

Monitoring Respiration—Event Definitions and Examples

Chapter Points

- An oronasal thermal sensor is recommended for apnea identification. The nasal pressure signal is recommended for hypopnea identification. An event with absent nasal pressure excursions but persistent oronasal sensor excursions >10% of baseline would not be scored as an apnea.
- In adults, an event may be an RERA or a hypopnea based on which hypopnea definition is being used.
- Hypoventilation in adults is defined as an increase in the PaCO_2 of 10 mm Hg or greater from an awake supine value.
- Hypoventilation in children is defined as a PCO_2 greater than 50 mm Hg for 25% or more of the total sleep time by either $\text{P}_{\text{ET}}\text{CO}_2$ monitoring or TcPCO_2 monitoring.
- Obstructive apneas and hypopnea in children are defined based on two missed breaths rather than an absolute time duration.
- Respiratory rules for children are used for patients younger than 18 years. Adult respiratory scoring rules may be used for children aged 13 years or older.
- In children, central apneas have absent inspiratory effort throughout the **entire duration** of the event and one of the following is met:
 1. The event lasts 20 seconds or longer.
 2. The event lasts 2 breaths (or the duration of 2 breaths as determined by the baseline breathing pattern) AND is associated with an arousal, an awakening, or a 3% or greater desaturation.

RESPIRATORY EVENTS IN ADULTS

History of Respiratory Event Definitions

To understand the origins of the current respiratory event definitions, a historical perspective is helpful. The apnea-hypopnea index (AHI) is the number of apneas and hypopneas per hour of sleep. This metric is often used to make the diagnosis of sleep apnea and to grade the severity. Definitions of apnea have been relatively standard (typically absent or nearly absent airflow for ≥ 10 sec), but varying definitions

of hypopnea (reductions in airflow) have resulted in a “floating metric.”¹ Early studies of patients with obstructive sleep apnea (OSA) focused on obstructive apnea,² hence, the name of the syndrome. However, it soon became obvious that reductions in airflow (hypopnea) also had clinical significance. The importance of *hypopnea*, defined as a reduction in airflow associated with a 4% or greater desaturation, was emphasized by Block and coworkers.³ Gould and colleagues⁴ noted that some patients fit the clinical picture of OSA but the majority of their respiratory events were hypopneas rather than apneas. They defined hypopnea as a 50% reduction in respiratory inductance plethysmography (RIP) belt deflections lasting greater than 10 seconds and proposed the term the “sleep hypopnea syndrome.” Others have used the term the “obstructive sleep apnea hypopnea syndrome.” A landmark paper on the incidence of obstructive sleep apnea (Wisconsin cohort study) defined hypopnea as a discernible reduction in the amplitude of calibrated RIP plus an arterial oxygen desaturation of 4% or more.⁵ The Sleep Heart Health Study,⁶ a large multicenter population-based investigation, defined hypopneas as a decrease in airflow or thoracoabdominal excursion of at least 30% of baseline for 10 seconds or more accompanied by a 4% or more decrease in oxygen saturation.⁵ Airflow was monitored with an oronasal thermal sensor and respiratory effort with RIP belts. Using this definition of hypopnea, the study found associations between an increase in the AHI and cardiovascular morbidity.

The widespread use of nasal pressure (NP) monitoring allowed recognition of more subtle and more frequent changes in airflow during sleep than was possible with thermal devices.⁷ It was also recognized that reductions in airflow from obstructive events not associated with desaturations could be associated with consequences such as arousal from sleep and sleep fragmentation (upper airway resistance syndrome).⁸ Therefore, definitions of hypopnea based on flow and arousal were proposed. In order to standardize definitions of respiratory events, a consensus statement was published in 1992 (“Chicago criteria”).⁹ Criteria for an obstructive apnea/hypopnea event (OAHE) was presented with no differentiation between obstructive apnea and hypopnea because “both events have similar pathophysiology.” An OAHE was defined as a 50% or greater reduction

in airflow from baseline lasting 10 seconds or longer using a valid measure of breathing OR any discernible reduction in airflow using a valid measure of breathing during sleep when associated with either an arousal or a 3% or greater arterial oxygen desaturation. Valid measures of breathing included a pneumotachograph, NP, RIPsum (or simultaneous reduction in both chest and abdominal RIP band signals). A 3% rather than a 4% desaturation was recommended based on reanalysis of Wisconsin cohort data showing similar associations with important outcomes using either 3% or 4% desaturations. A *respiratory effort-related arousal (RERA)* was defined as an event lasting 10 seconds or longer with a pattern of progressively more negative esophageal pressure terminated by a sudden change in pressure to a less negative pressure and arousal.

The choice of the definition of apnea and hypopnea can make a significant difference in the AHI and, therefore, a significant difference in the incidence of OSA.^{10–12} Ideal definitions of AHI would identify a population with symptoms and with an increased risk of adverse outcomes (if untreated). As previously noted, AHI values based on hypopnea definitions requiring an associated desaturation in large population studies have shown that increases in AHI are associated with cardiovascular morbidity. Another consideration in choosing a definition of hypopnea is the desire to have a high interscorer reliability. Whitney and associates¹⁰ reviewed the results when three experienced scorers analyzed the sleep studies of 20 randomly selected patients using different definitions of hypopnea. The sleep studies had been performed using a thermal sensor for airflow. Hypopnea was defined as a reduction in the nasal-oral thermal flow signal or the chest and abdominal RIP excursions to 70% of baseline or lower for a duration of 10 seconds or longer. There was a very large range of resulting AHIs (Table 9–1). Using a definition of hypopnea based entirely on a reduction in flow magnitude, there was a reasonably high interscorer reliability (see Table 9–1). However, inclusion of a desaturation criteria in the hypopnea definition did significantly improve the interscorer reliability for identifying these events. One rationale for not including arousal in hypopnea definitions is that scoring of arousals has relatively low interscorer reliability (see Table 9–1). However, the reliability of scoring hypopneas with a definition using a combination of flow and either arousal or desaturation resulted in only slightly lower interscorer reliability than flow plus desaturation alone. Of note, the method used to define a reduction in flow (nasal-oral thermal sensor versus RIP or NP) and the patient population studied may affect the changes in the AHI produced by varying definitions of hypopnea. Tsai and coworkers¹² defined *AHI-A* as a discernible reduction in thoracoabdominal deflection (RIP) of 10 seconds or longer associated with a 4% or greater arterial oxygen desaturation and *AHI-B* as a discernible reduction in thoracoabdominal deflection longer than 10 seconds plus either a 4% or greater desaturation OR an arousal. They found AHI-B was, on average, only about 2 events/hr greater than AHI-A. However, depending on the AHI cutoff criteria, AHI-B did diagnose more patients as having OSA.

TABLE 9–1

Effects of Varying Hypopnea Definitions on Interscorer Reliability and Apnea-Hypopnea Index (Events by Three Scorers)*

	MEAN EVENTS/HR			ICC
AHI #1 Hypopnea = 30% reduction in airflow	25.9	32.9	27.4	0.74
AHI #2 Hypopnea = 30% reduction in airflow + 3% desaturation	11.35	9.97	10.8	0.97
AHI #3 Hypopnea = 30% reduction in airflow + 4% desaturation	6.08	5.38	5.75	0.99
AHI #4 Hypopnea = 30% reduction in airflow + 3% desaturation OR arousal	14.11	14.58	14.06	0.95
AHI #5 Hypopnea = 30% reduction in airflow + 4% desaturation OR arousal	9.75	10.78	10.05	0.94
Arousal index	13.5	20.63	17.31	0.54

*Hypopnea is defined as a reduction in nasal-oral thermal flow or chest and abdominal RIP excursions to 70% of baseline for 10 seconds or longer. AHI = apnea-hypopnea index; ICC = intraclass correlation, a measure of interscorer reliability; RIP = respiratory inductance plethysmography. Adapted from Whitney CW, Gottlieb DJ, Redline S, et al: Reliability of scoring respiratory disturbance indices and sleep staging. *Sleep* 1998;21:749–757.

A clinical practice parameter published by the American Academy of Sleep Medicine (AASM) recommended a definition of hypopnea similar to the one used in the population-based studies (30% reduction in flow + $\geq 4\%$ desaturation).¹³ The rationale for the choice was that large population-based studies had shown an increased risk of cardiovascular consequences associated with an increased AHI based on this hypopnea definition. The Centers for Medicaid and Medicare Services (CMS) subsequently adopted this practice parameter definition of hypopnea for establishing criteria for continuous positive airway pressure (CPAP) reimbursement (<http://www.cms.hhs.gov/mcd/viewdecisionmemo.asp?id=204> 2008).

The recently published AASM scoring manual¹⁴ provides definitions of apnea, hypopnea, and RERAs. There are different respiratory scoring rules for adults and children. An accompanying review¹⁵ discussed the evidence for the new respiratory rules. In the following sections, the AASM scoring manual definitions for apnea, hypopnea, and RERA events are presented (Table 9–2). Although the new criteria are expected to standardize terminology, the hypopnea controversy will likely continue. A recent study by Ruehland and colleagues¹⁶ found that compared with a diagnosis of OSA based on Chicago criteria, using the AASM recommended definition of hypopnea would result in 40% of patients being classified as not having OSA. If the AASM alternative hypopnea definition was used, 25% of the patients diagnosed with OSA by the Chicago criteria would be classified as negative for OSA.

TABLE 9-2

Adult Respiratory Event Rules

Apnea	Score apnea when all of the following are met: • Oronasal thermal sensor (or alternative) drops by $\geq 90\%$ of baseline. • Duration ≥ 10 sec. • At least 90% of events duration must meet apnea amplitude reduction criteria. Classification 1. Obstructive: continued or increased inspiratory effort for duration of apnea. 2. Mixed • Initially absent inspiratory effort in the first portion of the event. • Resumption of inspiratory effort during second portion of event. 3. Central: Absent inspiratory effort for duration of apnea. (Desaturation NOT needed to score an apnea.)
Hypopnea recommended	All criteria must be met: • NP excursions (or alternative sensor) drop by $\geq 30\%$ of baseline amplitude. • Duration ≥ 10 sec. • At least 90% of duration must meet hypopnea amplitude criteria. • $\geq 4\%$ arterial oxygen desaturation from pre-event baseline.
Hypopnea alternative	All criteria must be met: • NP excursions (or alternative sensor) drop by $\geq 50\%$ of baseline amplitude. • Duration ≥ 10 sec. • At least 90% of duration must meet hypopnea amplitude criteria. • $\geq 3\%$ arterial oxygen desaturation from pre-event baseline OR arousal.
RERA	• A sequence of breaths lasting at least 10 sec. • Increasing respiratory effort or flattening of the NP waveform. • Followed by an arousal from sleep. • Does not meet criteria for an apnea or hypopnea.
Hypoventilation*	• Increase in PaCO_2 or validated surrogate ≥ 10 mm Hg above a supine awake value.

*For adults, hypoventilation is based on the PaCO_2 . No other sensor was recommended for documentation of hypoventilation. It was stated that $\text{P}_{\text{ET}}\text{CO}_2$ or TcPCO_2 may be used as surrogate measures of PaCO_2 if there is demonstration of reliability and validity.

NP = nasal pressure; PaCO_2 = arterial partial pressure of carbon dioxide; $\text{P}_{\text{ET}}\text{CO}_2$ = end-tidal carbon dioxide pressure; RERA = respiratory effort–related arousal; TcPCO_2 = transcutaneous carbon dioxide pressure.

From Iber C, Ancoli-Israel S, Chesson A, Quan SF for the American Academy of Sleep Medicine: The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications, 1st ed. Westchester, IL: American Academy of Sleep Medicine, 2007.

The term *respiratory disturbance index*¹⁷ (RDI) is used by some sleep centers and publications. In many sleep centers, the terms RDI and AHI mean the same thing. However, the 2005 AASM practice parameters for indications for polysomnography (PSG) defined the RDI as equal to the AHI + RERA index. Here, the RERA index is the number of RERAs/hr of sleep. The 1992 Consensus statement of the AASM recommended making a diagnosis of OSA based on the number of apneas/hypopneas obstructive events + RERAs/hr of sleep and also presented severity criteria based on this metric.⁹ However, the term RDI was not specifically used. Of note, the term RDI was not defined in the AASM scoring manual. It is important to note the definition of RDI when reading sleep study reports or publications concerning sleep apnea.

Recommended Respiratory Sensors in Adults¹⁴

The sensors and methods for respiratory monitoring are discussed in detail in Chapter 8. The recommended sensor for apnea detection is a thermal flow sensor at the nose and mouth (ornasal thermal sensor). If the thermal signal is inadequate, the NP signal may be used. The recommended

sensor for hypopnea detection is NP with or without a square root transformation. If the NP signal is inadequate, either the oronasal thermal signal or the RIP signal (calibrated or uncalibrated) may be used. Whether the RIP sum signal or both chest and abdomen RIP signals are to be used was not specified. The sensors recommended for detecting respiratory effort include esophageal manometry or RIP (calibrated or uncalibrated). An alternative sensor for detection of respiratory effort is diaphragmatic/intercostals EMG. The sensor for detection of arterial oxygen desaturation is pulse oximetry. It is recommended that oximeters use a maximal averaging time of 3 seconds at a heart rate of 80 bpm or greater. At lower heart rates, most oximeters choose the averaging time based on heart rate and average at least 3 pulses. The recommended sensor for detection of an RERA (see later) is esophageal manometry. Flattening in the NP signal or RIP are alternative sensors that may be used.

Definition of Apnea (AASM Scoring Manual)¹⁴

Sensor: The recommended sensor for apnea detection is a thermal flow sensor at the nose and mouth.

Apnea Scoring Rules in Adults (AASM Scoring Manual)¹⁴

Apnea Rule: Score an apnea when all of the following criteria are met:

1. There is a **drop** in the peak thermal sensor excursion by $\geq 90\%$ of baseline.
2. The duration of the event lasts at least 10 seconds.
3. At least 90% of the event's duration meets the amplitude reduction criteria for apnea.

Apnea Types

1. Score a respiratory event as an OBSTRUCTIVE apnea if it meets apnea criteria and is associated with **continued or increased inspiratory effort** throughout the entire period of absent airflow.
2. Score a respiratory event as a CENTRAL apnea if it meets apnea criteria and is associated with **absent inspiratory effort** throughout the entire period of absent airflow.
3. Score a respiratory event as a MIXED apnea if it meets apnea criteria and is associated with **absent inspiratory effort** in the **initial part** of the event, followed by **resumption of inspiratory effort** in the **second part** of the event.

Figure 9-1 presents examples of obstructive, central, and mixed apneas using esophageal pressure to detect respiratory effort. Figure 9-2 presents examples of the corresponding events using chest and abdominal RIP belts.

The nasal-oral thermal sensor and not the NP signal is used to score apnea. Absent NP signal excursions do not meet criteria for scoring apnea if nasal-oral thermal sensor excursions are still present and do not meet criteria for scoring an apnea. In the event shown in Figure 9-3, NP excursions are absent for greater than 10 seconds. However, the event is not scored as an apnea because the thermal signal is not decreased by 90% of baseline. The combination of absent NP excursions and persistent nasal-oral thermal sensor excursion is likely due to oral breathing. Also note that the apnea criteria do NOT depend on the presence of either arterial oxygen saturation (SaO_2) or arousal. The AASM scoring manual states that if the oronasal thermal signal is not functioning, one then uses the NP signal to score apnea. Although not specifically recommended by the AASM scoring manual, one could also use the RIPsum signal.

Hypopnea Scoring Rules in Adults¹⁴

In the AASM scoring manual, two hypopnea definitions are presented (a recommended hypopnea definition and an alternate hypopnea definition).

Hypopnea (Recommended)

Score a hypopnea if all of the following criteria are met:

1. The NP signal excursions (or those of the alternative hypopnea sensor) **drop by $\geq 30\%$ of baseline**.

2. The duration of this drop occurs for a period of at least 10 seconds.
3. There is a **4% or greater desaturation from the pre-event baseline**.
4. At least **90% of the event's duration** must meet the amplitude reduction of criteria.

This recommended hypopnea definition is essentially the definition recommended by the 2001 AASM Clinical Practice Parameter¹³ and later accepted by CMS. As discussed previously, evidence for the use of this definition includes the fact that a similar definition was used in the Wisconsin Cohort Study and the Sleep Heart Health Study and that an increased AHI based on this hypopnea definition was associated with an increased risk of cardiovascular morbidity in those studies. In addition, as previously mentioned, definitions of hypopnea using changes in SaO_2 tend to have high interscorer reliability. The respiratory event illustrated in Figure 9-4 meets the *recommended* criteria for a hypopnea because the NP signal excursions are essentially zero for over 10 seconds and the event is associated with an SaO_2 of 4% or greater.

Hypopnea (Alternative)

Score a hypopnea if all of the following criteria are met:

1. The NP signal excursions (or those of the alternative hypopnea sensor) **drop by $\geq 50\%$ of baseline**.
2. The duration of this drop occurs for a period of at least 10 seconds.
3. There is a **$\geq 3\%$ desaturation** from the pre-event baseline **or the event is associated with an arousal**.
4. At least 90% of the event's duration must meet the amplitude reduction of criteria for hypopnea.

The alternative definition of hypopnea is similar to the 1999 AASM Task Force Consensus definition of an obstructive apnea/hypopnea event. The use of 3% rather than 4% is based on the fact that reanalysis of some of the large studies using a 3% desaturation-based instead of a 4% desaturation-based hypopnea definition found similar results.⁹ The definition recognizes that some reduction in airflow events are not associated with a drop in the SaO_2 of 4% or greater but are associated with arousal. Frequent respiratory arousals in the absence of significant desaturation can result in fragmented sleep and daytime sleepiness. However, interscorer reliability of scoring hypopneas with a definition based on either desaturation or arousals is slightly lower than with the scoring of events associated only with desaturations (see Table 9-1).

Event Duration Rules¹⁴

- A. Event duration (apnea or hypopnea) is measured from the **nadir preceding** the first breath that is clearly reduced to the **beginning of the first breath** that approximates the baseline breathing amplitude (Fig. 9-5).
- B. When the baseline amplitude cannot be easily determined (underlying breathing variability is large), events

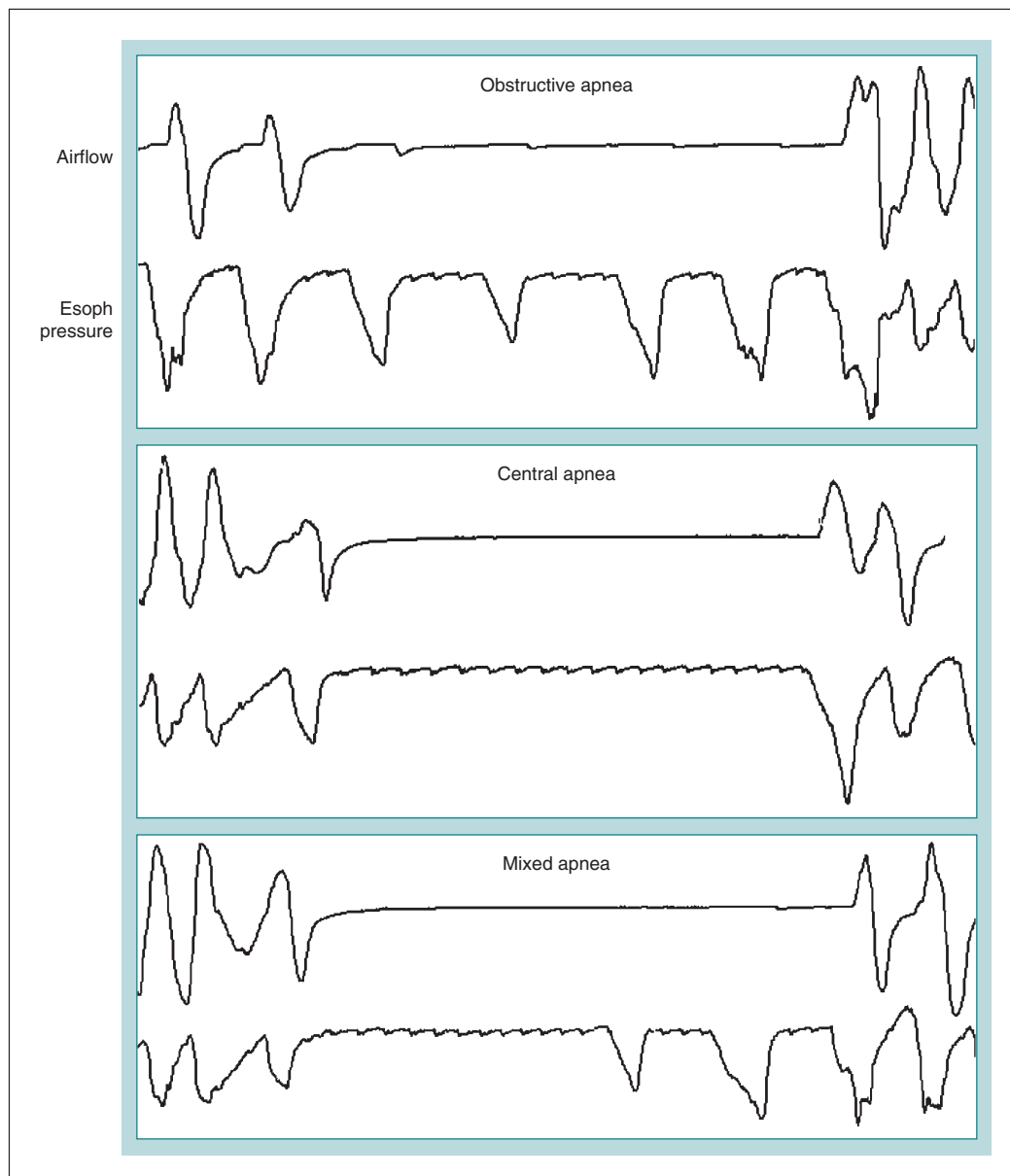


FIGURE 9-1 Examples of obstructive, central, and mixed apnea. Airflow was recorded using a pneumotachograph in a mask over the nose and mouth and respiratory effort by esophageal pressure monitoring. The frequent small deflections in the esophageal pressure are cardiac artifact.

can also be terminated when either there is a **sustained increase in breathing amplitude** or, in the case in which a desaturation has occurred, there is **event-associated resaturation of at least 2%**.

Clarification of Event Duration Criteria for Apneas and Hypopneas

The AASM scoring manual steering committee publishes responses to questions about the scoring rules and clarifications as frequently asked questions (FAQs) (<http://www.aasmnet.org/Resources/PDF/FAQsScoringManual.pdf>).

In response to a question concerning event duration, the FAQ R11 stated that the amplitude criteria to define events need last for only 9 contiguous seconds. For example, if 9 contiguous seconds of an event has a 90% or greater drop in nasal-oral thermal sensor excursions, the event is scored as an apnea even if, based on the event duration rules, the event lasts for longer than 10 seconds. Of note, an apnea or a hypopnea is NOT scored unless the event duration is 10 seconds or longer.

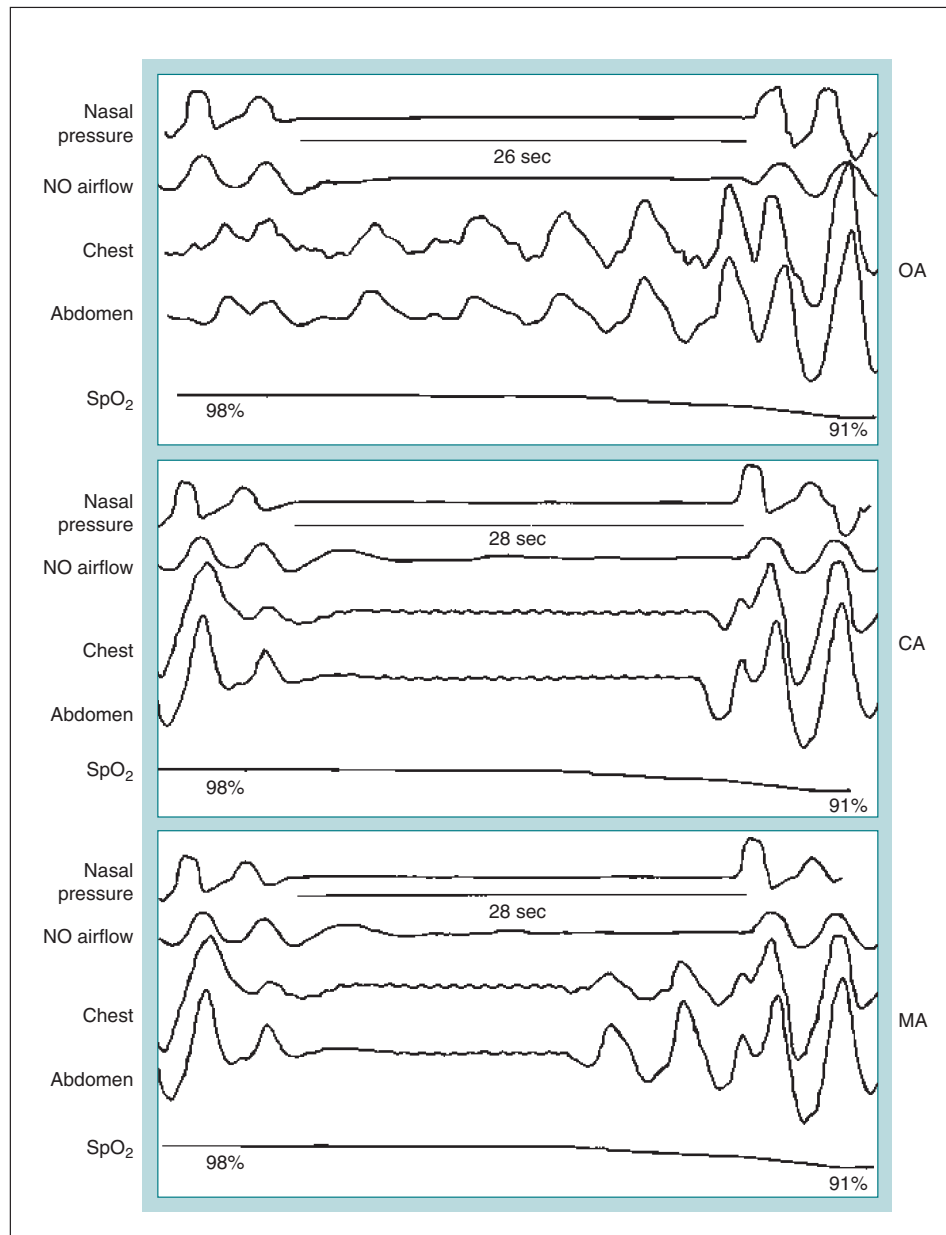


FIGURE 9-2 Obstructive apnea (OA), central apnea (CA), and mixed apnea (MA) events are illustrated. NO airflow = the nasal-oral thermal airflow sensor signal; chest and abdomen = RIP belt signals; SpO₂ = pulse oximetry.

RERA Rule in Adults (AASM Scoring Manual)¹⁴

Score an RERA, if there is a sequence of breaths lasting at least 10 seconds characterized by increasing respiratory effort or flattening of the NP waveform leading to an arousal from sleep when the sequence of breaths does not meet criteria for an apnea or a hypopnea (Fig. 9-6).

RERA Detection

As noted previously, the preferred sensor for the detection of RERAs is esophageal manometry, although NP and RIP

can be used.¹⁴ As discussed in Chapter 8, flattening of the NP signal is associated with airflow limitation and usually increasingly negative esophageal pressure (or supraglottic pressure). Arousal often follows a crescendo increase in esophageal pressure deflections (at least during non-rapid eye movement [NREM] sleep) as seen in Figure 9-7. However, respiratory arousal can also occur after a long period of airflow limitation and relatively constant but increased esophageal pressure deflections. Whereas both hypoxia and hypercapnia may drive inspiratory effort during

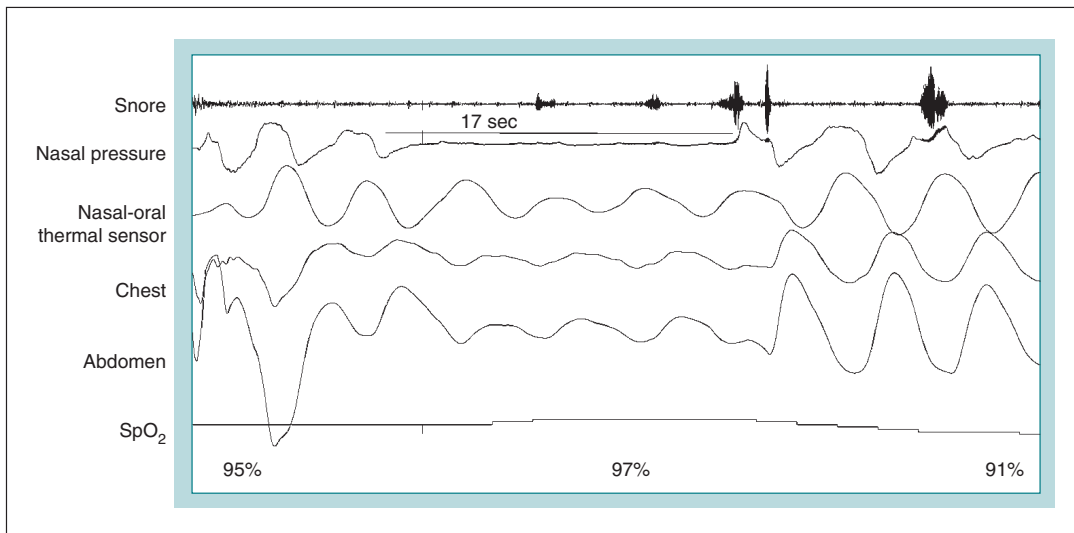


FIGURE 9-3 This event is not scored as an apnea because excursions in the nasal-oral thermal sensor do not meet criteria for apnea. The lack of deflections in the nasal pressure signal is likely due to oral breathing during the event. The event would meet criteria for hypopnea using either the recommended or the alternate American Academy of Sleep Medicine (AASM) criteria. SpO_2 = pulse oximetry.

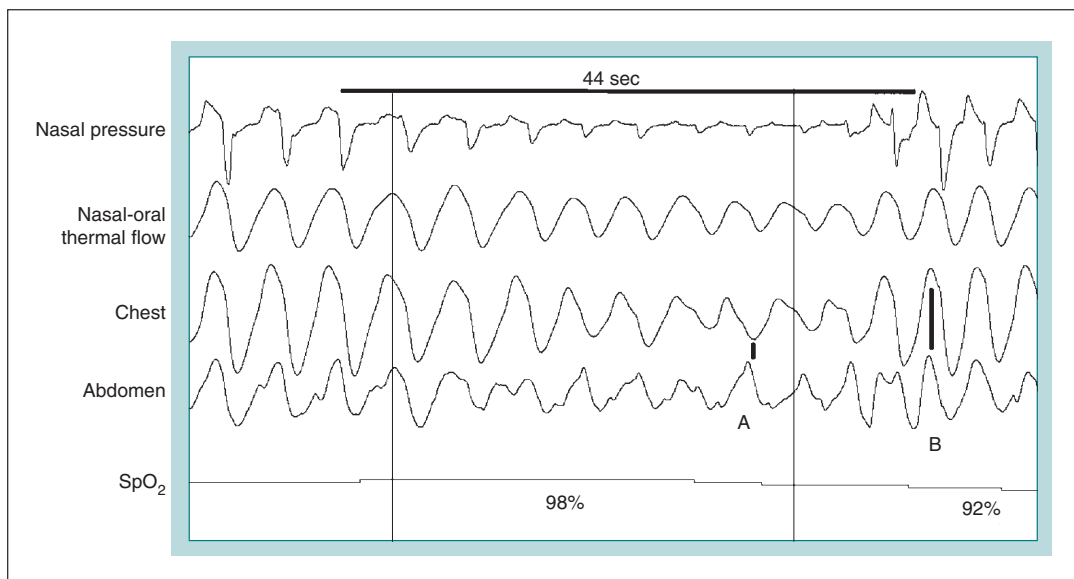


FIGURE 9-4 An event meeting the recommended definition of hypopnea. The amplitude of the nasal pressure signal drops by more than 30% of baseline for well over 9 contiguous seconds and the event duration is longer than 10 seconds. In addition, the event is associated with a greater than 4% desaturation. Note the paradox in the chest and abdomen tracings at A during the event but not at B after the event. SpO_2 = pulse oximetry. The vertical lines are 30 seconds apart.

obstructive respiratory events, it is the magnitude of the inspiratory effort (magnitude of esophageal pressure excursion) and the threshold for arousal that determine whether arousal occurs.¹⁸ During experimental mask occlusion in normal subjects, arousal usually occurs when esophageal pressure deflections (negative pressure) reaches 20 to 30 cm H_2O . However, snorers and patients with OSA may not arouse until esophageal pressures reach 40 to 80 cm H_2O .

This implies a decrease in arousability (high arousal threshold) in these groups.

Because esophageal pressure monitoring is infrequently used, RERA detection is usually based on flattening of the NP signal (flow limitation arousal).^{14,19} After arousal, there is usually a sudden change in the NP contour from flat to round (see Fig. 9-7). Ayappa and colleagues¹⁹ compared arousal associated with flow limitation (FLA) and arousal

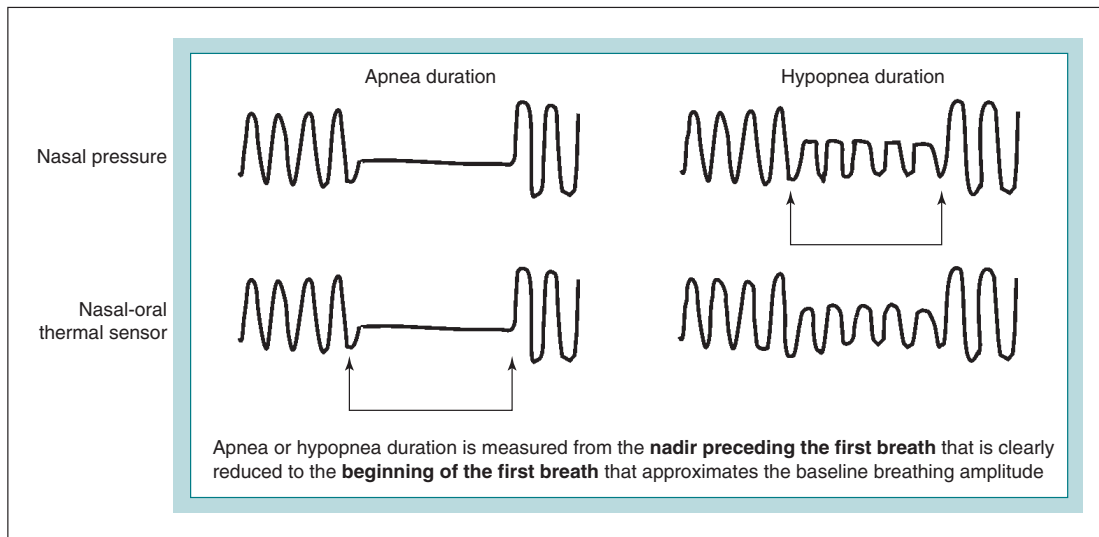


FIGURE 9-5 Event duration rules. Note that the oronasal thermal sensor is used to define the apnea duration and the nasal pressure signal the hypopnea duration.

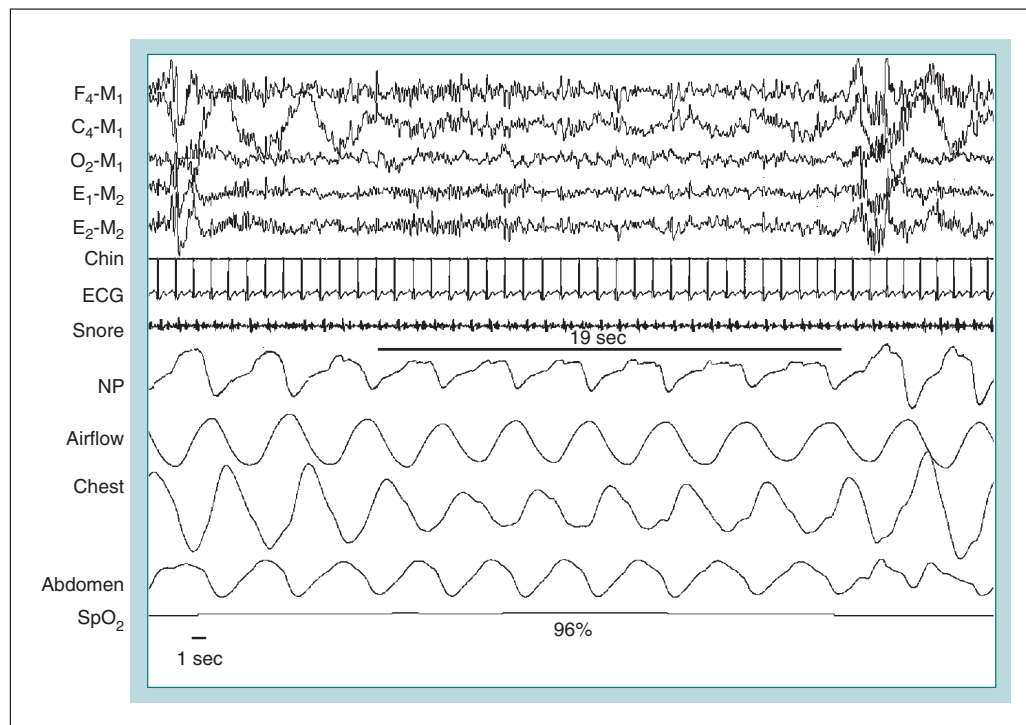


FIGURE 9-6 Respiratory effort-related arousal (RERA). Flattening of nasal pressure for more than 10 seconds followed by an arousal. There is no desaturation so it would not qualify as a hypopnea (by the recommended definition). The drop in flow is not 50% of baseline so the event would not qualify as a hypopnea (alternative definition). ECG = electrocardiogram; NP = nasal pressure; SpO₂ = pulse oximetry.

associated with increased respiratory effort by esophageal manometry (RERAs). The FLA index and RERA index were highly correlated (Fig. 9-8). However, a few FLA events were noted with flow limitation but without an increase in respiratory effort. Some RERAs (esophageal pressure

manometry) were noted without flow limitation. Thus, although flow limitation (NP flattening) and high respiratory effort most often occur together, this is not invariably true. Fortunately, the majority of RERAs will be detected with NP monitoring.

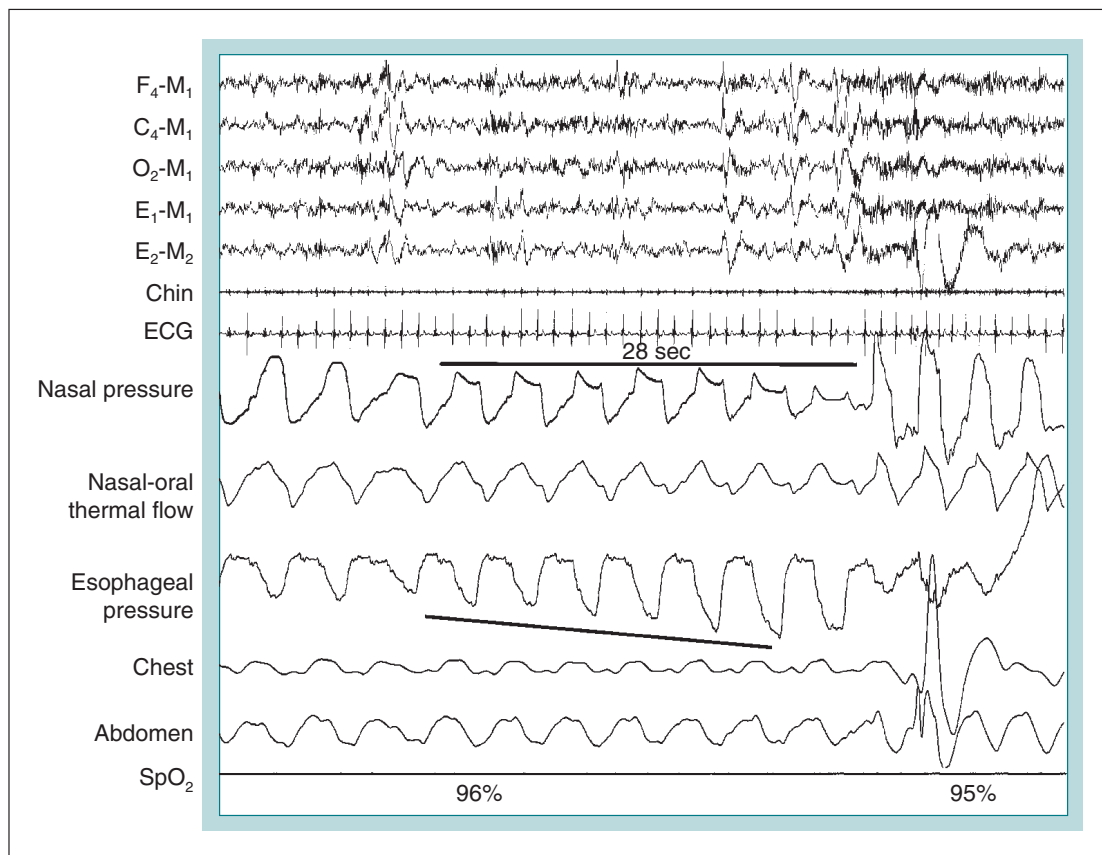


FIGURE 9-7 RERA. The event demonstrates increasing respiratory effort by esophageal pressure (*slanted line*) and flattening of the nasal pressure signal for longer than 10 seconds followed by an arousal. After the event termination, there is a decrease in esophageal pressure excursions and the nasal pressure contour becomes round. The event is not associated with a desaturation and is not a hypopnea by the recommended hypopnea scoring rule. The event also is not associated with a 50% drop in the nasal pressure excursions. Therefore, the event is not a hypopnea using the alternative hypopnea scoring rule. ECG = electrocardiogram; SpO₂ = pulse oximetry.

Hypopnea or RERA?

Of note, if the *recommended* definition of hypopnea is used, some obstructive events that would otherwise meet criteria for the alternate definition of hypopnea would be scored as RERAs. Such an event would be associated with an arousal but not 4% or greater desaturation and have NP flattening for 10 seconds or longer with drop in the excursions of the NP signal by 50% or more from baseline (Fig. 9-9). Note that part of the RERA definition is that the event **does not meet criteria for a hypopnea**.

Relationship of Arousal and Respiratory Event

The AASM scoring manual did not specify a maximum time interval from respiratory event termination until arousal initiation for the arousal to be considered respiratory. FAQ R19 states “The scoring manual does not specify the time requirement linking arousals and respiratory event. When arousals do occur with respiratory events, they usually occur within 5 seconds of airway opening.” Arousals associated with respi-

ratory event termination can occur slightly before, concurrent with, or after event termination.²⁰

Scoring Apneas and Hypopneas during Wake

In some cases, apneas and hypopneas may begin during an epoch scored as sleep but end in an epoch scored as wake (or vice versa). Scoring manual FAQ R10 states “**If any portion of either the apnea or hypopnea occurs during an epoch that is scored as sleep, then the corresponding respiratory event can be scored and included in the computation of the AHI.** However, if the apnea or hypopnea occurs entirely during an epoch scored as wake, it should not be scored or counted toward the apnea-hypopnea index because of the difficulty of defining a denominator in that situation.”

Classification of Hypopneas

The AASM scoring manual recommends that hypopneas not be classified (obstructive, central, or mixed) without a

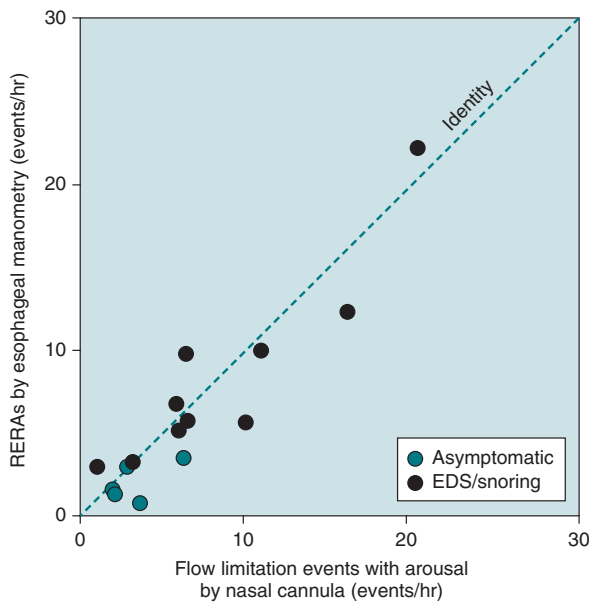


FIGURE 9-8 Flow limitation arousals and respiratory effort–related arousals (RERAs) by esophageal monitoring (events/hour) were highly correlated, although not identical. Reproduced from Ayappa I, Norman RG, Krieger AC, et al: Non-invasive detection of respiratory effort–related arousals (RERAs) by a nasal cannula/pressure transducer system. *Sleep* 2000;23:763–771.

quantitative assessment of ventilatory effort (esophageal manometry, calibrated RIP, or diaphragmatic/intercostal electromyography [EMG]). Of course, an accurate measure of airflow (PNT or NP) would also be needed. The AASM scoring manual did not provide definitions for hypopnea types. However, a possible scheme for defining types of hypopneas is presented in Table 9-3 and Figure 9-10. One can define an *obstructive hypopnea* as one due to an increase in upper airway resistance (usually with increased respiratory effort). A *central hypopnea* would be due to a reduction in respiratory effort with a proportionate decrease in airflow. A *mixed hypopnea* would be characterized by both increased upper airway resistance (NP flattening and airflow limitation) and decreased respiratory effort (decreased esophageal pressure excursions). In the absence of esophageal pressure monitoring, the shape of the NP tracing (or PNT) can provide some clues (see Table 9-3). The presence of a flattened NP tracing, snoring, or chest-abdominal paradox suggests airflow limitation (increased upper airway resistance), whereas a rounded shape without snoring is consistent with a lack of airflow limitation. Even with sophisticated monitoring equipment, it may be difficult to precisely classify some hypopneas.

Chest-Abdominal Paradox

During normal inspiration, the rib cage expands and the diaphragm contracts, moving the abdominal contents

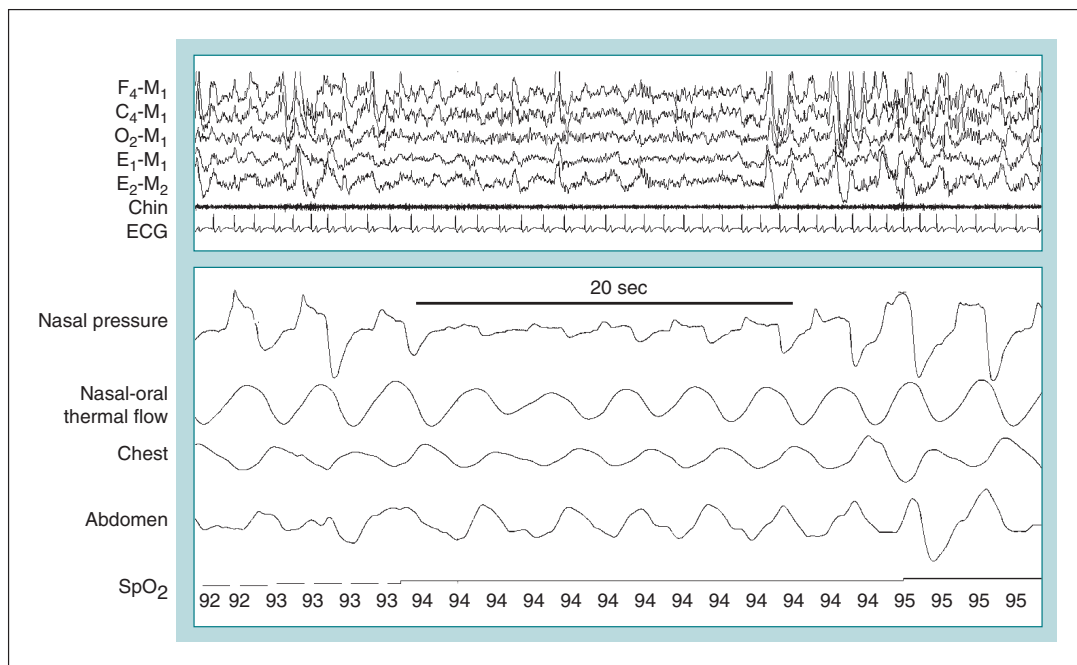


FIGURE 9-9 RERA if the recommended hypopnea definition is used or hypopnea if the alternative hypopnea definition is used. Note that the 20 second arrow is the duration of the 50% drop in NP excursions. However, the event duration as defined by the event duration rules would be longer (nadir preceding first breath that is clearly reduced to the beginning of the first breath that approximates baseline breathing). The event duration would begin one breath earlier and end one breath later than the 20 second line. ECG = electrocardiogram; SpO₂ = pulse oximetry.

TABLE 9-3

Idealized Findings in Hypopnea

TYPE	PNT/NP AMPLITUDE/SHAPE	CHEST/ABDOMEN DEFLECTIONS	ESOPHAGEAL PRESSURE DEFLECTIONS	UPPER AIRWAY RESISTANCE	SNORE
Central	Decreased amplitude Round shape	Decreased No paradox	Decreased	Normal	None
Obstructive	Decreased amplitude Flattened shape	Variable Paradox common	Increased	Increased Airflow limitation	Present
"Mixed"	Decreased amplitude Flattened shape	Decreased Paradox common	Decreased	Increased Airflow limitation	May be present

NP = nasal pressure; PNT = pneumotachogram.

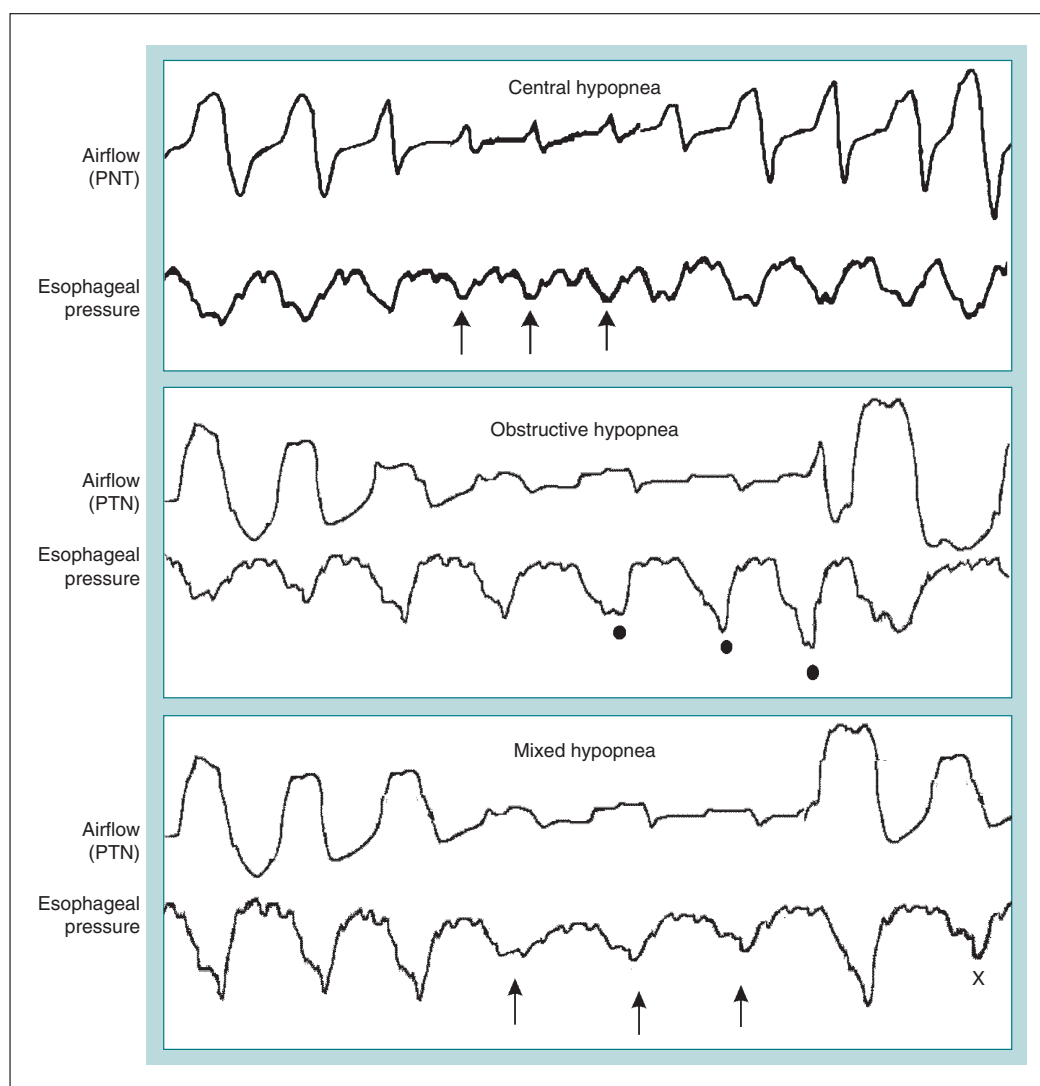


FIGURE 9-10 Examples of central, obstructive, and mixed hypopneas with an accurate measure of airflow (pneumotachograph [PNT]) and esophageal pressure monitoring. In central and mixed hypopnea, the esophageal excursions decrease (*up arrows*). In mixed hypopnea, airflow limitation is present (flattened airflow), and in central hypopnea, the airflow contour is round. In obstructive hypopnea, the esophageal pressure excursions are increased (*black circles*) for at least part of the event.

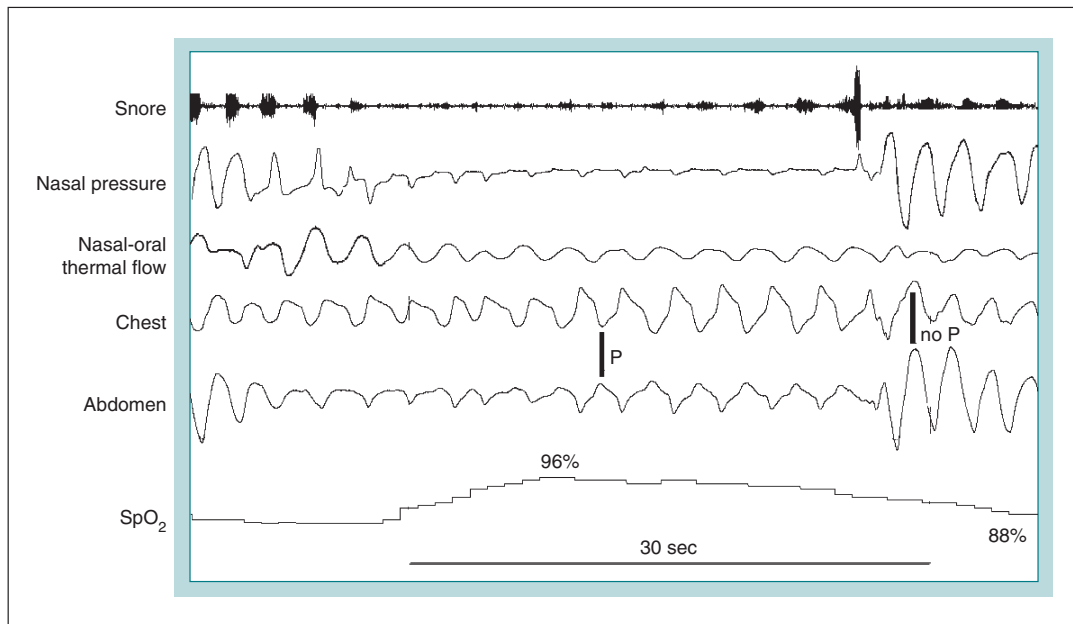


FIGURE 9-11 An obstructive hypopnea with paradox (P) in chest and abdominal movement during the respiratory event but not during less obstructed breathing (no P). SpO₂ = pulse oximetry.

downward; the abdomen also moves outward. During chest-abdomen paradox, the chest moves outward and the abdomen inward or vice versa. Paradox is most helpful at identifying high upper airway resistance when it is present during the obstructive event and NOT present during unobstructed breathing (Fig. 9-11; see also Fig. 9-4).

Conditions in which paradox may occur²¹:

1. Loss of diaphragm tone/weakness: The abdomen is sucked inward as the rib cage expands during inspiration.
2. Loss of accessory muscle tone: Destabilizes the rib cage so it may be sucked inward when the diaphragm contracts (abdomen expands).
3. Partial upper airway obstruction: High pleural pressures can overcome mechanisms maintaining rigidity of thorax—parts are sucked inward. This is common in children with more pliable chest walls.
4. Complete upper airway obstruction: The total volume of respiratory system does not change—when the abdomen expands (diaphragm contracts) the chest volume must decrease.

False Classification of Apneas as Central

As discussed in Chapter 8, even with RIP, an obstructive apnea (by esophageal pressure manometry) may appear to be a central apnea.^{22,23} In Figure 9-12, the RIP rib cage and abdominal band tracings are nearly flat but persistent respiratory effort is definitely noted in the esophageal pressure tracing. Although misclassification of a few events is unlikely to have major clinical consequences, proper adjustment

of chest and abdominal bands (position and tightness) is crucial to avoid significant errors in event classification. Computer software often adjusts sensitivity with an “autogain” to avoid large breaths being off-scale. However, this may decrease the gain so that small efforts are not recognized. In Figure 9-13, with an increase in the gain (size) of chest and abdominal tracings, the event is clearly not a central apnea.

Regarding central apneas, it is worth noting that the upper airway can actually close during a central apnea.²⁴ This should not be surprising, considering the obstructive portion of mixed apneas. Some have proposed that the observation of cardiac oscillations in airflow tracings allows one to conclude that the upper airway is open (Fig. 9-14).²⁵ However, a study by Morrell and associates²⁶ found that during ventilator-induced central apneas in dogs, cardiac oscillations could be present in the flow tracings even if the airway was noted to be closed by direct visualization. The appearance of cardiac oscillations in the airflow tracings is rarely noted in obstructive apnea. Therefore, the presence of cardiac oscillations in the flow may be a clue that a central apnea is present but one may not be able to infer that the upper airway is indeed open.

Hypoventilation in Adults¹⁴

Hypoventilation during wakefulness is usually defined as an arterial partial pressure of carbon dioxide (PaCO₂) equal to or greater than 45 mm Hg. During sleep, there may be periods of time in which the SpO₂ is reduced without associated events that meet criteria for apnea or hypopnea. Such

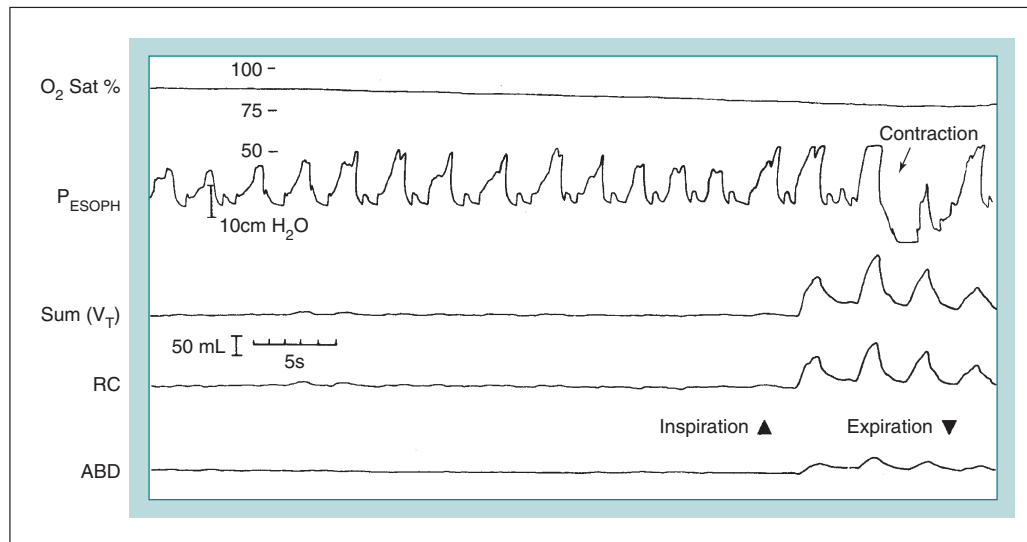


FIGURE 9-12 An obstructive apnea appears to be a central apnea based on the rib cage (RC) and abdominal (ABD) respiratory inductance plethysmography (RIP) tracings. The true nature of the event is shown by the persistent esophageal pressure (P_{ESOPH}) deflections. Data from Tobin MJ, Cohen MA, Sackner MA: *Breathing abnormalities during sleep. Arch Intern Med 1983;143:1221–1228.*

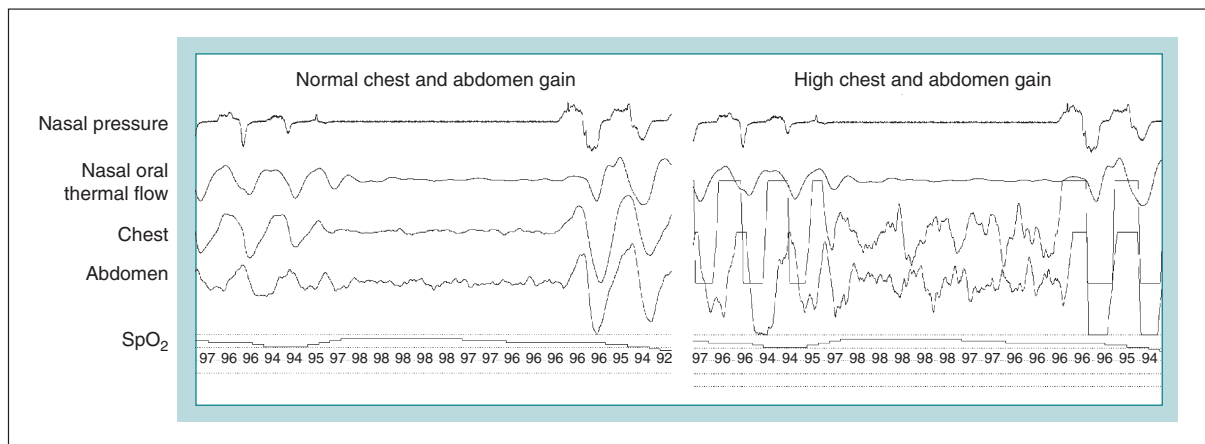


FIGURE 9-13 Left, The event may at first appear to be a central apnea. However, with an increase in gain in the chest and abdomen tracings, the obstructive nature of the event is apparent. Right, The many small fluctuations in the chest and abdomen tracings are due to cardiac oscillations that are readily apparent only at the high gain. SpO_2 = pulse oximetry.

periods of arterial oxygen desaturation are sometimes termed “hypoventilation.” However, this is presumptive without direct measurement of $PaCO_2$ or a surrogate. The AASM scoring manual provides criteria for hypoventilation during sleep and discourages use of the term “hypoventilation” without documentation of an elevated $PaCO_2$.

Hypoventilation Rule (AASM Scoring Manual¹⁴)

Score hypoventilation during sleep if there is a ≥ 10 mm Hg increase in $PaCO_2$ during sleep in comparison with an **awake supine value**.

The AASM scoring manual also notes that persistent oxygen desaturation in the absence of apnea or hypopnea is

not sufficient to document hypoventilation. It is observed that finding an increase in the $PaCO_2$ obtained immediately upon awakening is suggestive of sleep hypoventilation. The manual concluded that sufficient evidence was not available to recommend a sensor to document hypoventilation. The manual also states that both end-tidal carbon dioxide pressure ($P_{ET}CO_2$) and transcutaneous carbon dioxide pressure ($TcPCO_2$) may be used as surrogate measures of $PaCO_2$ if demonstrated to be reliable and valid.

Continuous arterial blood gas monitoring during PSG is not practical (or well tolerated) and arterial blood gas testing is most often performed at the start (to validate a surrogate measure of PCO_2) or on awakening often at study

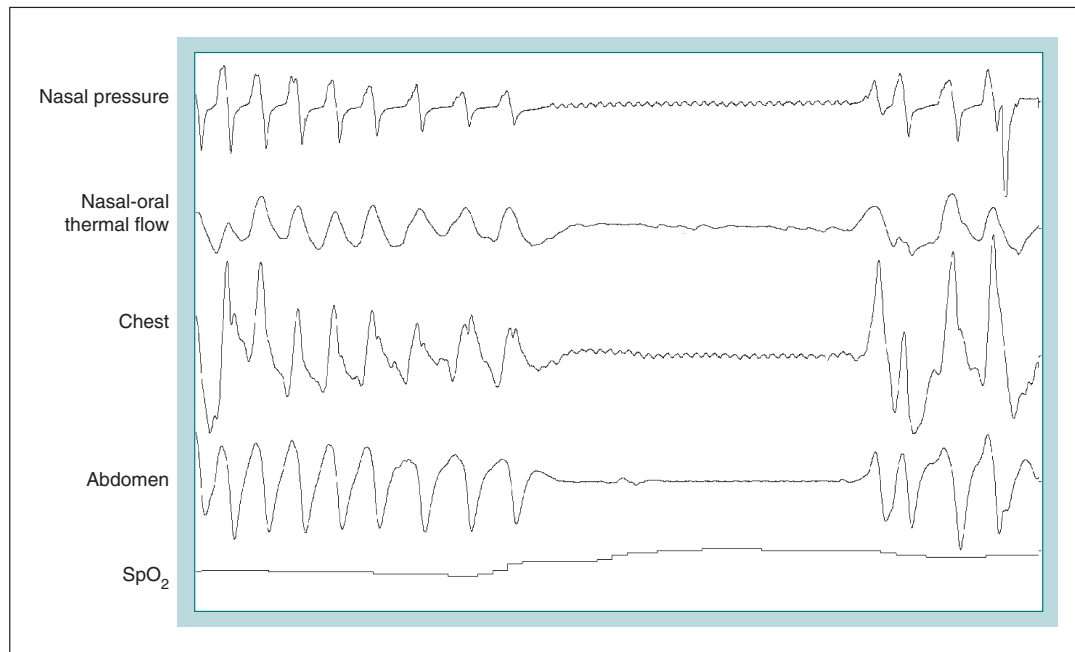


FIGURE 9-14 A central apnea is seen with cardiac oscillations in the chest and airflow channels. The oscillations are also seen in the nasal pressure signal. There is controversy about whether this means that the upper airway is open or closed. As discussed previously, the upper airway can close during central apnea. SpO₂ = pulse oximetry.

termination (to provide evidence for hypoventilation during sleep). In children, an arterialized capillary blood gas rather than an arterial sample is often performed.

The most common approaches to documenting hypoventilation during sleep monitoring include measurement of P_{ET}CO₂ or TcPCO₂. These methods are discussed in Chapter 8. Figure 9-15 presents a tracing from a patient with a neuromuscular disorder. The awake P_{ET}CO₂ was 43 mm Hg, but during sleep, the P_{ET}CO₂ reached the mid 70s. As discussed in Chapter 8, a P_{ET}CO₂ tracing should show an alveolar plateau to be accepted as an accurate estimate of the PaCO₂. In Figure 9-15, many of the breaths are not associated with a good alveolar plateau. The last 2 breaths illustrate a desired alveolar plateau. It should also be noted that the PaCO₂ typically exceeds the P_{ET}CO₂ by 4 to 6 mm Hg in normal individuals. The difference can be increased in patients with lung disease.

Cheyne-Stokes Breathing Rule¹⁴

Score Cheyne-Stokes breathing (CSB) if there are at least three consecutive cycles of cyclic crescendo and decrescendo change in breathing amplitude and **at least one** of the following:

1. Five or more central apneas or hypopneas per hour of sleep.
2. The cyclic crescendo and decrescendo change in breathing amplitude has a duration of at least 10 consecutive minutes.

CSB is characterized by central apnea or hypopnea at the nadir of respiratory effort (Fig. 9-16) as well as an intervening pattern of crescendo-decrescendo ventilation (flow or tidal volume) between apneas/hypopneas. CSB is most commonly noted in patients with systolic congestive heart failure (CHF) but can occur after stroke or with diastolic heart failure. When CSB is associated with systolic CHF, a few other characteristic PSG findings are of interest. First, the cycle time (time from the onset of one apnea to the next apnea) is usually approximately 50 to 60 seconds with long ventilatory phases (crescendo-decrescendo) between the central apneas.²⁷ If associated arousals are present, they are often at the zenith of respiratory effort. In addition, due to low cardiac output, there is a long circulation time and the nadir in desaturation is delayed relative to the event termination. Figure 9-17 presents a schematic showing the differences between central apnea in primary (idiopathic) central apnea and CSB.

Respiratory Parameters Reported in PSG (Adults)^{14,17}

The following is a list of respiratory parameters that are recommended for presentation in a PSG report. Of note, the RDI was not defined in the AASM scoring manual but is added for completeness. Not all sleep centers report an RDI. Two definitions of the RDI in common use are presented here. The sleep study report should specify the RDI definition (if reported) and the definition of hypopnea (recommended or alternative) that was used for scoring the sleep study.

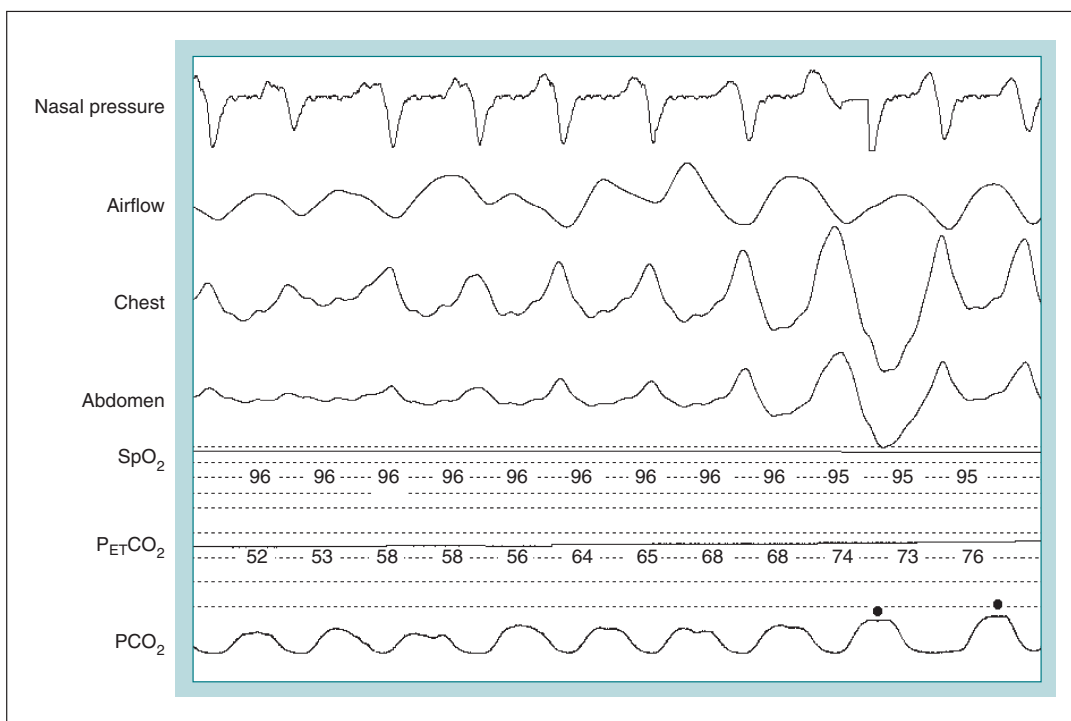


FIGURE 9-15 Documentation of an increased partial pressure of carbon dioxide (PCO₂) during sleep. Note the alveolar plateaus (black circles). PCO₂ = exhaled PCO₂ waveform tracing; P_{ET}CO₂ = most recent end-tidal reading; SpO₂ = pulse oximetry.

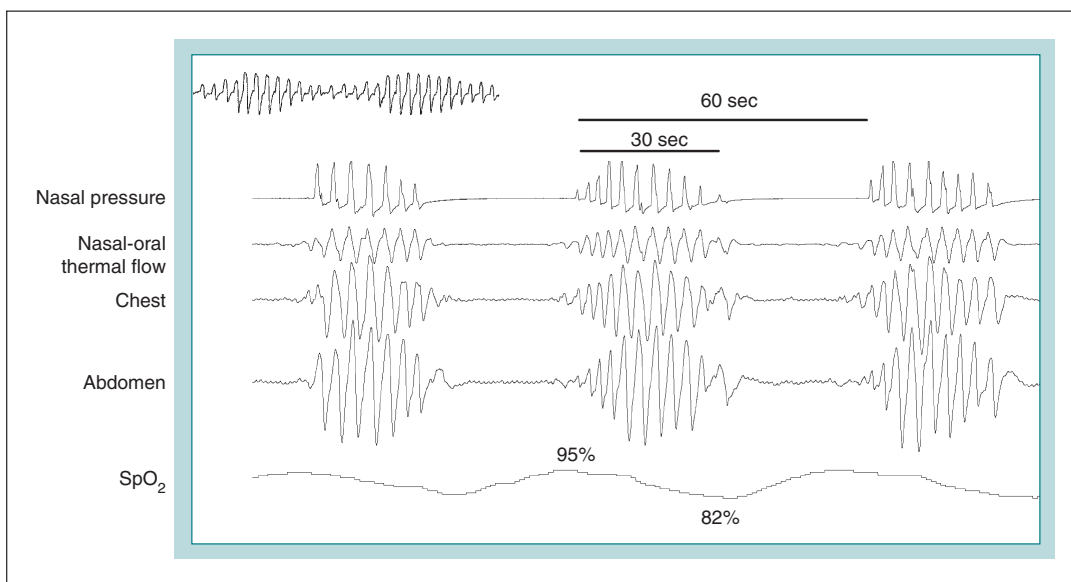
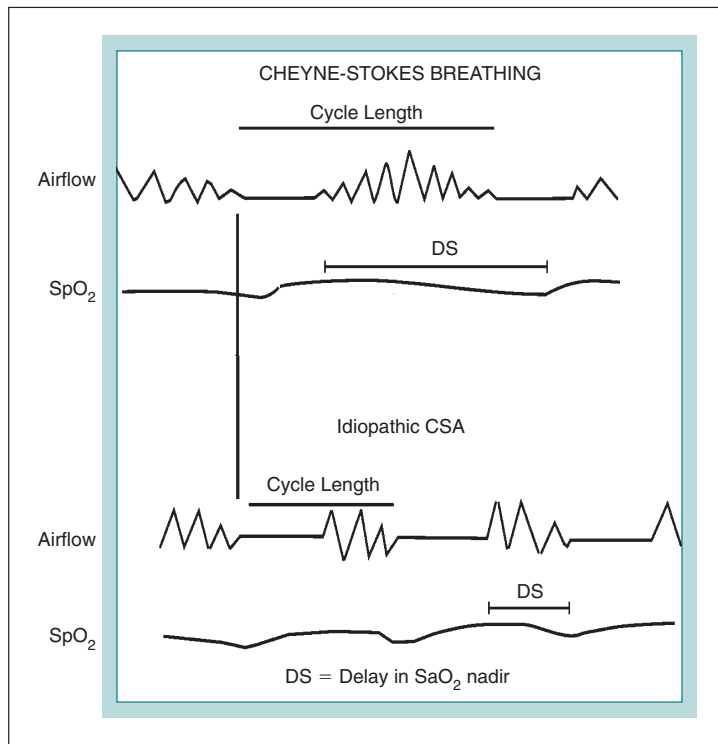


FIGURE 9-16 Cheyne-Stokes respiration with a crescendo-decrescendo pattern of respiration with central apneas at the nadir of effort. Note the nadir in the pulse oximetry (SpO₂) is very delayed following the end of the apneas. **Top left corner,** A tracing of Cheyne-Stokes breathing with a hypopnea at the nadir.

FIGURE 9-17 Differences between Cheynes-Stokes breathing and idiopathic (primary) central sleep apnea (CSA). SaO_2 = arterial oxygen saturation; SpO_2 = pulse oximetry.



1. AH = number of apneas + number of hypopneas.
2. Number of obstructive, central, and mixed apneas.
3. Number of hypopneas.
4. AHI = number of apneas and hypopneas per hour of sleep

$$60 \times \text{AH} / \text{TST (total sleep time [min])}$$

5. AHI during supine and nonsupine sleep.
6. AHI NREM and AHI rapid eye movement (REM).
7. OD = number of arterial oxygen desaturations.
8. Oxygen desaturation index (ODI) = $(\text{OD} \times 60) / \text{TST (min)}$.
9. Number of RERAs.
10. RERA index = $(\text{number of RERAs}) \times 60 / \text{TST (min)}$
11. RDI
 - Definition #1 RDI = AHI
 - Definition #2 RDI = AHI + RERA index

RESPIRATORY EVENT SCORING RULES IN CHILDREN

The AASM scoring manual provides separate rules for the scoring of respiratory events in children. The rules are based on a systematic review of the literature in children. Although many of the rules are similar to those in adults, there are differences. In children 13 years or older, the sleep specialist has the option to use adult rules. The sensors for monitoring

respiration in children are very similar to those for monitoring adults (Table 9-4). In children, it is very common for some respiratory sensors to fail during monitoring. For example, sensors might be pulled off by the child or the NP cannula may be dislodged or occluded with secretions.

Ages for Which Pediatric Scoring Rules Should Be Used

Criteria for respiratory events during sleep for infants and children can be used for children younger than 18 years. An individual sleep specialist may choose to score children **≥13 years of age** using adult criteria.

In adult patients, a 10-second breathing pause (minimum apnea duration) is approximately 2 missed breaths (at a respiratory rate of 12 breaths/min). In children, the respiratory rates are much faster and obstructive apneas shorter than 10 seconds can have physiologic significance. Therefore, the 2 missed breath rule is used for apneas in children. Short central apneas are common in children and are often seen after deep breaths (sighs) or arousals. Therefore, central apneas must be longer (≥ 20 sec) or associated with physiologic significance to be scored. If a central apnea is greater in duration than 2 missed breaths but less than 20 seconds, it must be associated with arousal, desaturation, or awakening to be scored. The respiratory scoring rules for children are listed in Table 9-4.

TABLE 9-4

Pediatric Respiratory Rules

Obstructive apnea	• Duration at least 2 missed breaths or equivalent duration. • >90% fall in signal for ≥90% of event duration. • Continued or increased inspiratory effort. • Event duration is from the end of last normal breath to the beginning of first breath achieving baseline amplitude.
Mixed apnea	• Duration at least 2 breaths or equivalent duration. • >90% fall in signal for ≥90% of event duration. • Absent inspiratory effort in the initial portion of the event, followed by resumption of inspiratory effort before the end of the event.
Central apnea	• Absent inspiratory effort. • Duration ≥ 20 sec. OR duration at least 2 missed breaths AND associated with arousal, awakening, or ≥3% desaturation.
Hypopnea	• NP signal falls by ≥50% from baseline. • Duration at least 2 missed breaths (or equivalent duration). • Fall lasts ≥90% of the event duration. • Arousal, awakening, or ≥3% desaturation occurs.
RERA	• All of the following in NP: a. Discernible but <50% fall in signal. b. Flattening of NP. c. The event accompanied by snoring, noisy breathing, elevation in the end-tidal PCO₂ or transcutaneous PCO₂, or increased WOB. d. Duration at least 2 breath cycles. • All of the following when using esophageal pressure: a. Progressive increase in respiratory effort. b. Snoring, noisy breathing, increased end-tidal or transcutaneous PCO₂, increased WOB. c. Duration at least 2 breath cycles.
Hypoventilation	≥25% of the total sleep time with a PCO ₂ > 50 mm Hg. (P _{ET} CO ₂ or TcPCO ₂ are acceptable.)
Periodic breathing	There are >3 episodes of central apnea lasting >3 sec separated by no more than 20 sec of normal breathing.

NP = nasal pressure; PCO₂ = partial pressure of carbon dioxide; P_{ET}CO₂ = end-tidal carbon dioxide pressure; RERA = respiratory effort–related arousal; TcPCO₂ = transcutaneous carbon dioxide pressure; WOB = work of breathing.
From Iber C, Ancoli-Israel S, Chesson A, Quan SF for the American Academy of Sleep Medicine: The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications, 1st ed. Westchester, IL: American Academy of Sleep Medicine, 2007.

Recommended Sensors in Children by AASM Scoring Manual¹⁴

As in adults, the recommended sensor to score an apnea is an oronasal thermal sensor. The alternative apnea sensors differ somewhat from those in adults and include NP, exhaled CO₂, or the summed signal of calibrated RIP. The recommended sensor for hypopnea is NP. The alternative sensor for hypopnea is a oronasal thermal sensor. Although not recommended, one could use the RIPsum as well. For detection of respiratory effort, recommended methods include esophageal manometry and RIP (calibrated or uncalibrated). For alveolar hypoventilation, acceptable signals are P_{ET}CO₂ and TcPCO₂.

Apnea Rules for Children¹⁴

Obstructive Apnea

Score an event as an OBSTRUCTIVE apnea if it meets all of the following criteria:

1. *Event lasts at least 2 breaths* (or the duration of 2 breaths as determined by baseline breathing pattern).
2. The event is associated with a >90% fall in the signal amplitude for ≥90% of the entire respiratory event compared with pre-event baseline amplitude.
3. The event is associated with continued or increased respiratory effort throughout the entire period of decreased airflow.
4. The **duration of the apnea** is measured from the end of the last normal breath to the beginning of the first breath that achieved the pre-event baseline inspiratory excursions.

Mixed Apnea

Score a respiratory event as a MIXED apnea if it meets both criteria 1 and 2 for obstructive apnea, and it is associated with absent inspiratory effort in the initial portion of the

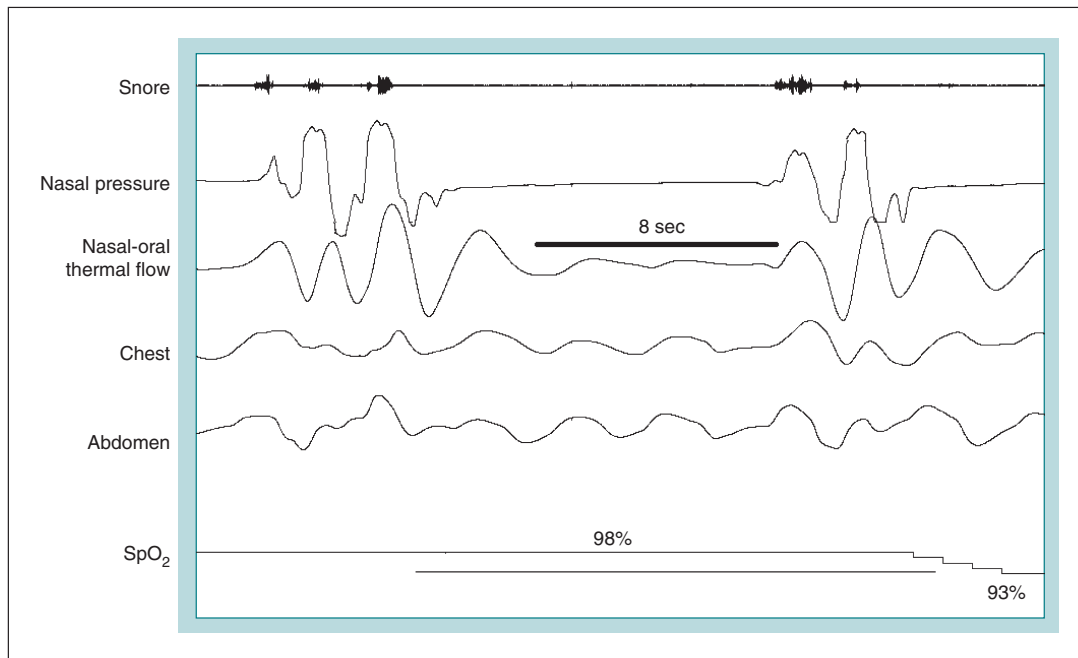


FIGURE 9-18 A short obstructive apnea in a 7-year-old child. There is a fall in the nasal-oral thermal flow of greater than 90% and continued inspiratory efforts are noted. Even though the event duration is short, it was followed by an arterial oxygen desaturation. Of note, a desaturation is NOT necessary to score an obstructive apnea. SpO₂ = pulse oximetry.

event followed by resumption of inspiratory effort before the end of the event.

Central Apnea

Score a respiratory event as a CENTRAL apnea if it is associated with absent inspiratory effort throughout the **entire duration** of the event and one of the following is met:

1. The event lasts 20 seconds or longer.
2. The event lasts 2 breaths (or the duration of 2 breaths as determined by the baseline breathing pattern) AND is associated with an arousal, an awakening, or a 3% or greater desaturation.

An example of a short obstructive apnea (only 2 breaths in duration based on thermal sensor) is shown in Figure 9-18. Examples of two possible central events are shown in Figure 9-19. In the top event, there is an absence of airflow with absent inspiratory effort. However, the duration is only 11 seconds and because it was not associated with an arousal (following the event) or an arterial oxygen desaturation, it would NOT be scored as a central apnea. The lower central event meets criteria for scoring a central apnea.

The AASM scoring manual presents only a single hypopnea definition for children (versus the recommended and alternative definitions in adults). The hypopnea definition for children is similar to the alternative adult definition except that the duration must be at least the equivalent of 2 missed breaths.

Hypopnea Rule (Children)¹⁴

Score a hypopnea if **all** the following criteria are met:

1. The event is associated with a **≥50% fall in the amplitude** of the NP or alternative signal compared with the pre-event baseline excursion.
2. The event lasts at least 2 missed breaths (or the duration of 2 missed breaths as determined by baseline breathing pattern) from the end of the last normal breathing amplitude.
3. The fall in NP signal amplitude must last for **≥90%** of the entire respiratory event compared with the signal amplitude preceding the event.
4. The event is associated with an arousal, awakening, or 3% or greater desaturation.

The AASM scoring manual stated that if the NP signal is not functioning, the oronasal thermal signal can be used to score hypopnea.

RERA Rules for Children¹⁴

Score an RERA if the conditions in either 1 or 2 are met (+ an arousal occurs):

1. Using a NP sensor, ALL must be met:
 - a. Discernible fall in amplitude of signal but it is less than 50% in comparison with baseline.
 - b. Flattening of NP waveform.

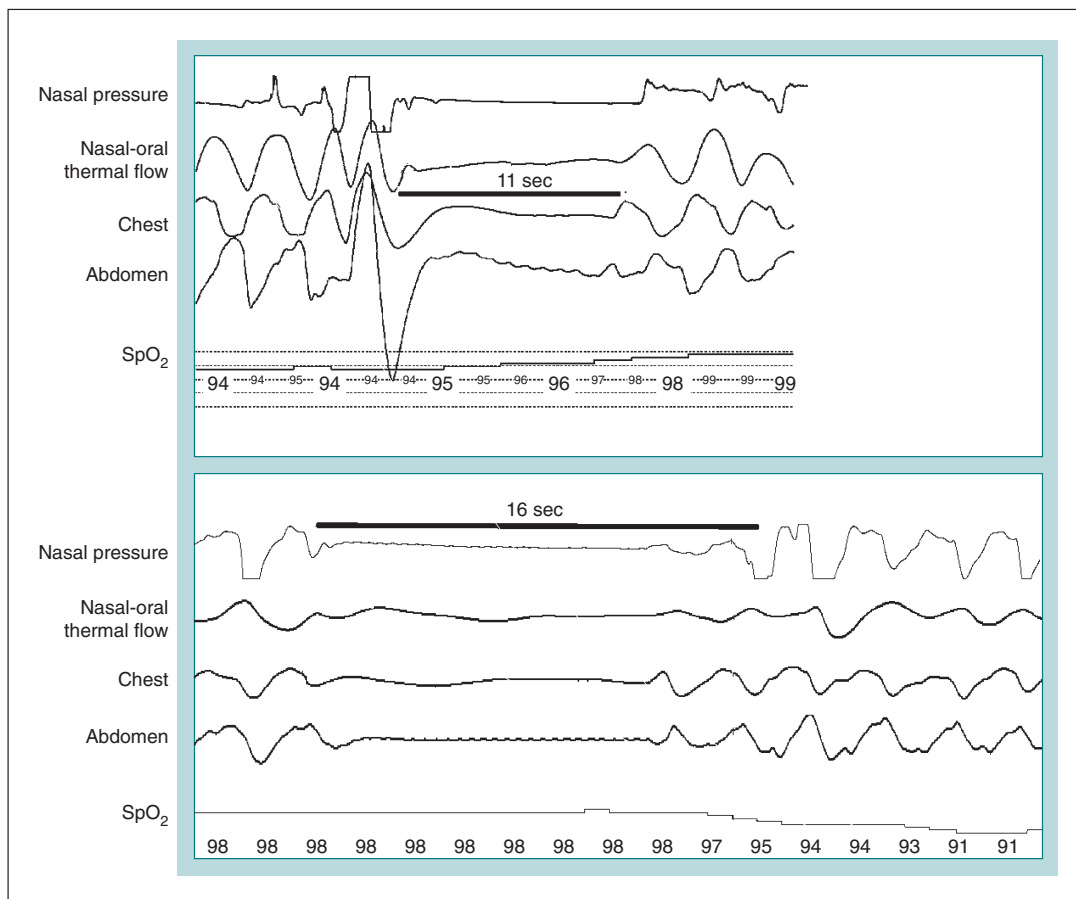


FIGURE 9-19 A respiratory event in a 6-year-old child. The *upper central event* would not be scored as a central apnea because the duration is less than 20 seconds and there is no associated arousal or desaturation. The *bottom central event* would be scored as a central apnea because it is longer than 2 missed breath cycles and is associated with an arterial oxygen desaturation. SpO₂ = pulse oximetry.

- c. The event is accompanied by snoring, noisy breathing, elevation in $P_{ET}CO_2$ or $TcPCO_2$, or visual evidence of increased work of breathing.
- d. The duration of the event is at least 2 breath cycles (or duration of 2 breath cycles as determined by baseline breathing pattern).
2. Using an esophageal pressure sensor. ALL must be met:
 - a. Progressive increase in inspiratory effort during the event.
 - b. The event is accompanied by snoring, noisy breathing, elevation in $P_{ET}CO_2$ or $TcPCO_2$, or visual evidence of increased work of breathing.
 - c. The duration of the event is at least 2 breath cycles (or duration of 2 breath cycles as determined by baseline breathing pattern).

The AASM scoring manual stated that an RERA cannot be scored without an adequate NP or esophageal manometry signal.

Hypoventilation Rule for Children¹⁴

Score the presence of **sleep-related hypoventilation** when **>25% of the total sleep time** as measured by the $TcPCO_2$ and/or the $P_{ET}CO_2$ is spent with a $PaCO_2 > 50$ mm Hg.

The AASM scoring manual noted that the $P_{ET}CO_2$ signal often malfunctions (dislodged or occluded with nasal secretions) during pediatric PSG or provides falsely low values in patients who have marked nasal obstruction, are obligate mouth breathers, or are receiving either supplemental oxygen or CPAP during the PSG. As previously noted, it is essential to obtain an **alveolar plateau** in the PCO_2 signal for the $P_{ET}CO_2$ value to be considered valid. As discussed earlier, the $TcPCO_2$ value is good for illustrated trends in $PaCO_2$ but a time lag in change in the $TcPCO_2$ values is noted after acute changes in respirations (slow response time).

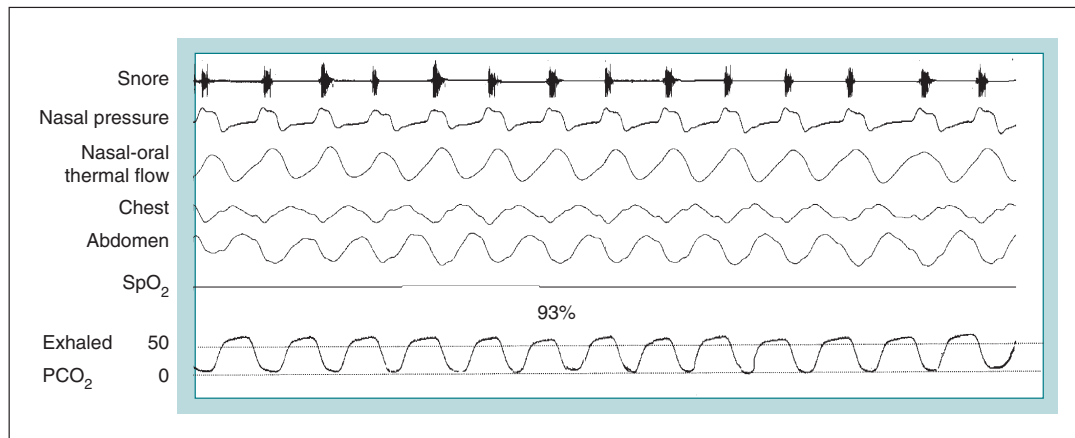


FIGURE 9-20 Obstructive hypoventilation. The end-tidal partial pressure of carbon dioxide (PCO_2) is greater than 50 mm Hg and there is evidence of snoring and flattening of the nasal pressure. A very mild drop in the pulse oximetry (SpO_2) is noted.

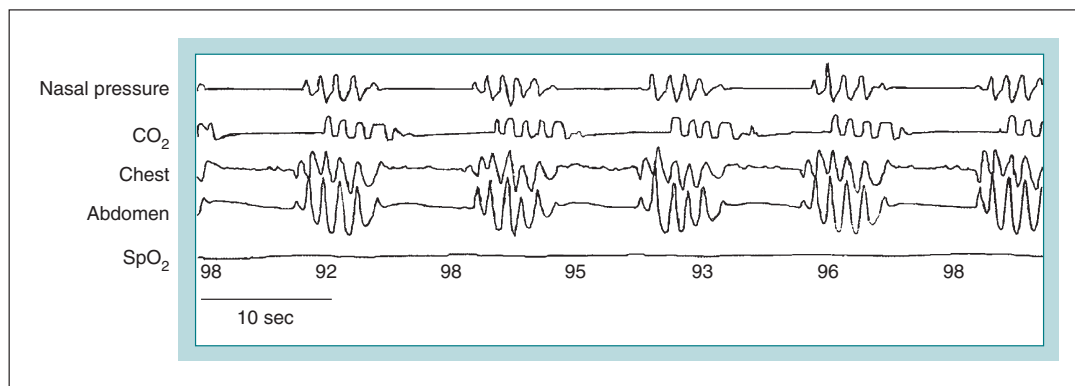


FIGURE 9-21 Periodic breathing in a newborn infant (43 wk conceptual age). Note the lag in the end-tidal PCO_2 tracing (CO_2) compared with the nasal pressure tracing. SpO_2 = pulse oximetry.

Obstructive Hypoventilation

Obstructive hypoventilation^{29,30} is a term used to describe the periods during which there is evidence of hypoventilation (increased $P_{ET}CO_2$) without discrete events but associated with evidence of upper airway narrowing (snoring, NP flattening, chest-abdominal paradox). Figure 9-20 presents an example of obstructive hypoventilation in a 6-year-old child. Although this term is not specifically defined in the AASM scoring manual, it is widely used.

Periodic Breathing Rule for Children¹⁴

Score periodic breathing if there are more than three episodes of central apnea that last longer than 3 seconds separated by no more than 20 seconds of normal breathing.

Figure 9-21 presents a 60-second tracing from a newborn infant. The central apneas are longer than 3 seconds, there are more than three central apneas, and the breathing between the central apneas is less than 20 seconds. This meets criteria for periodic breathing. This is a normal breathing pattern in preterm and term infants.

Respiratory Parameters Reported in PSG (Children)

Many sleep centers report respiratory events in children somewhat differently than those in adults. The differences include reporting the central AHI and obstructive AHI separately and reporting data concerning the $P_{ET}CO_2$ and/or $TcPCO_2$. Specifically, the maximum $P_{ET}CO_2$ and time spent greater than 50 mm Hg (absolute time or as % TST) are typically reported. Not all sleep centers report an RDI. The RDI should be defined if included in the report.

1. $A + H$ = number (#) of apneas + number of hypopneas.
2. Number of obstructive apneas, central apneas, mixed apneas, and hypopneas.
3. AHI = number of apneas and hypopneas/hr of sleep

$$60 \times AH/TST \text{ (min)}$$
4. Obstructive AHI = (# obstructive apneas + # mixed apneas + # hypopneas) $\times 60/TST$ (min).
5. Central AHI = number of central apneas $\times 60/TST$ (min).

6. AHI during supine and nonsupine sleep.
7. AHI NREM and AHI REM.
8. OD = number of arterial oxygen desaturations.
9. ODI = $(OD \times 60)/TST$ (min).
10. # RERA = number of RERAs.
11. RERA index = number of RERAs $\times 60/TST$ (min).
12. RDI
 - Definition #1 RDI = AHI
 - Definition #2 RDI = AHI + RERA index
13. Time with $P_{ET}CO_2$ or $TcPCO_2$ greater than 50 mm Hg (as total minutes or as % TST).

CLINICAL REVIEW QUESTIONS

1. Hypoventilation during wakefulness for adults is defined as a $PaCO_2 \geq 45$ mm Hg. Hypoventilation during sleep is defined as:
 - A. $PaCO_2 \geq 5$ mm Hg above an awake supine value.
 - B. $PaCO_2 \geq 10$ mm Hg above an awake supine value.
 - C. $P_{ET}CO_2 \geq 5$ mm Hg above the wake value.
 - D. $P_{ET}CO_2 \geq 10$ mm Hg above the wake value.
2. In the table, which group (A, B, C, or D) is correct for recommended and alternate definitions of hypopnea in adults and hypopnea in children? NP = nasal pressure excursions.

	CHANGE IN NP FROM BASELINE	DESATURATION
A. Adult hypopnea (recommended)	Drop of $\geq 30\%$	$\geq 4\%$
Adult hypopnea (alternate)	Drop of $\geq 30\%$	$\geq 4\%$ (or arousal)
Child hypopnea	Drop of $\geq 50\%$	$\geq 3\%$ (or arousal)
B. Adult hypopnea (recommended)	Drop of $\geq 30\%$	$\geq 4\%$
Adult hypopnea (alternate)	Drop of $\geq 50\%$	$\geq 3\%$ (or arousal)
Child hypopnea	Drop of $\geq 30\%$	$\geq 3\%$ (or arousal)
C. Adult hypopnea (recommended)	Drop of $\geq 30\%$	$\geq 4\%$
Adult hypopnea (alternate)	Drop of $\geq 50\%$	$\geq 3\%$ (or arousal)
Child hypopnea	Drop of $\geq 30\%$	$\geq 3\%$ (or arousal)
D. Adult hypopnea (recommended)	Drop of $\geq 30\%$	$\geq 4\%$
Adult hypopnea (alternate)	Drop of $\geq 50\%$	$\geq 3\%$ (or arousal)
Child hypopnea	Drop of $\geq 50\%$	$\geq 3\%$ (or arousal)

3. In children, hypoventilation is defined by which of the following?

- A. $PaCO_2 \geq 50$ mm Hg for $\geq 10\%$ of total sleep time.
 - B. $PaCO_2 > 50$ mm Hg for $\geq 25\%$ of total sleep time.
 - C. $PaCO_2 \geq 50$ mm Hg for $\geq 25\%$ of total sleep time.
 - D. $PaCO_2 < 55$ mm Hg for $\geq 25\%$ of total sleep time.
4. At what **age and above** can adult scoring rules be used at the discretion of the clinician?
 - A. 12 years.
 - B. 13 years.
 - C. 14 years.
 - D. 16 years.
 5. According to the AASM scoring manual, score periodic breathing in children if:
 - A. >3 episodes, central apnea lasting >3 seconds, separated by no more than 20 seconds.
 - B. >3 episodes, central apnea lasting >3 seconds, separated by no more than 10 seconds.
 - C. >3 episodes, central apnea lasting >2 seconds, separated by no more than 20 seconds.
 - D. >3 episodes, central apnea lasting >5 seconds, separate by no more than 20 seconds.

Answers

1. B. The AASM scoring manual defines hypoventilation based on the arterial $PaCO_2$ of ≥ 10 mm Hg above the waking value. The $P_{ET}CO_2$ or $TcPCO_2$ can be used to define hypoventilation only when it has been validated as an estimate of the patient's ventilation.
2. D
3. B
4. B
5. A

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