Occurrence and Mechanisms of Sudden Oxygen Desaturation in Infants Who Sleep Face Down

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ABSTRACT. Objective. Infants who sleep prone and face down on soft bedding are particularly vulnerable for sudden infant death syndrome. It has been suggested that 1 mechanism of death in this situation involves rebreathing of expired air. Many infants tolerate rebreathing while lying prone face down for long periods with stable saturations. Others occasionally have rapid desaturations and may require intervention to terminate rebreathing. The present study had 3 objectives: 1) to determine the frequency of rapid desaturations in a large group of healthy infants, 2) to elucidate the mechanism of these desaturations, and 3) to determine the timing of these events during periods of rebreathing.

Methods. We studied respiratory tracings and videotapes of 56 healthy 1- to 6-month-old infants who were sleeping face down and rebreathing on soft bedding in our laboratory. We compared the frequency of desaturations during rebreathing and nonrebreathing periods. We measured respiratory frequency and apnea occurrence before desaturation and nonrebreathing control episodes. We also measured minute ventilation during steady state before desaturation and just before desaturation.

Results. There were 25 desaturation episodes in infants while rebreathing, occurring in 11 (19.6%) of the 56 infants. Episodes were significantly more frequent during rebreathing than during nonrebreathing periods. Three desaturation episodes reached <85%; 2 required intervention to terminate rebreathing. The respiratory frequency was not different between nonrebreathing control and desaturation episodes. Brief apneas were significantly more frequent preceding desaturation than control episodes (44% vs 4%). Just before episodes, there was a transient decrease in minute volume despite increasing inspired carbon dioxide in 3 episodes. There was evidence of partial or complete pharyngeal airway obstruction in 3 episodes. Thirty-six percent of all episodes were immediately preceded by behavioral arousal.

Conclusions. Rebreathing in prone sleeping infants is associated with an increased frequency of episodic desaturations. Desaturation may result from respiratory pattern changes such as brief apneas often associated with evidence of behavioral arousal or failure to increase ventilation in the face of rising inspired carbon dioxide, also associated with behavioral arousal. Pediatrics 2003;111:e328–e332. URL: http://www.pediatrics.org/cgi/content/full/111/4/e328; SIDS, desaturation, prone.

ABBREVIATIONS. SIDS, sudden infant death syndrome; CNS, central nervous system; CO₂, carbon dioxide; O₂, oxygen; ECG, electrocardiogram; Vt, tidal volume; SAT, saturation.

Sudden infant death syndrome (SIDS) is the third leading cause of death in infants after congenital anomalies and prematurity or low birth weight.1 Prone sleep is a known risk factor for SIDS, and face-down prone sleep increases this risk further.2 Despite the American Academy of Pediatrics’ recommendation of supine sleep position for infants,3 20% of infants in the United States continue to be placed prone for sleep.4 Although the majority of rebreathing infants reach steady state with regard to ventilation and oxygenation, even with documented airway obstruction,5 a few infants have been noted to rapidly desaturate, occasionally requiring rescue.6,7 It has also been shown that infants usually arouse in response to hypercarbia, such as in a rebreathing environment.8 We sought to determine the frequency of failure to arouse and escape from the face-down position during periods of rapid desaturation in a large group of healthy infants. Because the mechanism of sudden desaturation while rebreathing is unclear, this was also studied. Desaturation may be associated with changes in respiratory pattern or airway obstruction, but there has been no documentation of this. Desaturation in a rebreathing environment is of special concern because central nervous system (CNS) depression occurs at saturations <50%, and this could prevent the infant’s escape from the asphyxiating environment.9

Anecdotal accounts of infants dying while face down indicate that death may occur relatively rapidly. In contrast, animal models of rebreathing indicate that death occurs after a longer period of time.10 Therefore, we sought to establish the onset of rapid desaturation after assuming the face-down position, as this could be the immediate precursor to death.

METHODS

Participants

We studied 56 healthy infants from the St Louis community (mean age: 103 days; range: 40–180), all of whom were healthy at the time of the study. Four of these were premature and were studied at a mean post conceptional age of 339 days (range: 292–377); 2 additional infant’s sibling had died of SIDS. The remaining infants had no history of significant medical problems. Of the 56, 11 (6 boys, 5 girls) experienced significant episodes of desaturations during the study (mean age at study: 73 days; range: 19–120). These infants formed the primary group for study of desaturations. The study was approved by the Washington Uni-
desaturations in which movement artifact was detected by insta-

breath carbon dioxide (CO₂) was measured via an 8F Silastic

catheter with 2 small holes that was attached to the upper lip,

to measure relative changes in nasal airflow. The flow signal was integrated to
give relative tidal volume. The infant’s heart rate electrocardio-
gram (ECG), respiratory rate (Respitrace), and oxygen (O₂) satu-
ration (Nellcor N-100C, Hayward, CA) were monitored. All out-
put data were continuously recorded on a polygraph (Beckman
R611). The infant and polygraph tracing were recorded with an infrared video camera (Videoconics, Campbell, CA) so as to allow
correlation between infant behaviors and physiologic recordings
on analysis at a later date. After the infant fell asleep, baseline data
were obtained. Approximately 10% of infants turned face down spontaneously. If not, then he or she was turned prone and the
head was positioned face down. Rebreathing was detected by an
elevation in the inspired CO₂ level

Rebreathing

Desaturation episodes were classified as occurring during re-
breathing periods (inspired CO₂ ≥1%) or during nonrebreathing
periods (inspired CO₂ undetectable). We calculated the duration
(in minutes) of rebreathing and nonrebreathing periods for each
infant. We then calculated for each infant the frequency of desatu-
ration episodes per rebreathing and nonrebreathing periods. The
timing of onset of desaturations after the infants assumed a face
down position was noted.

Respiratory Parameters: Rebreathing Desaturation
Episodes Versus Nonrebreathing Control

The number of desaturations was determined for each infant
during control and rebreathing periods. We then randomly se-
lected nonrebreathing control periods with no desaturations for
each infant by a random sampling procedure based on that de-
scribed by Huntsberger and Leaverton.15 Each page of the tracings
represented 30-second epochs of the study. We used a random-
number generator to select a page (www.randomizer.org). If the
selected page met control criteria, then we selected that page. If
not, then another number was drawn until a nonrebreathing page
without desaturation was selected. The beginning of the page was
used as the control period. This entire method was repeated for
desaturation for each infant using this method. We estab-
ished 25 controls, 1 for each desaturation. We also evaluated the
respiratory pattern 10 seconds before the onset of the desaturation
and control periods, comparing respiratory frequency and occurence
of brief apneas (Fig 1A).

Change in Minute Ventilation During Rebreathing
Before and Immediately Before Desaturation Episodes

We calculated the relative change in minute ventilation by
measuring respiratory frequency and tidal volume (V̇) by the
height of the integrated flow signal or the height of the Respirat-
ance signal during 2 time periods: 1) the 8 seconds before the onset of
the desaturation through to the desaturation nadir (to account
for the 5- to 7-second averaging time of the pulse oximeter) and 2) the
previous 8 seconds to the aforementioned time period if the
infant’s saturations were stable at that point (Fig 1B). If the satu-

Fig 1. Methods used in analysis of behaviors and respiratory parameters. A. Respiratory pattern was evaluated 10 seconds before desaturation onset in both desaturation and control periods, B. Average minute ventilation was calculated during the 8 seconds before onset through to desaturation nadir. This was compared with average minute ventilation during the preceding 8 seconds. These time periods were selected to take into account the 5- to 7-second averaging time of the pulse oximeter.
rations were not stable, then we evaluated 8-second intervals sequentially preceding the interval until a stable time period was found. Both measures of $V_T$ were used in the infants, but the same measure was used for each desaturation and preceding interval to allow for a measure of relative change in minute ventilation. Average minute ventilation was calculated by averaging $V_T$ over the number of breaths counted multiplied by the frequency. This procedure was done in 17 of 25 desaturations in which $V_T$ could be calculated for both time periods by the same method. In addition, we measured average end-inspiration CO$_2$ during both time periods.

**Caused of Desaturation**

We reviewed the polygraph tracings and videotapes of the infants to evaluate for a correlation in ventilatory patterns or behavioral features 10 seconds before the onset of desaturation. Arousal was defined as evidence of vocalization and/or body movements.

**Data Analysis**

Statistical analyses were performed using the Wilcoxon rank test and the paired Student $t$ test. Results are reported as mean ± standard error of the mean. Results were considered significant at $P < .05$.

**RESULTS**

**Desaturation Occurrence and Timing During Rebreathing**

Eleven (19.6%) of the 56 infants we studied experienced 25 episodes of desaturations with a mean of 2.3 spells per infant (range: 1–7; Fig 2). Spells did not occur in the SIDS siblings or any of the preterm infants. There was no apparent correlation of gender or age of the infant and occurrence of spells. Desaturations occurred more frequently during rebreathing than during nonrebreathing periods (0.07 ± 0.02 vs 0 episodes/min, rebreathing and nonrebreathing, respectively; $P < .01$). Eight desaturation episodes reached ≥90%. Three additional desaturations occurring in 3 infants reached ≥85%. Onset of desaturation was variable but often occurred within as short a time as 1 to 3 minutes after infants assumed the face-down position.

**Respiratory Parameters: Rebreathing Desaturation Episodes Versus Nonbreathing Control**

Respiratory frequency was not significantly different during the 10 seconds before desaturation than nonrebreathing control periods (40.3 ± 2.3 vs 45.4 ± 3.7, desaturation and control, respectively; $P > .05$). Brief apneas occurred more frequently before desaturations than nonrebreathing control periods (72 ± 20% vs 4 ± 4%, desaturation and control, respectively; $P < .01$). The mean apnea duration was 2.98 seconds (range: 1.0–12.2 seconds).

**Change in Minute Ventilation During Rebreathing Before and Immediately Before Desaturation Episodes**

The average change in minute ventilation across the 17 desaturation episodes that could be accurately evaluated was a decrease from 466.5 ± 79.3 to 429.7 ± 48.4 (arbitrary units mm/min; $P = .56$). In 9 of theses 17 episodes, minute ventilation decreased by an average of 33.5%. In 8 of these episodes, the decrease in ventilation was associated with brief apnea.

**Cause of Desaturation**

Eleven of the 25 desaturation episodes were preceded by 1 or more short apneas. These were all central apneas with the exception of 1 in which there were clear indications of completely obstructed respiratory efforts. Three of these apneic episodes were associated with grunting or crying. One episode was associated with a transient decrease in minute ventilation without accompanying apnea. This was attributable to a decrease in $V_T$. An additional 3 episodes were associated with a failure to increase minute ventilation despite rising inspired CO$_2$. Five desaturation events were preceded by a spontaneous shift in head position, which increased airway contact with the bedding during the 10 seconds before desaturation. Snorting or snoring sounds, suggesting
upper airway obstruction, preceded 2 episodes in 2 infants in 1 of whom this was associated with evidence of arousal of sleep (Fig 3).

Most episodes of desaturation resolved when the infant turned and/or lifted his or her head. However, 2 infants had 1 episode each of desaturations <85% while rebreathing. Most spells that we observed were brief central apneas. In 9 episodes, a decrease in minute ventilation was noted, which coexists with hypercarbia in a rebreathing setting. Increased minute ventilation increases 3-fold in infants in similar rebreathing environments. Others have shown in experimental settings that minute ventilation increases by a factor of 1.25 to 2.75 with rising CO2 in a similar range to that observed in our participants when rebreathing. Increasing minute ventilation is a primary mechanism for achieving a steady state during rebreathing. Because ventilation reaches maximum attainable levels during rebreathing, it would be difficult for the infant to recover from a transient decrease in respiratory rate or V̇E, producing desaturation without getting access to fresher air.

Most infants demonstrated an appropriate motor response after desaturation was present by either moving the head to the side or lifting it up. Two (8%)
of the infants studied had arousal responses that were ineffective in avoiding a potentially dangerous environment. One of these infants reassumed the face-down position during his arousal response, which led to an increase in inspired CO₂ and additional desaturation. Previous work by Lijowska et al has shown that the arousal response to an asphyxial environment may sometimes aggravate an already dangerous situation if the infant is ineffective at clearing the airway and/or turns the head further into the bedding. Thus, although arousal is believed to play an integral role in protecting infants from sudden death while sleeping, such as by head repositioning, the associated cardiopulmonary changes, such as altered respiratory patterns or apnea, may also precipitate hypoxemia in some infants.

**CONCLUSION**

Normally occurring respiratory patterns associated with normal infant behavior usually have little consequences for blood gas homeostasis. However, in a low-O₂ environment associated with the infant's face being covered by bedding, these same respiratory patterns may produce a rapid desaturation. When associated with arousal activity that is ineffective in gaining access to fresh air or failure to arouse, such desaturations can produce an immediate danger, potentially leading to death.

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