A Review of Normal Values of Infant Sleep Polysomnography

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Key Words
apnea; infant; neonate; polysomnography

Background: The objective of this study was to summarize current information about the normal values on infant sleep polysomnography for clinical use.

Methods: MEDLINE (Ovid), EMBASE (Ovid), and CINAHL (Ovid) from January 1976 to May 2007 were searched. Two reviewers independently reviewed all relevant articles, using preset inclusion criteria. The population of interest included children aged less than 1 year. Studies in infants with known major anomalies were excluded. The results on apneas were extracted and analyzed.

Results: For obstructive apnea, the upper limit of normal values was less than 1.0 per hour, and for mixed apnea, the current data suggested the upper limit of normal values was less than 1.0 per hour. For central apnea defined as cessation of respiratory efforts for more than 3 seconds, the current data suggested that the upper limit of the normal central apnea index was 45 per hour for 1-month-old infants, 30 per hour for 2-month-old infants, 22 per hour for 3-month-old infants, and between 10 and 20 for the older age groups. For the desaturation episode defined as SpO2 less than 80% for any length of time, the current data suggested the upper limit of normal values to be 14.7 episodes per hour for day 1, 41 episodes for day 4, and 15.1 episodes for day 39.

Conclusion: The normal values of obstructive apnea, mixed apnea, and central apnea are well established for neonates and infants. With these normal values, sleep polysomnography study should be routinely used to quantify the severity of breathing disorders during sleep in those neonates at risk for these disorders.

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1. Introduction

After delivery, continuous breathing pattern becomes essential, and it represents a dramatic departure from fetal life when the breathing movement is irregular. Hence, it is not surprising that apnea is a common phenomenon during early infancy. During infancy, apnea is commonly defined as breathing cessation that lasts for more than 20 seconds or as a briefer episode if associated with bradycardia or pallor or cyanosis. In the field of neonatology, apnea is often not routinely differentiated into central or mixed or obstructive apnea. The use of polysomnography (PSG) with simultaneous assessment of multiple relevant variables would help differentiate the types of apnea. This differentiation might well be important for shedding clues as to the underlying etiologies and prescription of proper treatments, e.g., caffeine for significant central apnea and continuous positive airway pressure for significant obstructive apnea. Obstructive sleep apnea was found in 58% of infants referred to a single center for apparently life-threatening events (ALTEs), and a population-based case-control study found that nieces/nephews of patients with obstructive sleep apnea syndrome (OSAS) were twice as likely as controls to have offspring who died of sudden infant death syndrome (SIDS). However, an extensive review was published to address questions about SIDS and its possible relationship with OSAS and found no strong evidence. Hence, the relationship between ALTEs or SIDS and OSAS remains controversial. To cast light on this controversy, sleep PSG appears to be a useful tool. However, the use of PSG in detecting sleep-related apneas in infants remains difficult because of the different definitions of apneas used in different studies, which has resulted in the current lack of widely accepted normal values for different parameters recorded in PSG of infants.

In the current review, we analyzed the available data in the literature on infant sleep PSG parameters in healthy infants. The primary objectives were (1) to provide information about the available normal data on infant sleep PSG for clinical use and (2) to review the technical specifications for infant PSG.

2. Methods

2.1. Sources

The following bibliographic databases were searched: MEDLINE (Ovid), EMBASE (Ovid), and CINAHL (Ovid), limited to studies conducted from January 1976 to May 2007. The keywords used for search included neonate, infant, PSG, normal, control, healthy, and apnea. The search strategy is available on request. The search was conducted in May 2007. Standard textbooks in this area were also hand-searched for additional data.

Bibliographies of review articles, systematic reviews, and retrieved articles were also searched for candidate articles. Non-English candidate articles were translated by a web-based translation engine (Systran, http://www.systransoft.com/index.html).

2.2. Study selection

Case-control, cohort, and epidemiological studies were retrieved for analysis. Case reports and letters to editors were not retrieved for analysis. For multiple publications of the same material, only one article was chosen. Two reviewers (CCH and DKN) independently reviewed all pertinent articles, using preset inclusion criteria. Discrepancies were resolved by consensus. Reviewers were not blinded to the source of publication or articles at any step during study selection.

2.3. Inclusion criteria

The population of interest included children aged less than 1 year. Studies in infants with known major anomalies (e.g., Down syndrome) were excluded. In this review, normal infants included those who were born at term after a normal gestation, were not suffering from SIDS or ALTEs, and have no family history of sleep apnea, SIDS, or ALTEs. PSG or pulse oximetry was performed in all infants. The methods of measurement and the number of polysomnographic parameters in all included studies were listed. Other confounding factors—i.e., gender of infants, age of infants, sources of recruitment, and nationalities—were also listed for each included study.

3. Results

A total of 147 articles met our initial search criteria. Ten met our primary inclusion criteria. The characteristics of the included studies are listed in Table 1.

3.1. The configuration of infant PSG

Various signals were recorded to monitor a wide range of electrophysiological functions in infants during sleep. Most studies used similar configurations to perform infant PSG (Table 2). Electroencephalogram (EEG), electrocardiogram (ECG), electro-oculogram (EOG), thoracic and abdominal efforts, and oronasal thermistor were used by Kahn, Schluter et al, Franco et al, Rebuffat et al, Kato et al, and Guilleminault et al. Submental and leg electromyogram (EMG) was used by Schluter et al, Franco et al, Guilleminault et al. Either transcutaneous oxygen monitor or pulse oximeter was used to measure oxygen saturation. Kahn and Schluter et al recorded both transcutaneous oxygen tension and pulse oximetry. Actigraph was recorded by Kato et al, Kahn, Rebuffat et al, and Franco et al to detect infant gross body movement. In the study by Schluter et al, video recording was added.

3.2. Definition of apneas

Contrary to the commonly used definition of apnea in neonatology, apnea was generally defined to last ≥3 seconds (Table 3). Obstructive apnea was defined as a continuous activity from a strain gauge that detects respiratory efforts and flat tracing from thermistors, i.e., no air movement. Central apnea was defined as flat tracings...
obtained simultaneously from strain gauges and thermistors. Mixed apnea was defined as central apneas followed by an obstructive apnea. The study by Guilleminault et al. defined central apnea as apnea longer than 4 seconds. Kahn also stated that obstructive events due to displacement of the thermistors, any doubtful episodes, such as obstructed breathing preceded by a movement or a sigh, were rejected.

3.3. Age-related changes in the normal values of apnea index

The studies conducted by Kato et al., Schluter et al., and Kahn evaluated the age-related changes in normal values of polysomnographic variables in infants. All studies reported the normative data on obstructive apnea index (OAI) and mixed apnea index (MAI). However, the study by Kato et al. did not provide the complete data for central apnea. Downward trends with increasing age were noted in the 90th percentile and 75th percentile curve of obstructive apnea and mixed apnea. Both obstructive apnea and mixed apnea indices were highest in the neonatal period. The duration of obstructive and mixed apneas also tended to decrease with age. The frequency of central apnea decreases with age, but the duration was steady at around 3–5 seconds across all age groups.

3.4. Normal values of obstructive apnea

In the study by Schluter et al., the median value of OAI was zero in all age groups. In the study by Kato et al., however, the median OAI was 0.15 per hour for 2-week-old infants and dropped to zero by the time they are 8 weeks old. For the upper limit of OAI, both studies by Schluter et al. and Kato et al. showed a similar decreasing trend as the infants got older. The 90th percentile of OAI was 0.65 to 0.78 per hour from 2 weeks onward, and decreased to a level of 0.25 to 0.48 per hour by 2–3 months of age. Another study by Kahn presented the age-specific rates of obstructive apnea and mixed apnea per hour of total sleep up to 27 weeks. The median values of OAI were zero across all age groups. However, the upper limit (90th percentile) was not provided in Kahn’s study. It confirmed the previous observation that pure obstructive apnea was rarely seen in infants.
Table 2  Configuration of PSG.

<table>
<thead>
<tr>
<th>First author, year</th>
<th>EEG, EOG, EMG, thoracic and abdominal breathing movements by plethysmography, oronasal airflow (method of measurement was not mentioned), transcutaneous blood gases, oxygen desaturation as measured by pulse oximeter and ECG.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schluter, 2001*</td>
<td>Different configurations were used during the study period, with following channels: 6 EEG channels, thoracic and abdominal breathing movements by plethysmography, oronasal airflow (method of measurement was not mentioned), transcutaneous blood gases, oxygen desaturation as measured by pulse oximeter and ECG.</td>
</tr>
<tr>
<td>Kato, 2000</td>
<td>Two EEG with central and occipital leads (C4/A1 and C3/A2), two EOG and ECG. Thoracic respiratory movements were measured by impedance and airflow with thermistors taped under both nostrils and on the side of the mouth. Oxygen saturation was recorded continuously by a transcutaneous sensor (Nellcor, USA). Gross body movements were measured using an actigram placed on one arm. The data were collected on a computerized infant sleep recorder (Alice Recording System III, Healthdyne, USA).</td>
</tr>
<tr>
<td>Guilleminault, 1981</td>
<td>EEG (C3/A2-C4/A1), EOG, Digastric EMG, ECG lead, Holter ECG, abdominal and thoracic strain gauges, nasal and oral thermistors, nasal catheter for measurement of percent of CO₂ in expired gases, ear oximeter, skin surface oxygen electrode to measure oxygen tension.</td>
</tr>
<tr>
<td>Franco, 2000</td>
<td>2 EEG channels, 2 EOG, Digastric EMG, Thoracic respiratory movements were measured by impedance and airflow with thermistors taped under both nostrils and on the side of the mouth. Gross body movements were measured using an actigram placed on one arm. Oxygen saturation was recorded continuously by a transcutaneous sensor. The data were collected on a computerized infant sleep recorder (Morpheus System, Medatec, Brussels, Belgium).</td>
</tr>
<tr>
<td>Rebuffat, 1994</td>
<td>EEG, EOG, ECG, Thoracic respiratory movements were measured by impedance and airflow with thermistors taped under both nostrils and on the side of the mouth. Gross body movements were measured using an actigram placed on one arm. Oxygen saturation was recorded continuously by a transcutaneous sensor. Motion artifacts were detected from body movements and the analysis of the oximeter waveform. The data were collected on standard polygraph records (paper speed 10 mm/s) or on computerized systems (Alice III, Apresco, Belgium).</td>
</tr>
<tr>
<td>Kahn, 2000</td>
<td>EEG, EOG, ECG, thoracic respiratory movements were measured by impedance and airflow with thermistors taped under both nostrils and on the side of the mouth. Gross body movements were measured using an actigram placed on one arm. Oxygen saturation was recorded continuously by a transcutaneous sensor. Motion artifacts were detected from body movements and the analysis of the oximeter waveform. The data were collected on standard polygraph records (paper speed 10 mm/s) or on computerized systems.</td>
</tr>
</tbody>
</table>

Table 3  Definition of apnea in studies.

<table>
<thead>
<tr>
<th>First author, year</th>
<th>Apnea</th>
<th>OA</th>
<th>CA</th>
<th>MA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schluter, 2001*</td>
<td>≥3 s</td>
<td>Cessation of oronasal airflow with ongoing respiratory efforts</td>
<td>Cessation of respiratory efforts</td>
<td>Not clear</td>
</tr>
<tr>
<td>Kato, 2000</td>
<td>≥3 s</td>
<td>Continuous deflections from strain gauges and flat tracing from thermistors</td>
<td>Flat tracings from both the strain gauges and the thermistors</td>
<td>Central apneas followed by an obstructive apnea</td>
</tr>
<tr>
<td>Guilleminault, 1981</td>
<td>Classified into 3–6 s, 6–10 s, 10–15 s, ≥15 s</td>
<td>Continuous deflections from strain gauges and flat tracing from thermistors</td>
<td>Flat tracings from both the strain gauges and the thermistors</td>
<td>Central apnea followed by an obstructive apnea</td>
</tr>
<tr>
<td>Franco, 2000</td>
<td>≥3 s</td>
<td>Continuous deflections from strain gauges and flat tracing from thermistors</td>
<td>Flat tracings were obtained simultaneously from strain gauges and thermistors</td>
<td>Central apneas followed by an obstructive apnea</td>
</tr>
<tr>
<td>Rebuffat, 1994</td>
<td>≥3 s</td>
<td>Continuous deflections from strain gauges and flat tracing from thermistors</td>
<td>Flat tracings were obtained simultaneously from strain gauges and thermistors</td>
<td>Central apneas followed by an obstructive apnea</td>
</tr>
<tr>
<td>Kahn, 2000</td>
<td>≥3 s for OA and MA, ≥4 for CA</td>
<td>Continuous deflections from strain gauges and flat tracing from thermistors</td>
<td>Flat tracings were obtained simultaneously from strain gauges and thermistors</td>
<td>Central apneas followed by an obstructive apnea</td>
</tr>
</tbody>
</table>

CA = central apnea; MA = mixed apnea; OA = obstructive apnea.

* Different setups of PSG were used during the study period.
3.5. Normal values of mixed apnea

For mixed apnea, the median value of MAI approached zero across all age ranges in infants studied by Kato et al. Four studies by Stebbens et al., O’Brien et al., and Poets et al. reported the median baseline pulse oximetry (SpO2) and desaturation (defined as SpO2 less than 80%) of infants using pulse oximetry in the beat-to-beat mode. The gestational age of infants was at least 37 weeks, and their median age ranged from 1 hour to 191 days of life. The median SpO2 ranged from 97.6% (92–100%) to 98.3% (88.7–100%) during the 1st month of life. From 5 weeks to 6 months, the SpO2 ranged from 99.6% (97.9–100%) to 99.9% (98.6–100%). The median rate of desaturation was 0 per hour (range: 0–14.7) at 1 hour of life. On day 4 of life, the median rate of desaturation was also zero (range: 0–41 per hour). The median rate of desaturation was 0.9 per hour (range: 0–15.1) for infants on day 39 of life. Only one study reported the median duration of desaturation with and without apnea separately. The median duration of desaturation without concomitant apnea at 1 hour of life was 9.3 seconds (0.5–286.8 seconds), and that with apnea was 0.8 seconds (0.3–89.6 seconds). The median duration of desaturation decreased from 5.1 seconds (4.2–9.9 seconds) at 4 days of life to 0.9 seconds (0.4–1.8 seconds) at 3 months of age. Forty-eight percent of desaturation was associated with concomitant apnea at 1 hour of life. Desaturation episodes were more often associated with apnea with increasing age, and the proportion of desaturation episodes associated with apnea increased from 48% at 1 hour of life to 93.8% at 6 months of age.

4. Discussion

In neonatology, apnea is often defined as cessation of breathing lasting more than 20 seconds. However, the normal value for apnea so defined is not available. Furthermore, recent evidence suggested that obstruction of the airway was frequently present in the so-called central apneas defined as longer than 20 seconds. Recent evidence suggested that obstruction of the airway was frequently present in the so-called central apneas defined as longer than 20 seconds. It was clear from current data that the upper limit of normal values was less than 1.0 per hour, and those with mixed apnea >1.0 per hour were suggestive of a disease that warrants investigations for the site(s) of obstruction. Data are currently lacking in the natural course of these obstructive apneas, and further research is urgently needed.

For mixed apnea, the current data suggested that the upper limit of normal values was less than 1.0 per hour, and those with mixed apnea >1.0 per hour were suggestive of a disease state warranting further investigations along the line of obstructive apnea.
episodes for day 4, and 15.1 episodes for day 39. It is important to realize that the current data were obtained from pulse oximeter using a beat-to-beat mode, whereas most commercial pulse oximeters used averaging of data. Hence, the normal values that are reported may not be directly applicable to patients monitored with a different mode. Another important parameter about desaturation would be the percentage of time spent in each saturation zone (e.g., SpO\textsubscript{2} >90%, between 80% and 90%). Unfortunately, there are currently no normal data on this very important parameter.

In conclusion, this review summarizes the available information on the normal values of sleep PSG data of normal full-term infants for use by clinicians. With these normal values, sleep PSG study should be routinely used to quantify the severity of breathing disorders during sleep in those neonates at risk for these disorders. The normal oximetry values warrant further research as the current data addresses only the number of episodes of SpO\textsubscript{2} less than 80% for any length of time. This addresses neither the length of episode nor the normal value of percentage of time spent in SpO\textsubscript{2} between 80% and 90%.

References