsequent REM periods becoming progressively longer and more robust. It typically occupies 20% to 25% of the major period of sleep and is characterized by relatively low-amplitude, mixed-frequency EEG theta waves, intermixed with some alpha waves, usually 1 to 2 Hz slower than wake (see Fig. 3.11). Brain waves are small and irregular, with pronounced bursts of eye activity (rapid eye movements), which are seen in the EOG leads.

Unlike the progressive relaxation noted during the NREM sleep stages N1, N2, and N3, physiological activity during REM sleep is significantly higher. Blood pressure and pulse rate may increase dramatically or may show intermittent fluctuations. Breathing becomes irregular, and brain oxygen consumption increases. Men exhibit penile erections, whereas

women experience clitoral engorgement. The body seems to have abandoned its effort to regulate its temperature during the REM phase and resembles a state of poikilothermy, drifting gradually toward the temperature of the environment.

If patients are awakened from this stage of sleep, they may often recall dreaming. Pathologically short REM sleep latency may point to a state of acute or cumulative sleep deprivation, may be caused by abrupt discontinuation of REM sleep-suppressing agents (such as antidepressants), narcolepsy-cataplexy syndrome, and may also suggest a major affective disorder. A variety of sleep disorders are strongly associated with REM sleep, including a variety of parasomnias (REM sleep behavior disorder, REM nightmares) and obstructive sleep apnea, which may be more pronounced during this sleep period.

Scoring Stage R Sleep

Epochs that display low-amplitude, mixed-frequency EEG, low chin EMG tone, and rapid eye movements should be scored as Stage R (see Figs. 3.11 and 3.12). Stage R should continue to be scored for subsequent epochs even without rapid eye movements, assuming the EEG shows low-amplitude, mixed-frequency activity without K complexes or sleep spindles, and the chin EMG tone remains low (see Fig. 3.13).

Rapid eye movements are conjugate, irregular, sharply peaked eye movements with an initial deflection lasting less than 500 milliseconds. This produces rapid conjugate eye movements that appear as out-of-phase EOG channel deflections on the PSG (see Figs. 3.11 and 3.12). During REM sleep the eyes move rapidly under closed eyelids while dreaming (see Fig. 3.14, A). Rapid eye movement can also be seen during wakefulness with the eyes open when a person is looking around his or her environment (see Fig. 3.14, B). This can usually be distinguished from rapid eye movements of stage R sleep because of the high EMG tone or video evidence of the patient being awake (see Fig. 3.14, B). The EOG activity is not needed to mark the start of a REM period.

Stage R sleep is characterized by *sawtooth waves* (see Fig. 3.15). These are 2- to 6-Hz, sharply contoured triangular

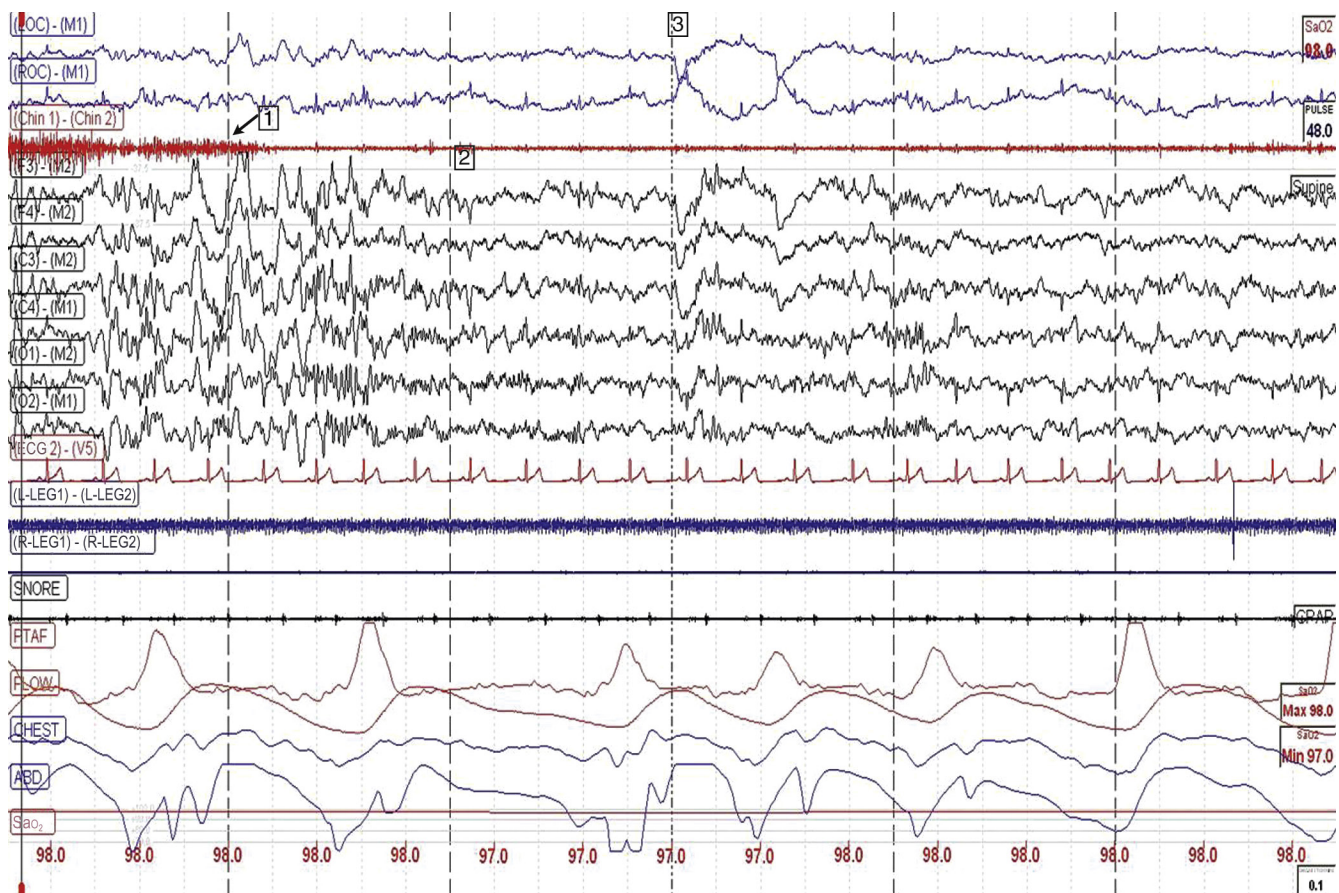


FIGURE 3.11 Transitioning into stage rapid eye movement (REM) sleep: 30-second epoch demonstrating the sudden decrease of chin electromyogram tone (arrow, 1) and a change in electroencephalogram frequency from delta slowing of stage N3 sleep to low-amplitude, mixed-frequency waves of stage R sleep (2). Rapid eye movements are also noted (3). Montage illustrated is according to the American Academy of Sleep Medicine scoring system.

EEG patterns that are jagged in morphologic structure and evenly formed (see Fig. 3.15). These may occur serially for a few seconds and are highest in amplitude over the central leads. REM sleep may be preceded by a series of sawtooth waves, though they are not required to score stage R sleep.

Low chin EMG tone is noted during REM sleep (see Figs. 3.11 to 3.13). Though typically lower than in other stages of sleep, baseline EMG activity in the chin should be no higher than in any other sleep stage. No specific amplitude criteria currently exist for this determination. Short, irregular bursts of EMG activity (less than 0.25 seconds), called *transient muscle activity*, may be seen in the chin, limb, EEG, or EOG leads, usually in association with rapid eye movements (see Fig. 3.15). In REM sleep behavior disorder, loss of normal REM sleep atonia is noted in patients, resulting in injuries and sleep disruption caused by dream enactment behavior during sleep (see Fig. 3.16).

REM sleep is sometimes divided into *phasic* (P) and *tonic* (T) components. P-REM sleep is characterized by phasic twitching in the EMG channel occurring concurrently with bursts of rapid eye movements (see Fig. 3.15). This activity has been suggestively correlated with dream content. The phasic EMG twitches in this stage are very short muscle twitches that may occur in the middle ear muscles, genio-glossal muscle, and facial muscles and are associated with increased penile and clitoral tumescence.

T-REM sleep generally consists of low-voltage activated EEG and is characterized by a marked decrease in skeletal muscle EMG activity, without obvious EOG activity (see Fig. 3.13). T-REM appears to be mediated by areas near the locus coeruleus.

End Scoring Stage R Sleep

Stage R scoring should continue until there is a clear change to another sleep stage. Stage R ends if an epoch meets criteria for stage W or N3 sleep. In addition, an increase in chin EMG tone with an absence of spindles or K complexes indicates the end of stage R (see Fig. 3.17) and the beginning of stage N1 if the epoch meets criteria for stage N1. An arousal or major body movement followed by slow eye movements also indicates termination of stage R and beginning N1 (see Fig. 3.17). Slow eye movements are defined as having their initial deflection lasting less than 500 milliseconds. If the chin EMG tone returns to a low level and the epoch demonstrates an absence of slow eye movements, this would characterize the continuation of stage R (as seen in Fig. 3.18). If a K complex or sleep spindle appears in the first half of the epoch without any subsequent rapid eye movements, the epoch will be scored as stage N2 even if chin EMG tone remains low. If a sleep spindle or K complex appears in the second half of the epoch, then the epoch would still be scored R and the next epoch would be scored N2.

Text continued on p. 95

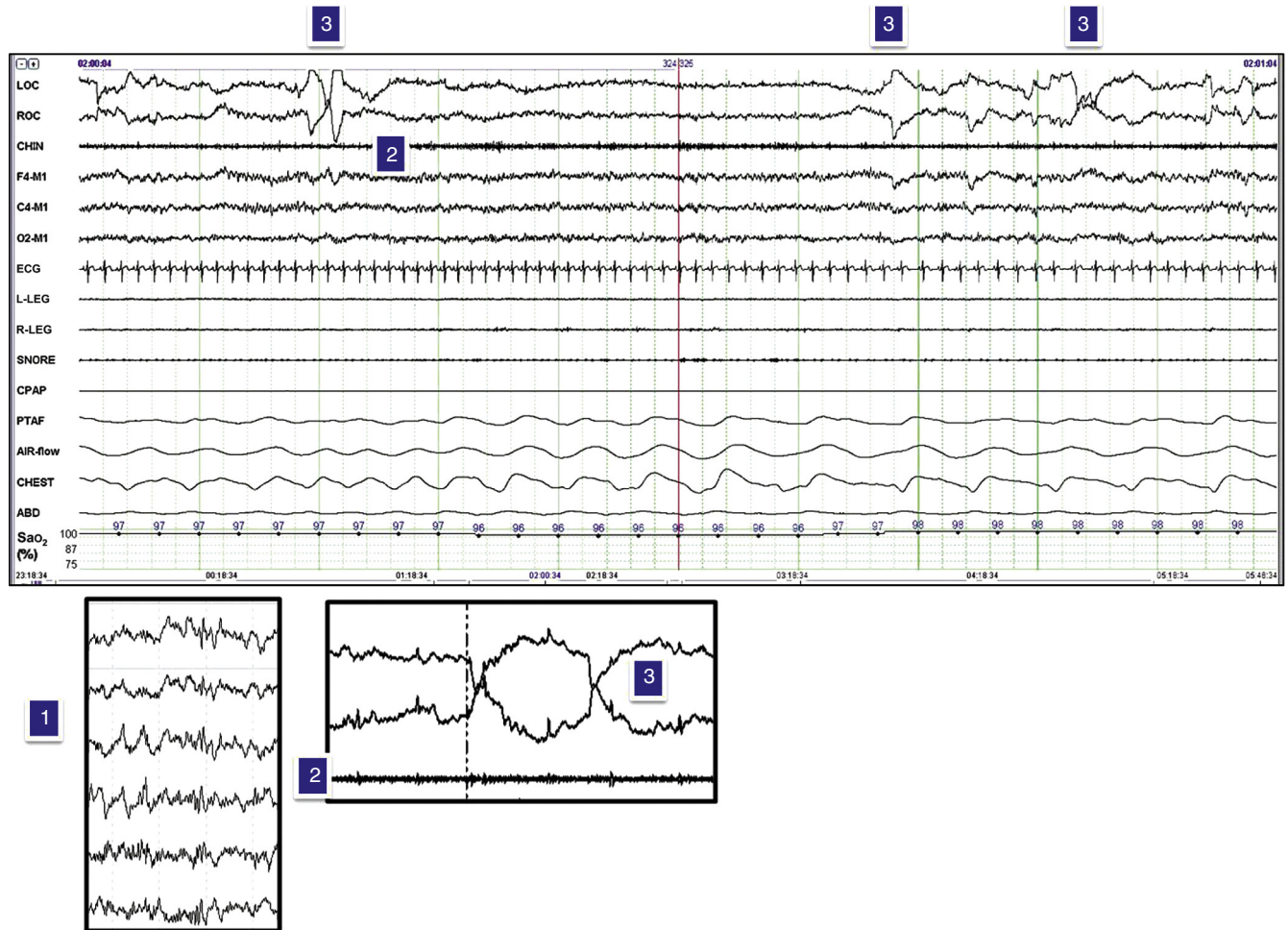


FIGURE 3.12 Stage rapid eye movement (REM) (60-second epoch) according to the new American Academy of Sleep Medicine guidelines. The specific characteristics of REM sleep include low-amplitude, mixed-frequency electroencephalogram (1), low chin electromyogram tone (2), and rapid eye movements (3).

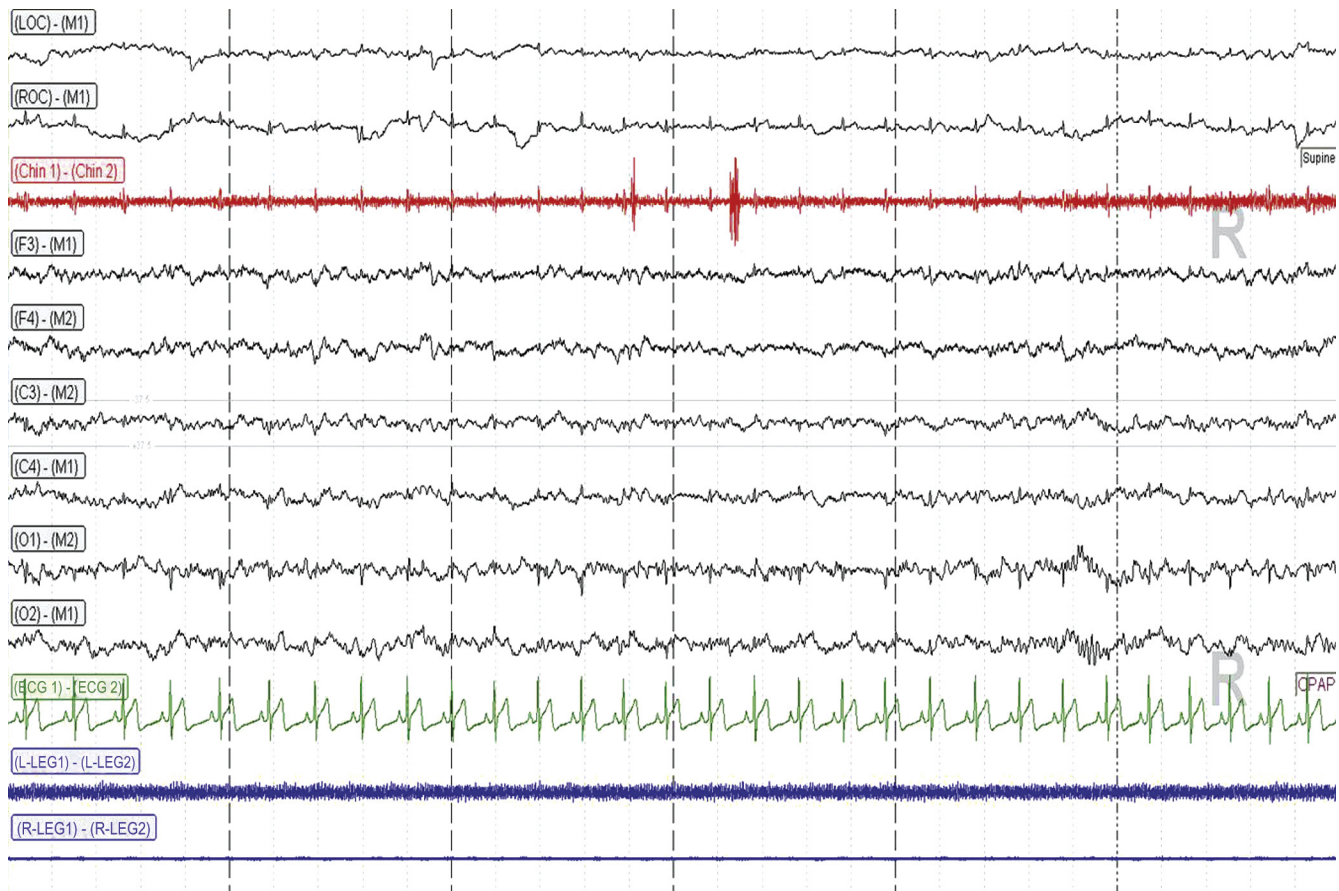


FIGURE 3.13 This 30-second epoch followed a previous epoch of stage R sleep. This epoch demonstrates tonic rapid eye movement (REM) sleep, consisting of low-amplitude, mixed-frequency electroencephalogram (EEG) with no rapid eye movements in this epoch. This would still be scored as stage R because the previous epoch contained rapid eye movements, the chin electromyogram tone is low, and the EEG showed mixed frequency without spindles or K complexes. Montage illustrated is according to the American Academy of Sleep Medicine scoring system.

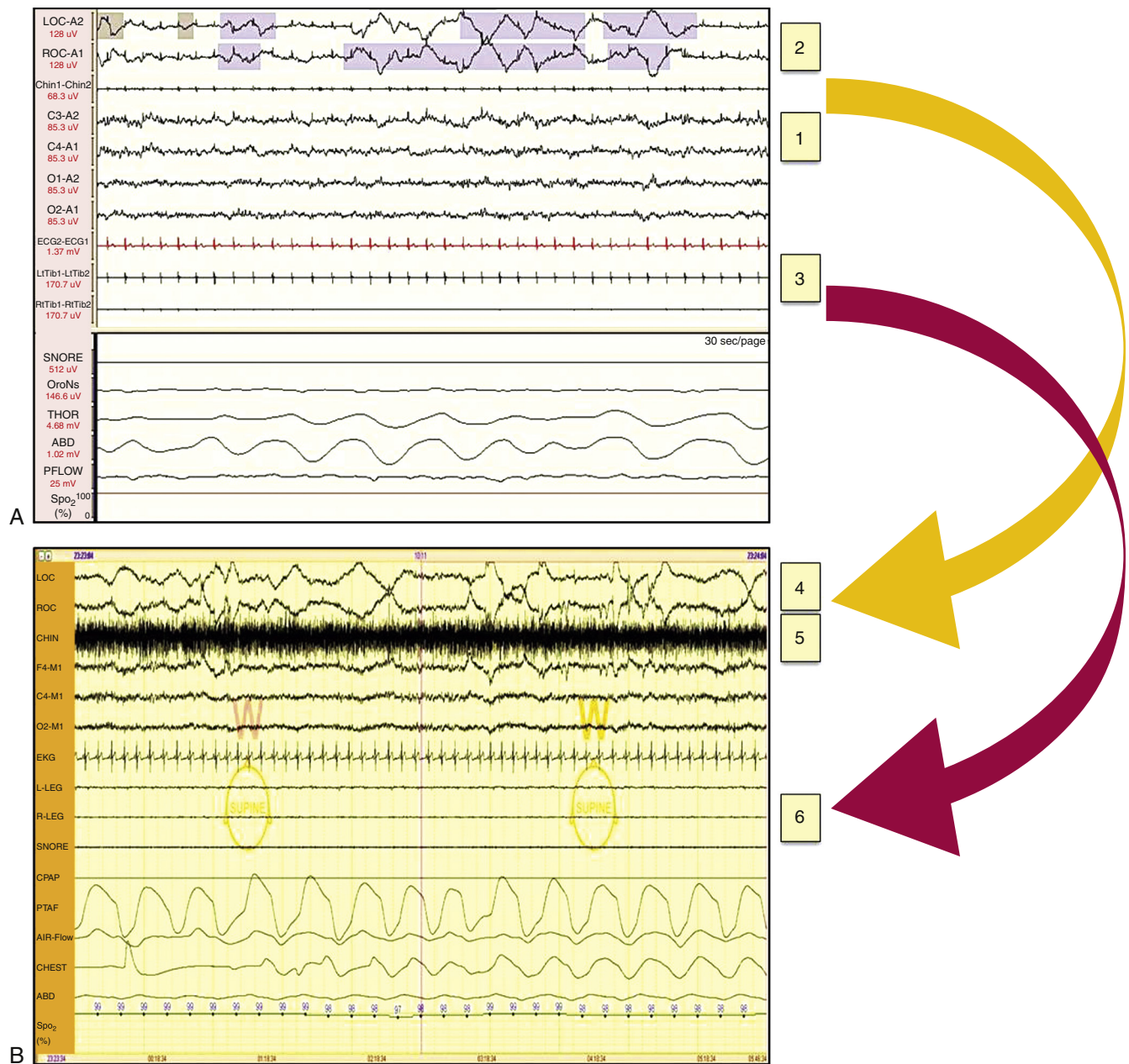


FIGURE 3.14 Rapid eye movements: stage rapid eye movement (REM) sleep versus wake. **A**, Stage REM sleep characterized by relatively low-amplitude, mixed-frequency electroencephalogram theta waves (1), intermixed with alpha waves. The electro-oculogram leads depict rapid eye movements that are paroxysmal, relatively sharply contoured, high-amplitude activity occurring in all eye leads simultaneously (2). Electromyogram (EMG) tone (3) should show the lowest tone in the record, but no specific amplitude or frequency criteria are in place. Montage depicted is according to R and K scoring criteria (30-second epoch). **B**, Stage W also demonstrates rapid eye movements (4) but has an elevated chin (5) and limb (6) EMG tone associated with it compared to during REM sleep as seen by the two arrows. Montage illustrated is according to the American Academy of Sleep Medicine scoring system.

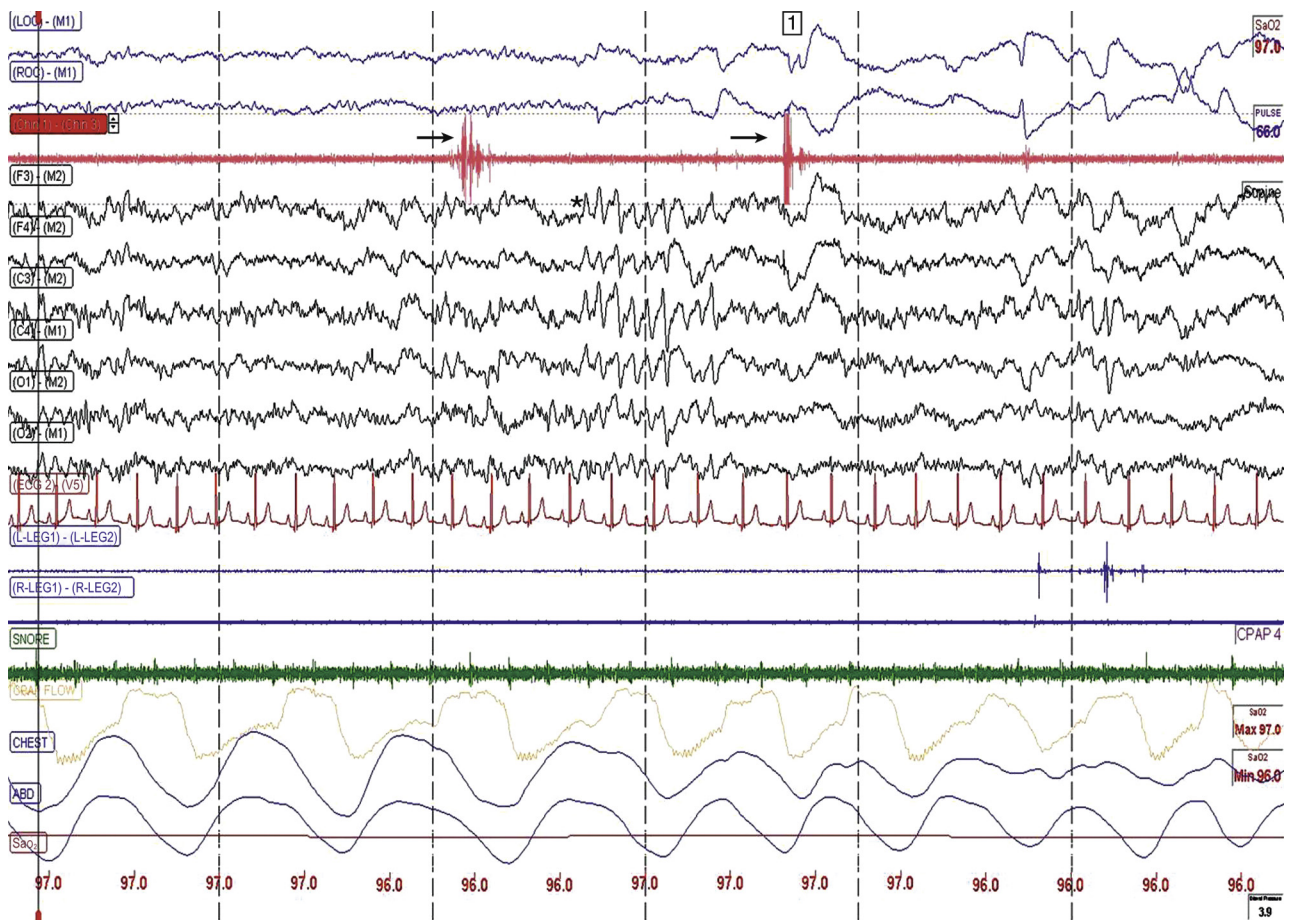


FIGURE 3.15 Thirty-second epoch of stage R sleep displaying sawtooth waves (*) and rapid eye movements (1), with transient muscle activity in the chin electromyogram lead (arrows). Montage depicted is according to American Academy of Sleep Medicine scoring criteria.

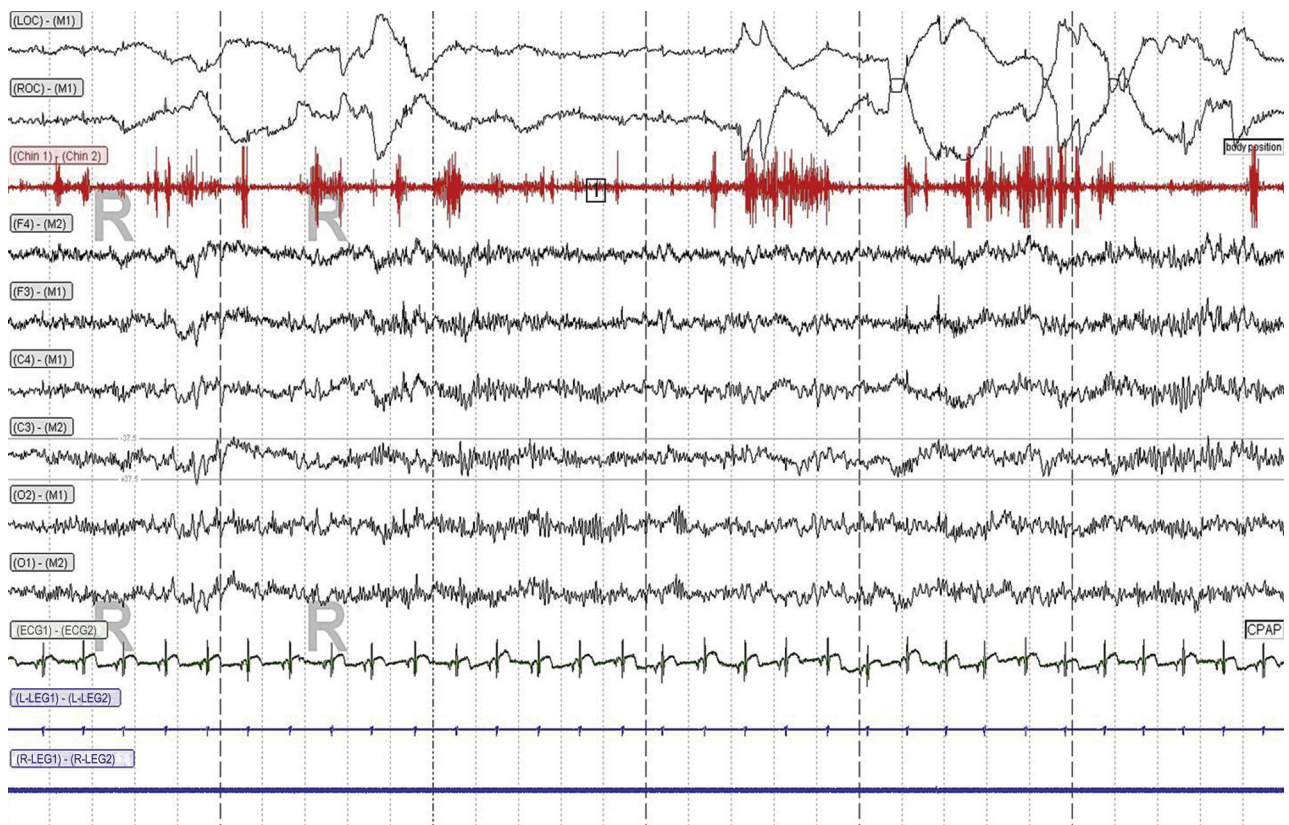


FIGURE 3.16 This 30-second epoch has abnormally high chin electromyogram tone for stage R sleep (1). This REM sleep without atonia can be seen in patients with REM sleep behavior disorder and should be reviewed clinically. Montage depicted is according to American Academy of Sleep Medicine scoring criteria.

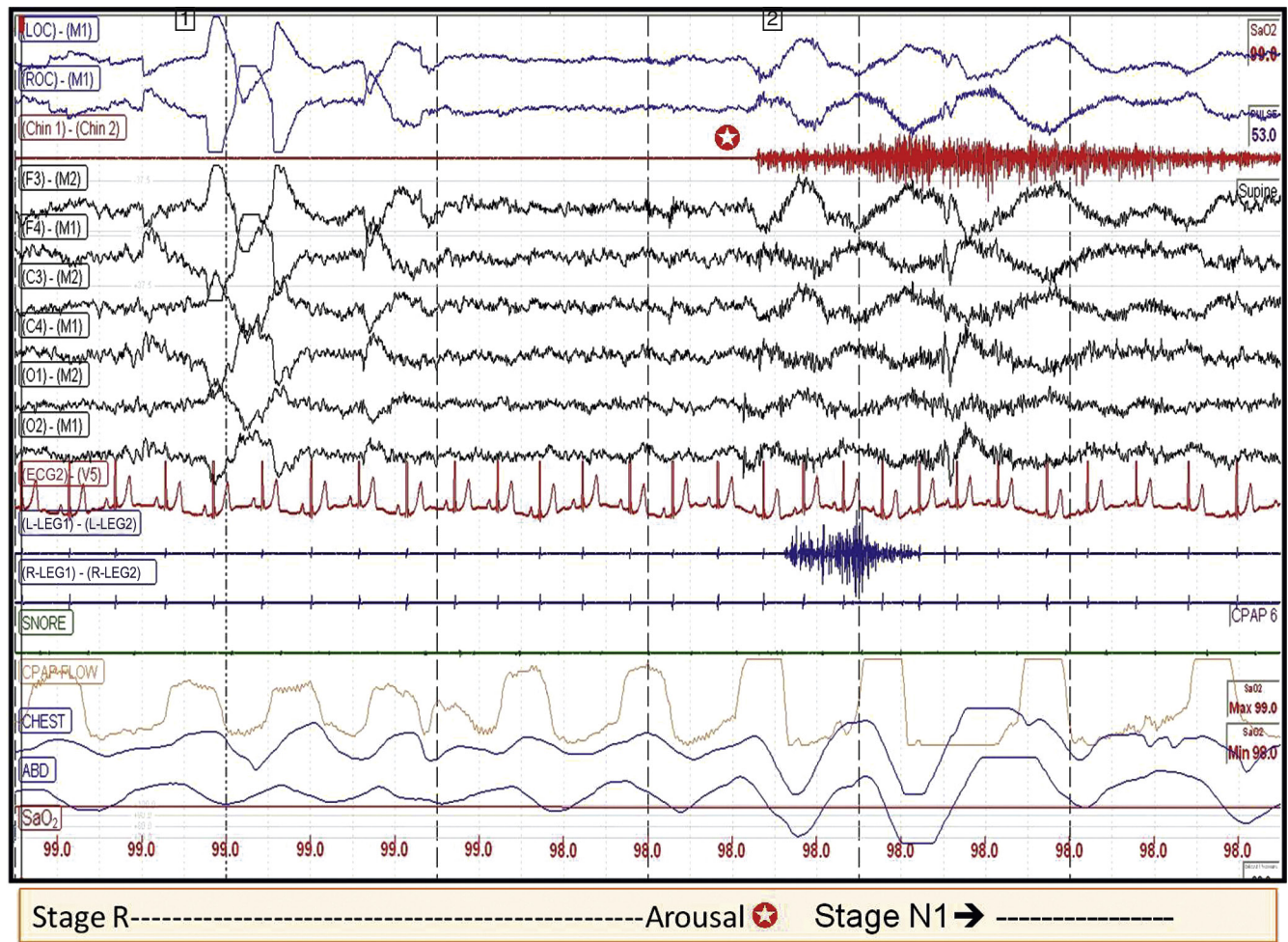


FIGURE 3.17 Stage R transitioning into stage N1 sleep. The figure shows stage R with arousal (☆) demonstrating rapid (1) and slow eye movement (2). Stage N1 is scored on next epoch if the background rhythm is theta. Montage depicted is according to American Academy of Sleep Medicine scoring criteria.

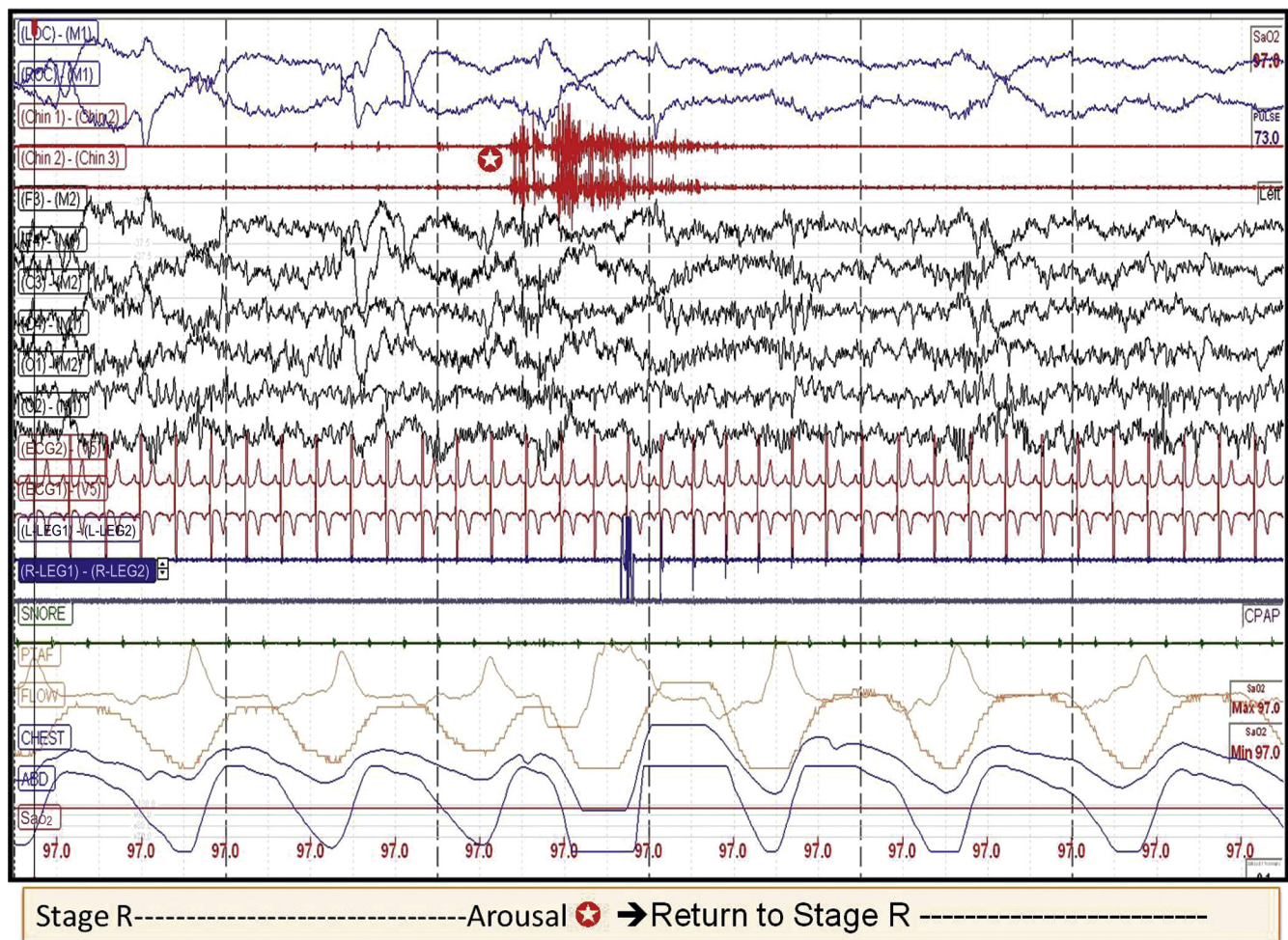


FIGURE 3.18 Rapid eye movement (REM) sleep with increased chin electromyogram and arousal with return back to REM sleep. Montage depicted is according to American Academy of Sleep Medicine scoring criteria.

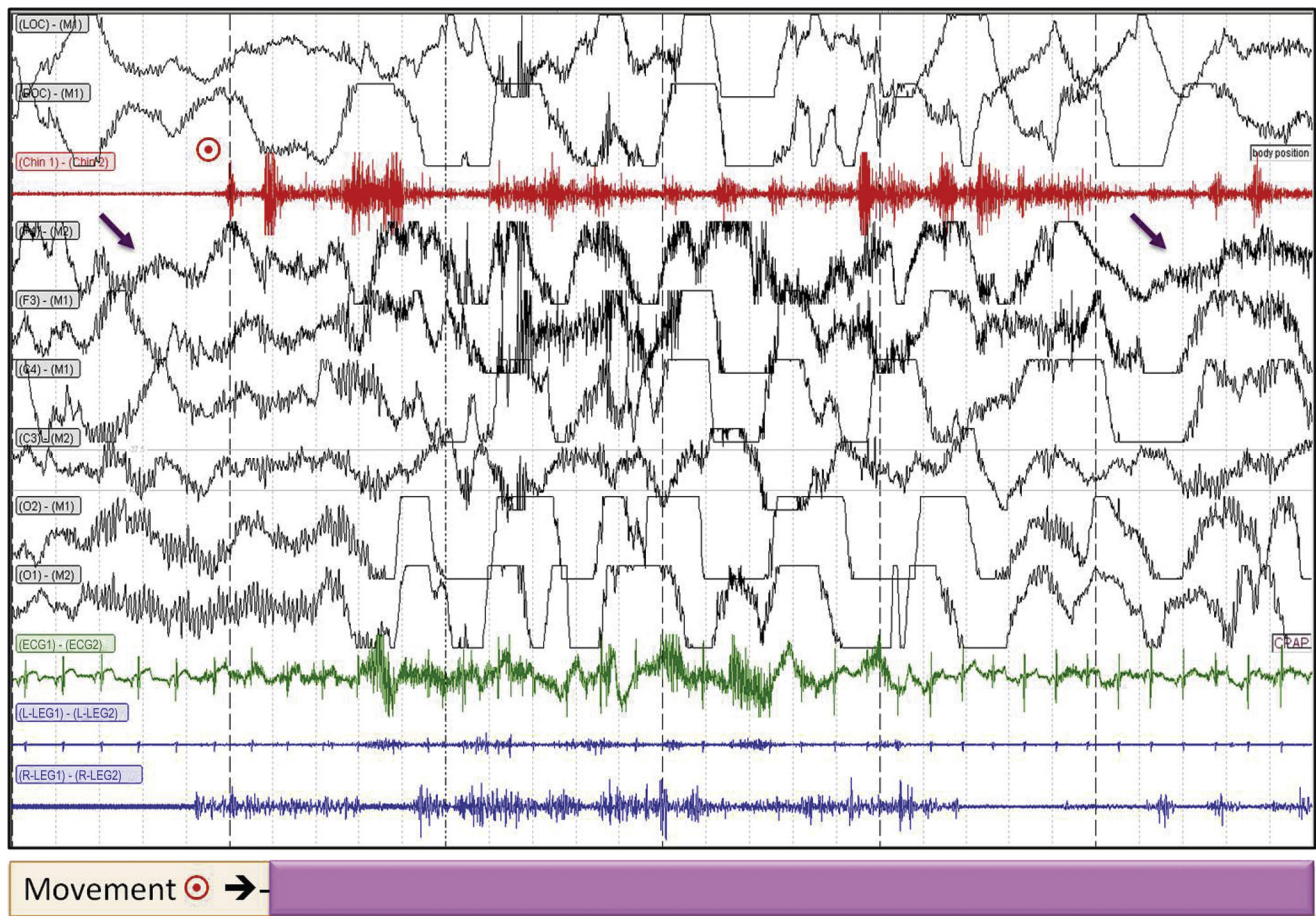


FIGURE 3.19 This 30-second epoch contains a major body movement (beginning at ©) obscuring most of the electroencephalogram signal (purple rectangle). There is a small portion during the beginning and end of the epoch (noted by the arrows) that is consistent with an alpha rhythm in the occipital leads; hence this epoch would be scored stage W. Montage depicted is according to American Academy of Sleep Medicine scoring criteria.

Major Body Movements

Major body movement is movement and muscle artifact obscuring the EEG for more than half an epoch, making determination of sleep stage difficult. In the new AASM scoring manual from 2007, if an epoch contains a major body movement, it can be scored as stage W if an alpha rhythm is present for any part of the epoch (even less than 15 seconds, as seen in Fig. 3.19). If no alpha rhythm is noted, but stage W precedes or follows the epoch with a major body movement, it can be scored as stage W. Lastly, if these situations are not noted, the epoch can be scored the same stage as the epoch that follows it.

Arousals can be scored during sleep stages if there is an abrupt change in the EEG frequency noted in the occipital or central derivations. This can be alpha, theta, or beta frequency (with the exclusion of spindle frequency) that lasts at least 3 seconds with at least 10 seconds of stable sleep preceding the change. During stage R, an arousal requires an increase in chin EMG lasting for at least 1 second. Other recording channels such as limb EMG, respiratory channels, and ECG may be used to help make the determination of an arousal, but EEG criteria must be met.

Transitions Between Stages of Sleep

To begin scoring stage N1 from stage W, the background EEG rhythm (usually alpha frequency) seen maximal in the occipital region needs to be replaced by low-amplitude, mixed-frequency activity (usually theta frequency) for more than half of the epoch. In patients who do not have an identifiable alpha rhythm, stage N1 can commence with slowing of the wake background frequency by 1 Hz or more, presence of vertex sharp waves, or slow eye movements. Vertex sharp waves, or V waves, are sharply contoured waves maximal over the central regions with duration less than 500 milliseconds.

To begin scoring stage N2 sleep, a K complex or sleep spindle must be present in the first half of the epoch or the second half of the previous epoch. Scoring of stage N2 can be continued even without the presence of K complexes or sleep spindles assuming the EEG continues to demonstrate low-amplitude, mixed theta frequency activity.

Stage N2 ends if the epoch meets criteria for stage W, stage N3, or stage R. In addition, following an arousal from stage N2 sleep, the epoch is scored stage N1 until a K complex or sleep spindle occurs again. Stage N2 ends after a major body movement followed by slow eye movements and absence of subsequent sleep spindles or K complexes.

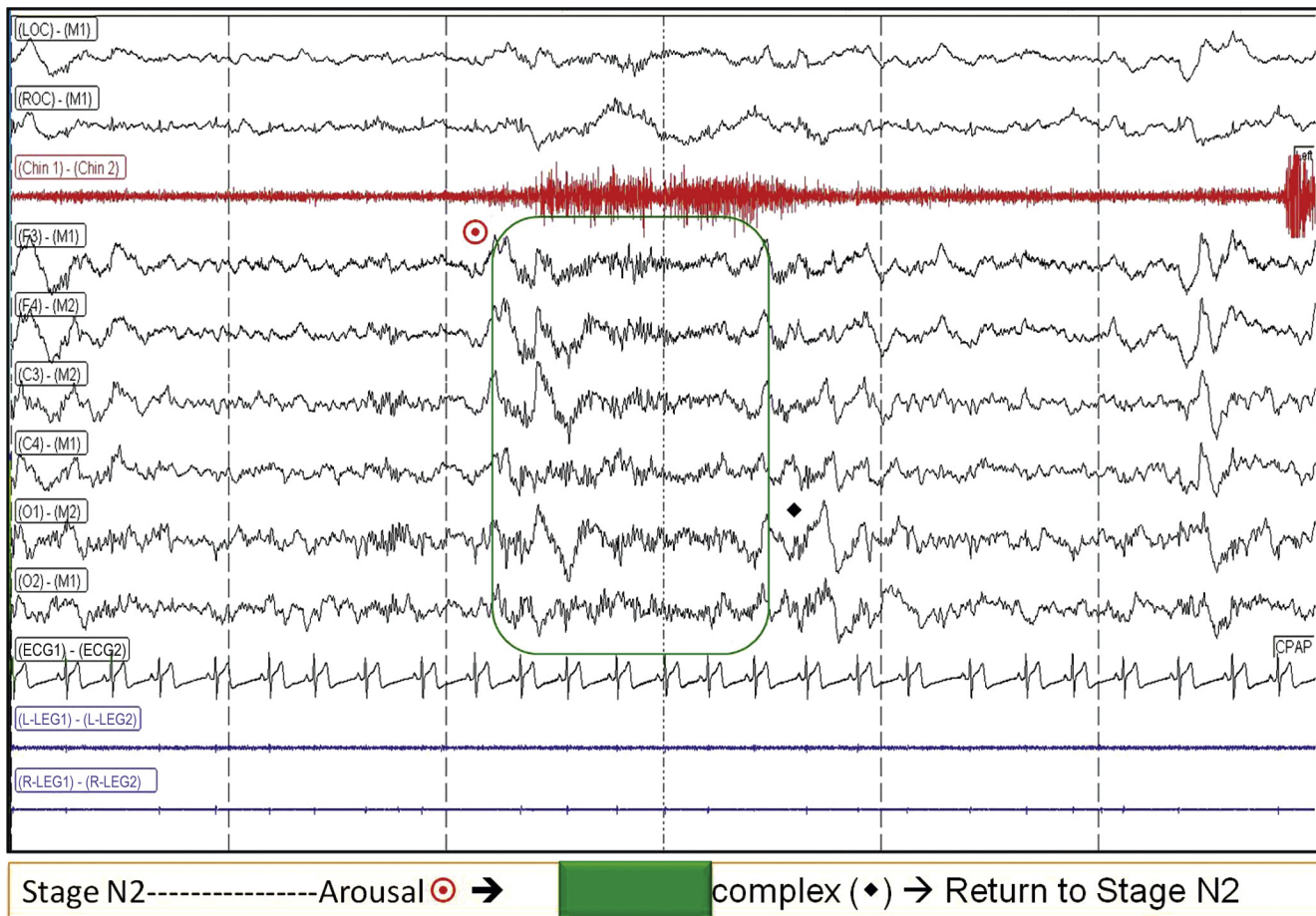


FIGURE 3.20 Stage N2 with arousal (⊙) and return to stage N2 caused by a K complex noted at the end of the epoch (♦). Montage depicted is according to American Academy of Sleep Medicine scoring criteria.

Stage N2 continues to be scored after a body movement if there are no slow eye movements following the major body movement. [Figure 3.20](#) demonstrates an arousal from Stage N2 sleep; however, in the same epoch a K complex is subsequently noted, keeping this epoch scored as N2. [Figure 3.21](#) shows an arousal from stage N2, with a slow eye movement, which then makes the subsequent epoch stage N1 given that there are no K complexes or spindles noted in the interim. As state earlier, stage N3 is scored when more than 20% of the epoch consists of slow wave activity. Slow wave activity is defined as 0.5 to 2 Hz with an amplitude of 75 μ V or more measured over the frontal regions.

When sleep transitions between stage N2 and stage R, epochs between K complexes and sleep spindles or between rapid eye movements can be difficult to distinguish. The new scoring manual requires that the scorer “look back” to determine correct scoring. The first epoch after a decrease in chin EMG should be scored as stage R even if there are no rapid eye movements provided that there are no sleep spindles or K complexes in the epoch. If the record shows sleep spindles or K complexes in the absence of rapid eye movements, the epoch is scored as N2 sleep, following a drop in chin EMG. Furthermore, an epoch with a K complex or spindle is scored as stage R if either is followed by a rapid eye movement while chin EMG tone is still low, as seen in [Figures 3.22 and 3.23](#). Because there is no drop in

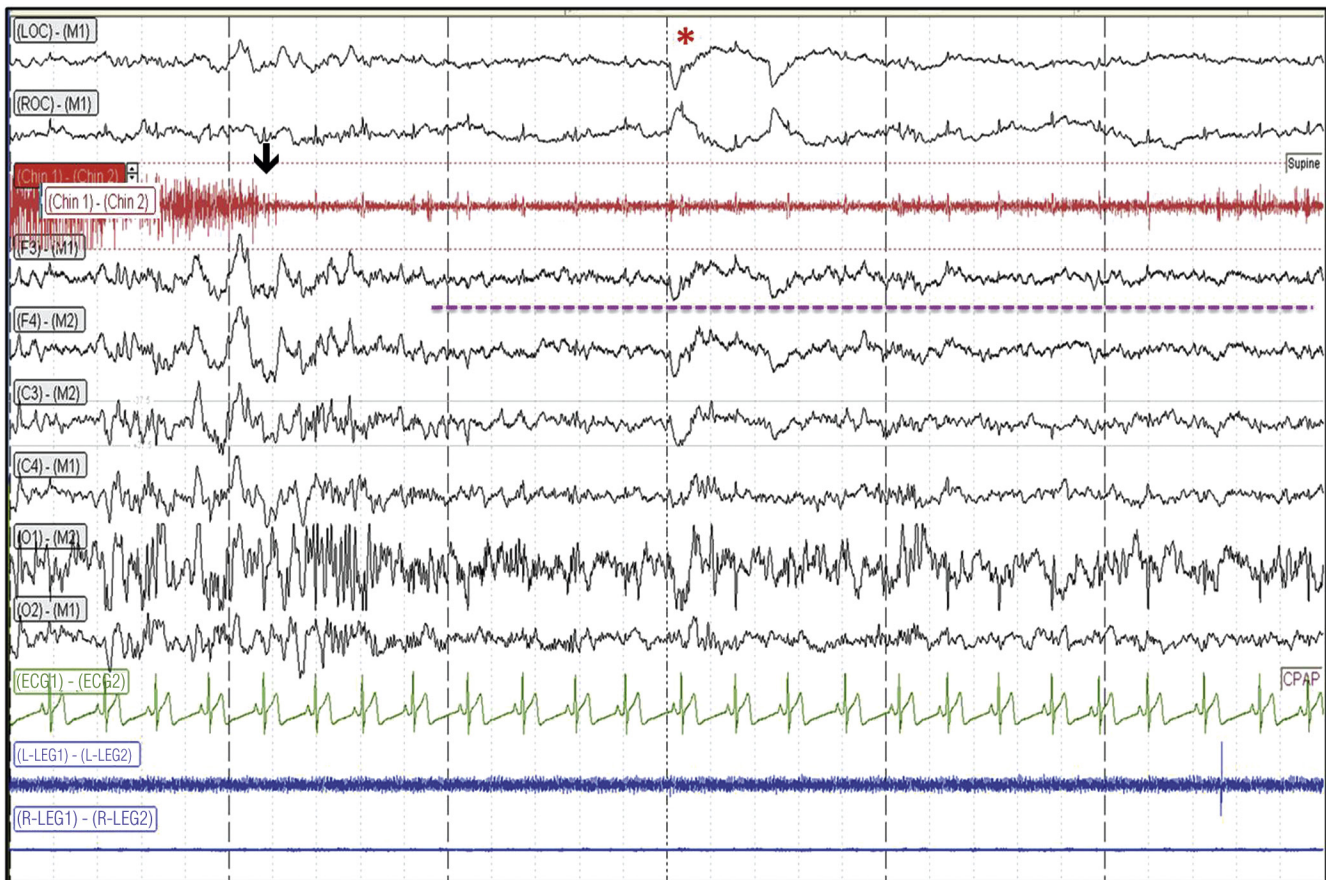
chin EMG (i.e., the patient already has low EMG tone during stage N2), the rule provides for scoring of the epoch that follows the last K complex or sleep spindle as stage R.

Conclusion

The AASM scoring manual (which slightly modified the R and K sleep stage scoring that previously was considered the gold standard for such scoring and expanded the scope of other physiological events) provides a methodology to standardize sleep recording and should serve as the most critical initial stepping stone for all sleep medicine trainees and practitioners.

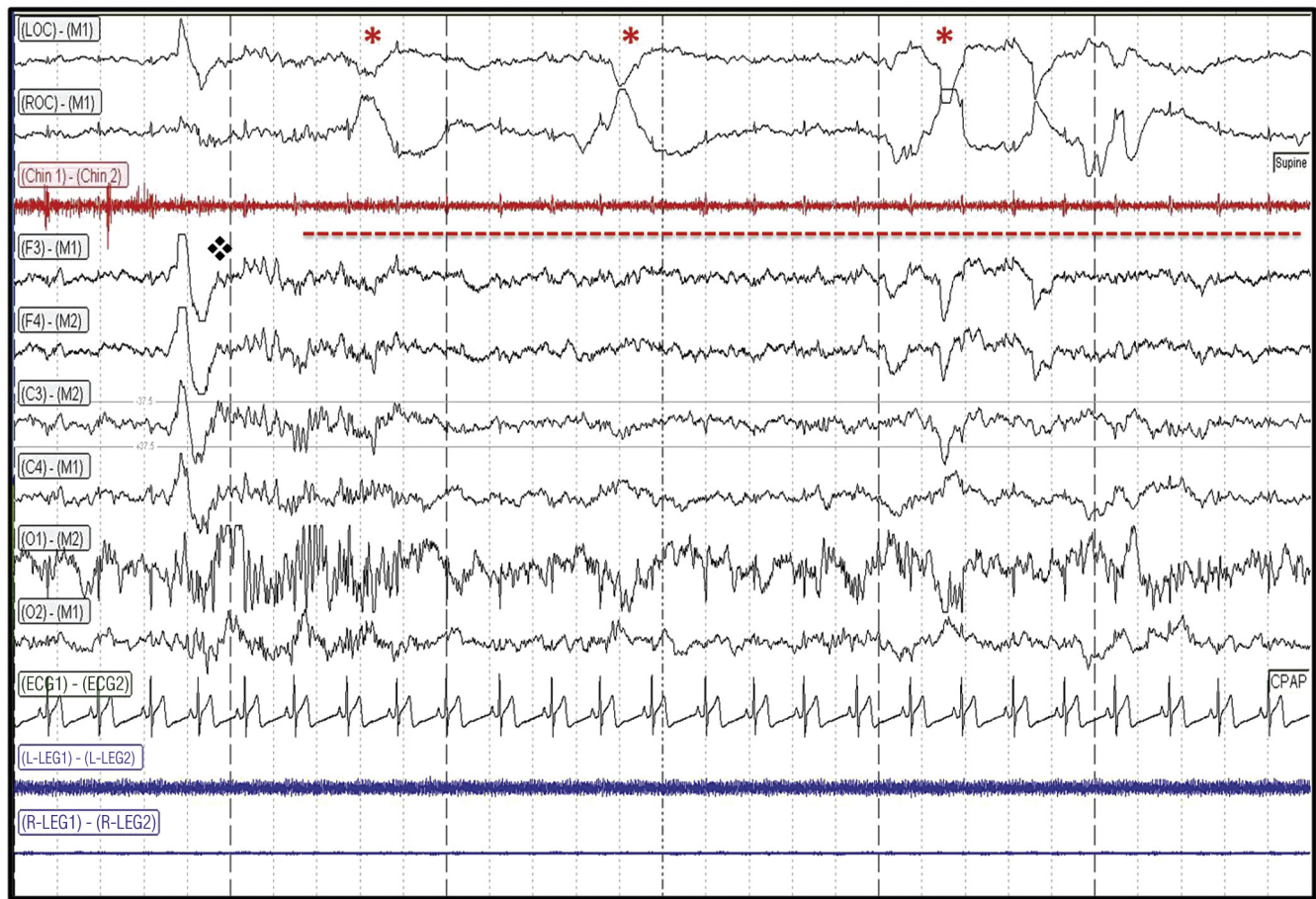
The following abbreviations are used in the sleep montage recordings:

- LOC, left electro-oculogram
- ROC, right electro-oculogram
- Chin, chin electromyogram
- ECG, electrocardiogram
- LtTib, left anterior tibialis surface electromyogram
- RtTib, right anterior tibialis surface electromyogram
- SNORE, snore sensor
- OroNs, oronasal airflow
- THOR, thoracic respiratory effort
- ABD, abdominal respiratory effort
- PFLOW, nasal pressure transducer
- SpO₂, pulse oximetry



Stage N2-----↓Chin EMG tone, rapid eye movement (*) low amplitude, mixed frequency theta →Stage R

FIGURE 3.22 This first of two epochs shows the termination of stage N2 with a decrease in chin electromyogram (*arrow*), rapid eye movement, and low amplitude, mixed theta electroencephalogram frequency (*dotted line*). This epoch would be scored as stage R. Montage depicted is according to American Academy of Sleep Medicine scoring criteria.



Stage R---K complex (◆) – rapid eye movements (*) → Stage R

FIGURE 3.23 This is the subsequent epoch following Figure 3.22 showing a K complex (◆). This epoch is still scored as stage R sleep, and not stage N2, because there are rapid eye movements (*) following the K complex and the chin electromyogram tone remains low (dotted line). Montage depicted is according to American Academy of Sleep Medicine scoring criteria.

Bibliography

- Iber C, Ancoli-Israel S, Chesson AL, Quan SF. *The AASM Manual for the Scoring of Sleep and Associated Events*. Westchester, Ill: American Academy of Sleep Medicine; 2007.
- Kryger MH. *Atlas of Clinical Sleep Medicine*. Philadelphia: Saunders/Elsevier; 2010.
- Kryger MH, Roth T, Dement WC. *Principles and Practice of Sleep Medicine*. 5th ed. Philadelphia: Saunders/Elsevier; 2011.

- Pressman MR. *Primer of Polysomnogram Interpretation*. Boston: Butterworth & Heineman; 2002.
- Rechtschaffen A, Kales A, eds. *A Manual of Standardised Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects*. Los Angeles: Brain Information Service/Brain Research Institute; 1968.
- Shepard JW, ed. *Atlas of Sleep Medicine*. Armonk, NY: Futura Publishing Co; 1991.
- Silber MH, Ancoli-Israel S, Bonnet MH, et al. The visual scoring of sleep in adults. *J Clin Sleep Med*. 2007;3(2):121-129.