Consequences of Getting the Head Covered During Sleep in Infancy

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ABSTRACT. ***Objective.*** **To study the consequences of getting the head covered by bedding (fiber quilt) on carbon dioxide (CO_2) accumulation around the face, behavior, and physiologic responses during prone and supine sleep in infants to add understanding to why victims of sudden infant death syndrome are often found under the bedding.**

Methodology. **Of 33 healthy term, usually nonprone sleeping infants, behavior and computerized polysomnography were successfully recorded for 30 during prone and supine sleep at 2½ months and for 23 prone and 25 supine at 5 months.**

Results. **For both ages and body positions, covering the head resulted in significant CO_2 accumulation around the face, fewer apneas (3 to 10 seconds), shorter duration of apneas after sighs, higher heart and respiratory rates, and peripheral skin temperature. Differences were generally greater at 2½ than at 5 months. While covered, the prone position was associated with higher CO_2 levels close to the face, slightly higher transcutaneous P_{CO_2}, and higher heart rates and peripheral skin temperatures than the supine position. In the supine position 23% were able to remove the cover from the head at 2½ and 60% at 5 months, whereas only 1 infant of 5 months managed to remove the cover when prone.**

Conclusions. **The observed responses are consistent with a potential for distress when the head is covered, particularly when placed prone. Probably most important with respect to sudden infant death syndrome is the infants' inability to remove the bedding from the head upon awakening from prone sleep.** ***Pediatrics*** **1997;100(2). URL: http://www.pediatrics.org/cgi/content/full/100/2/e6;** ***behavior, CO_2 rebreathing, hyperthermia, SIDS, sleeping position.***

ABBREVIATIONS. SIDS, sudden infant death syndrome; CO_2, carbon dioxide; ALTE, apparent life-threatening event; REM, rapid eye movement; EEG, electroencephalogram; EOG, electrooculogram; EMG, electromyogram; ECG, electrocardiogram; P_{O_2}, partial pressure of oxygen; P_{CO_2}, partial pressure of carbon dioxide; O_2, oxygen.

In 1944, Abramson[1] discussed accidental mechanical suffocation as a cause of sudden death in infants sleeping prone, but the next year Wolley et al[2] rejected suffocation and rebreathing into the bedding as the sole mechanisms for sudden infant death. Recently, rebreathing has reappeared as a possible explanation for sudden infant death syndrome (SIDS).[3] Although the concentration of carbon dioxide (CO_2) in the atmosphere is .03% to .04%, the exhaled air of infants contains 4% to 5% CO_2,[4] and it has been speculated that under certain conditions, such as sleeping face down on soft bedding, extensive CO_2 accumulation around the infant's face may result in rebreathing, asphyxia, and suffocation.[3,5,6] The possibility of CO_2 rebreathing has mainly been studied in experimental in vitro and animal models,[3,5–10] whereas studies in infants are limited.[11–13]

We have previously shown that a significant number of SIDS victims are found with their head covered by bedding and usually in the prone position.[14] The purpose of the present investigation was to study the effect of getting the head covered by bedding on CO_2 accumulation around the face, behavior, and physiologic responses in sleeping infants, and to compare outcome measures for the prone and supine sleeping positions.

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SUBJECTS AND METHODS

Subjects

Thirty-three infants (17 girls and 16 boys) were recruited for an overnight sleep study both at 2½ (mean, 74 days; range, 71 to 79 days) and 5 (mean, 152 days; range, 147 to 158 days) months of age. The ages were chosen to correspond with the age of highest risk for SIDS (2½ months) and a period of significantly lower risk (5 months) in Norway.[15] Only term infants (≥37-weeks-postconceptual age) without prenatal or perinatal complications were included. No infants with a history of family diseases, apparent life-threatening events (ALTE), or SIDS in siblings were allowed. Mean birth weight was 3631 g (range, 2870 g to 4840 g) and all were healthy at the time of study.

A questionnaire containing information on infant care practices, such as feeding, preferred sleeping position, sleep environment, weight gain, and psychomotor development in relation to the ability to move, was completed by the parents at the time of each study.

Informed written consent was obtained from the parents of all the infants, and the study was approved by the Regional Committee on Medical Research Ethics.

Study Conditions

The infants were admitted early in the evening for a 12-hour polysomnographic recording of sleep-related behavior. Their normal feeding schedule was followed during the evening, and they were further fed in the middle of the night before the sleeping position was changed. After the evening feed the room was darkened and the infants were placed to sleep in the supine position. The mother was allowed to stay with her infant until it fell asleep if this was the routine at home. The study conditions were identical at 2½ and 5 months of age.

The infants were studied in an infant bed (bars as side walls) with a firm foam rubber mattress (normal hospital cot mattress; polyurethane-30N, 9.5 cm thick) lined with a thin blanket. All were dressed in a diaper and two shirts, and covered with a duvet (polyester fiber quilt; 145 × 115 cm with a cotton quilt cover, total weight 1300 g; tog value 13).[16] The same fiber quilt and identical cotton quilt covers were used in all the studies. Duvets are the covers most commonly used in Norway, and both the fiber quilt and the cotton quilt covers used in the present study were similar to those used at home for infants at this age. A light clothing (2.5 tog)[16] was chosen to ease the nursing of the infant and the supervision of the sensors, and the room temperature was kept at 23°C (±.5°C) to obtain an environmental temperature close to the corresponding thermoneutral range.[17] The duvet covered the lower part of the body (up to midthorax).

The overnight sleep was divided into two equal periods of prone and supine sleep. The initial position was chosen at random using the sealed envelope method. Because most infants were usually placed supine to sleep, and none slept prone at home all were allowed to fall asleep while supine. During the first non-REM (quiet sleep) interval, one-half of the infants were turned to the prone position according to the randomization. All were moved to the opposite position midway through the study after being fed. The study of covering the infants' head in addition to the body with the duvet was performed once during each sleep period, and was started during the third sleep cycle after the last feed. Ten minutes after a change of sleep state into non-REM was documented, the duvet was gently draped over the infant's head.

Polysomnography

A computer-aided multichannel system with the operating CARDAS software (Computer Aided Record Display and Analysis Systems) and the Oxcams/Pi Logic IMS-2000 multi-channel monitor (Oxcams/Pi Logic Ltd., Dyfed, United Kingdom) were used for the polysomnographic recordings. For each infant the sleep variables recorded included two electroencephalograph derivations (C3-A2, C4-A1; EEG), two electrooculographic derivations (ROC/A1, LOC/A2; EOG), and one chin electromyogram (EMG). Continuously recorded physiologic parameters were: electrocardiogram (ECG, three leads placed on the upper part of the trunk), thoracic and abdominal respiratory movements (strain gauge, Sensorband, Mediplus AB, Malmø, Sweden), peripheral skin temperature (left foot, Skin Surface Temp xHH-10005-x, Ellab as, Denmark), oxygen saturation (right foot, oxygen trend curve, pulse rate, and pulse waveform, 50 Hz fast response mode, data average time 3 seconds, update interval .375 seconds, Ohmeda Biox-3700, Ohmeda Medical System Division, Louisville, CO), intermittent transcutaneous pressure of oxygen (Po_2) and CO_2 (Pco_2) (limited to the last 11 infants at 2½ months and the last 13 infants at 5 months of age, left or right side of abdomen depending on sleep position; Microgas 7640, Kontron Instruments Ltd, United Kingdom), body movements (pressure sensitive pad placed under the blanket on the mattress; Pad-HF, B8208, Pi Logic Ltd., Dyfed, United Kingdom), and sound (microphone in front of the face during prone and supine face to side position, on the neckband of the shirt in the supine face up position; Sound, B8202, Pi Logic Ltd., Dyfed, United Kingdom). Attempts to estimate core temperature were abandoned because a method for central skin temperature measurement (Thermistor Zeal, Pi Logic Ltd., Dyfed, United Kingdom) did not correlate sufficiently with rectal temperature, and rectal monitoring was unsuccessful in a pilot project because it interfered with sleep behavior. It has been shown that peripheral skin and rectal temperatures change simultaneously, and that changes in skin temperature fluctuate less throughout the night than core temperature.[18] Furthermore, upon warming, peripheral vasodilatation and subsequent increases in peripheral body temperature occur to promote heat loss.[19] We therefore found it acceptable to record peripheral skin temperature alone to fulfill the purpose of this study. Attempts to measure air flow by thermistors were abandoned mainly because sleep behavior was disturbed, especially in the prone position, but also because of low sensor sensitivity in the younger infants (EdenTech infant airflow sensor, EdenTech Corp, Eden Prairie, MN).

CO_2 Measurement

The CO_2 accumulation around the infant's face was measured intermittently with a CO_2 gas analyzer (infrared, real time monitor, accuracy of CO_2 measurement .1%, sampling period 60 seconds, Binos 11/GAV 100, Leybold-Haraeus AG, West Germany). The flow of gas through the analyzer necessary for measurement was 100 mL/min. The gas analyzer was calibrated with standard gases before each measurement. To keep the gas volume around the baby's head as constant as possible, the gas volume used for CO_2 analysis was recirculated by a pump (peristaltic pump; Millipore model 80 002 30; Millipore Corp, Bedford, MA). A special quality tube with low oxygen permeability (Norprene food grade A-60F, 3.1 mm inside diameter; Cole Parmer) was used to connect the different parts of the system. The two openings of the tube were placed 3 and 4 cm in front of and 3 cm cranial to the nostrils when the head was in the face to the side position. If the infant accepted the test situation under the duvet, the CO_2 concentration was measured 1, 5, 15, 30, 45, and 60 minutes after covering of the head. The CO_2 concentration was also measured before the head was covered, and repeated after the duvet was removed.

Recorded Responses

Sleep states were defined according to the behavioral, EEG, EOG, and EMG criteria recommended by other investigators.[20–22] Each minute of the recording was coded as non-REM, REM (active), indeterminate sleep, or awakening. Non-REM sleep was defined as eyes closed with no eye movements, no body movements except occasional generalized startles, high voltage and slow-wave pattern or sleep spindles on EEG, resting muscle tone on EMG and decreased heart and respiratory rates. REM sleep was defined as visible eye movements under the eye lids independent of facial or gross body movements, frequent small movements of head, face, and limbs, low voltage and fast desynchronized pattern on EEG, muscle atonia on EMG, and rapid and irregular heart and respiratory rates. Periods of sleep not meeting these criteria were classified as indeterminate sleep, and periods with open eyes, body movements and vocalization were classified as awake. When the head was covered, eye movements were interpreted on the basis of EOG. Only technically unblemished data were used for the analyses of physiologic responses, ie, if arousals or artefact time exceeded 15 seconds the sequence was excluded from the analysis as were intervals of sleep in which the heart rate from the ECG tracing differed with more than an average of 3 beats/min from the pulse rate recorded by the pulse oximeter. Behavior was charted separately, but plotted along with the polysomnography.

Behavioral and physiologic parameters before the head was covered refer to the mean values obtained from periods of non-REM and REM sleep of similar length as after covering the head for both prone and supine sleep.

As all parameters were continuously stored on a hard disk either as trend curves or as digitalized signals, the values of physiologic parameters corresponding to the CO_2 measurements in the air close to the face were available. Each parameter was determined as the mean of the last 10 seconds of recording before each CO_2 measurement. If the quality of the recorded signals were unsatisfactory, the mean value of the 10-second interval closest to, but within 20 seconds of the CO_2 measurements, was chosen.

A movement of the head or extremities was defined by artefacts in a limited number of channels and an increase in the amplitude of the activity-channel whereas arousals caused artefacts in most channels. Arousals were further subdivided into short arousals, ie, body movements lasting between 3 and 15 seconds without changes in EEG, and longer arousals lasting longer than 15 seconds, often associated with changes in EEG and subsequent awakening. A sigh was defined as an isolated and sudden change in the amplitude of either the thoracic or abdominal respiratory channel.

The duration of an apnea was measured from the end of inspiration in the last breath before to the end of inspiration in the first breath after the apnea. Apneas lasting 3 seconds or longer were recorded and further divided into 3 through 10, and 11 seconds and longer. Periodic breathing was defined as the succession of more than two apneas longer than 3 seconds separated from each other by less than 20 seconds of breathing movements.

The ECG was stored continuously both as single heart beats and as a trend curve. The heart rate could therefore be counted manually despite artefacts from arousals and body movements. Respiratory rate was determined from the thoracic and/or abdominal amplitude in the polysomnography.

Transcutaneous Pco_2 and Po_2 were measured intermittently throughout the night to prevent skin damage (electrode temperature +44°C). The sensor was applied to the skin during non-REM sleep in the second sleep cycle. The Microgas was calibrated with standard gases and adjusted to the actual atmospheric pressure before each application. Transcutaneous Pco_2 and Po_2 before covering were determined as the mean of at least 3 minutes of technically appropriate recordings.

As the signals of the pulse oximeter are very sensitive to body movements, it was often difficult to interpret the oxygen saturation during and immediately after arousals and body movements. Only intervals with distinct pulse waves were used for further analysis.

The cover was removed from the head if awakening with continuous head and body movements beyond 60 seconds occurred, if the infant managed to remove the duvet from the head, or after a maximum of 60 minutes under the duvet. The cover was also removed if a permanent increase in heart rate beyond 20% and/or respiratory rate beyond 40% of pretest values occurred, if the oxygen saturation dropped to 90% or less, or if peripheral skin temperature increased beyond 38°C.

The data were analyzed with SPSS for MS windows release 6. The paired *t* test and the Wilcoxon signed rank test for dependent samples were used for statistical analyses where appropriate. Analysis of differences in response between supine and prone sleep (paired *t* test) was limited to those who accepted both sleeping positions at each particular age. Analysis of variation with age (paired *t* test) was limited to infants who accepted each particular position after being covered at 2½ and 5 months. Before analysis of differences between mean number of events during non-REM and REM sleep before and after covering the head (sleep behavior), the number (n) was adjusted to a rate of events per 20 minutes.

RESULTS

Of the 33 infants enrolled in the study 30 were successfully tested in both the prone and supine sleeping positions at 2½ months. At 5 months, 26 infants were tested; 22 in both positions, one only in the prone, and 3 only in the supine position. One infant was excluded at 2½ months attributable to maternal illness, and one at 5 months attributable to possible seizures. Three infants were excluded from the analysis attributable to technical problems with the CO_2 gas analyzer (one infant at 2½ and two infants at 5 months). The others were not tested because they were withdrawn from the study by the parents (two infants at 5 months) or because they woke up immediately when the head was covered in either or both sleeping positions (one infant at 2½ and six at 5 months).

The characteristics of the infants tested are listed in Table 1, and did not differ from those who were not tested. The mean weight was at the 50th percentile for Norwegian infants. Supine was the dominating sleeping position and none slept prone, but all infants were regularly put in the prone position when awake. They were regularly covered with a duvet (fiber quilt) and none used a pillow during sleep.

CO_2 Accumulation

The CO_2 concentration close to the infants' face never exceeded .1% before the head was covered or after removal of the duvet. There was a significant CO_2 accumulation around the face under the duvet at 2½ and 5 months of age, and although there was a considerable overlap between body positions, the maximum median CO_2 concentration was significantly higher in the prone than in the supine position at both ages (Fig 1). The time to attain maximum CO_2 concentration did not differ significantly for the prone and supine positions at 2½ (12.5 min ± 12.6 min vs 12.6 min ± 16.0 min; $P = 1.0$) and 5 months (9.0 min ± 10.9 min vs 6.9 min ± 7.1 min; $P = .3$). There was no significant difference in median CO_2 concentration in either position with increasing age. At 2½ months, the highest CO_2 concentration was recorded during non-REM sleep in the majority of prone (87%) and supine infants (60%). At 5 months there were no significant differences according to sleep state (76%, both positions).

Subsequent to body movements or arousals during sleep, the duvet was regularly lifted from the mattress. When such movements of the duvet coincided with CO_2 measurements, a sudden drop in CO_2 was observed. Visible temporary or permanent air channels were commonly created after such movements and resulted in low and stable CO_2 levels throughout the rest of the study.

Sleep Behavior

Indeterminate sleep represented less than 2% of total sleep under the duvet, and was excluded from

TABLE 1. Characteristics of the Infants Tested at 2½ and 5 Months of Age

	2½ Months (n = 30)	5 Months (n = 26)
Gender, female/male	15/15	14/12
Breastfeeding	24 (80%)	19 (73%)
Weight in g (mean ± 1 SD)	5821 ± 696	7468 ± 831
Sleeping in bed with parents	0	1
Supine preferred position	23	26
Side or supine preferred position	3	0
Side preferred position	4	0

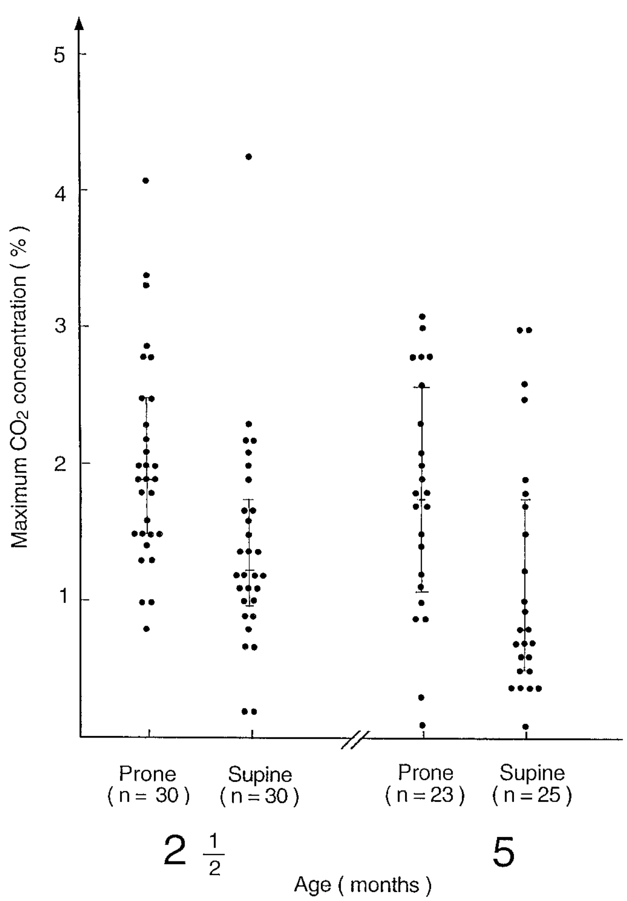

Fig 1. Maximum CO_2 concentrations registered during prone and supine sleep while the head was covered. Individual, median, and 25th and 75th quartiles are plotted.

the analysis. The mean time tolerated under the duvet varied from 19 to 33 minutes depending on age and body position (range, 68 seconds to 60 min). For both positions and for either or both non-REM or REM sleep, covering the head at 2½ months resulted in more frequent body movements, significantly shorter duration of apneas after sighs, and fewer apneas (3 to 10 seconds) (Table 2). In the supine position covering was also associated with more frequent short arousals and isolated sighs, and fewer sighs with apneas, and episodes of periodic breathing (Table 2). At 2½ months covering the head did not cause changes in number of short arousals or apneas during non-REM sleep, or in number of body movements or apneas exceeding 10 seconds during REM sleep. Comparing prone and supine while covered at 2½ months, the infants spent relatively more time in REM sleep ($P = .04$), and had later arousals ($P = .05$) and change of sleep state ($P = .001$) when prone. For both positions at 5 months covering resulted in fewer apneas (3 to 10 seconds) and shorter duration of apneas after sighs (Table 2). Sleep behavior did not differ with position after covering at 5 months.

Independent of body position and age, spontaneous awakening terminated the test in most infants (22 of 30 prone and 23 of 30 supine infants at 2½ months, and 20 of 23 prone and 22 of 25 supine infants at 5 months). In the supine position 7 (23%) infants at 2½ months and 15 (60%) at 5 months managed to remove the duvet from the face by using all four extremities. In the prone position one (4%) infant at 5 months managed to remove the cover by moving the head up and down. The rate of removal was significantly higher for the supine position at both ages ($P < .01$ and $P < .001$). For the infants who awoke spontaneously but did not remove the duvet, head and body movements continued until the cover was removed by the attendant. Although the majority of infants cried upon awakening under the duvet, the noise was markedly muffled by the cover. According to the criteria given in the study protocol, four tests were actively terminated during prone sleep at 2½ and one at 5 months attributable to increases in heart and respiratory rates, and a simultaneous drop in oxygen saturation and a rise in body temperature in one (89% and 38°C). No tests were terminated because of such responses in the supine position ($P = .07$ and $P = .3$) for 2½ and 5 months, respectively.

Physiologic Responses

Covering the head was associated with significant increases in heart and respiratory rates, and peripheral skin temperature in both body positions and at both ages except for heart rate at 5 months when sleeping supine (Table 3). There was a minor, but significant increase in transcutaneous P_{CO_2} after covering during prone sleep at both ages, and transcutaneous P_{O_2} was higher after covering in both positions at 2½ months (Table 3). Comparing prone and supine sleep when the head was covered, prone was associated with a higher mean heart rate at both ages, and a higher mean peripheral skin temperature and transcutaneous P_{O_2} at 2½ months, but there were no significant differences in transcutaneous P_{CO_2} or oxygen saturation (Table 3). With increasing age, heart and respiratory rates decreased significantly for both positions before and after covering, and peripheral skin temperature was significantly lower during prone sleep after covering at 5 months. There were no differences with age for other parameters. The skin on the trunk and face of all but four infants was warm upon touch when the cover was

TABLE 2. Comparison of Sleep Behavior Before and After Covering the Head With the Duvet During Prone and Supine Sleep

Sleep Parameter	2½ Months									
	Prone n = 30					Supine n = 30				
	No Cover	Cover	DBM	SE	*P*	No Cover	Cover	DBM	SE	*P*
Body movements, non-REM (n)	0.5	1.7	1.2	0.6	.05	0.4	1.7	1.3	0.4	.003
Short arousals, REM (n)	2.6	6.7	4.1	2.4	.1	3.9	7.3	3.4	1.4	.02
Sighs, non-REM (n)	1.0	2.0	1.0	0.6	.07	0.9	2.8	1.9	0.7	.01
Sighs with apnea, non-REM (n)	1.4	1.3	0.1	0.2	.8	2.1	1.1	1.0	0.2	<.001
Sighs with apnea, REM (n)	1.9	1.8	0.1	0.6	.8	3.4	1.5	1.9	0.6	.006
Post sigh apnea duration, non-REM (sec)	8.0	4.8	3.2	0.9	.01	10.5	4.8	5.7	1.0	<.001
Post sigh apnea duration, REM (sec)	5.7	2.6	3.1	0.9	.001	7.6	3.8	3.8	1.0	.01
Apneas 3 to 10 sec, REM (n)	12.0	6.3	5.7	2.1	.01	15.1	7.8	7.3	2.5	.007
Episodes of periodic breathing, non-REM (n)	0.2	0.1	0.1	0.1	.6	0.3	0.1	0.2	0.1	.007
Episodes of periodic breathing, REM (n)	0.4	0.2	0.2	0.2	.3	0.7	0.3	0.4	0.1	.004
	5 Months									
	Prone n = 23					Supine n = 25				
No Cover	Cover	DBM	SE	*P*	No Cover	Cover	DBM	SE	*P*	
Body movements, non-REM (n)	1.5	2.5	1.0	0.6	.1	0.8	2.3	1.5	0.6	.01
Sighs, non-REM (n)	1.2	2.6	1.4	0.7	.05	1.5	2.4	0.9	0.6	.1
Sighs with apnea, REM (n)	2.1	1.2	1.3	0.8	.3	3.3	1.3	2.0	0.9	.03
Post sigh apnea duration, non-REM (sec)	8.8	2.7	6.1	1.0	<.001	7.4	3.9	3.5	1.0	.003
Post sigh apnea duration, REM (sec)	5.7	1.3	4.4	3.4	<.001	7.0	2.4	4.6	1.0	<.001
Apneas 3 to 10 sec, REM (n)	15.9	6.3	9.6	3.4	.01	11.9	2.7	9.2	1.7	<.001

Abbreviations: n, mean number of events per 20 min; DBM, differences between means; SE, standard error of differences between means; *P*, level of significance for the uncovered vs the covered period.

TABLE 3. Physiological Parameters Before and After Covering the Head With the Duvet

	2½ Months											5 Months										
	Prone n = 30					Supine n = 30						Prone n = 23					Supine n = 25					
	No Cover	Cover	DBM	SE	P	No Cover	Cover	DBM	SE	P	P^1	No Cover	Cover	DBM	SE	P	No Cover	Cover	DBM	SE	P	P^1
Heart rate (beats/min)	125.7	131.1	5.4	1.7	.003	119.4	123.3	3.9	1.7	.03	<.001	117.2	124.4	7.1	1.6	<.001	113.7	116.1	2.4	1.4	.1	<.001
Respiratory rate (breaths/min)	28.3	36.3	8.0	1.3	<.001	27.6	34.9	7.3	1.6	<.001	.4	25.4	32.6	7.2	1.4	<.001	24.8	30.2	5.5	6.3	<.001	.2
Peripheral skin temperature (°C)	36.2	36.6	0.4	0.1	.001	36.0	36.4	0.4	0.1	.004	.01	36.1	36.4	0.3	0.1	.02	35.8	36.1	0.3	0.1	.05	.09
Transcutaneous Pco_2, (mm Hg)	40.3	41.1	0.8	0.3	.02	39.9	40.0	0.1	0.3	.7	.6	39.4	39.9	0.05	0.1	.007	37.7	37.8	0.1	0.2	.3	.3
Transcutaneous Po_2, (mm Hg)	65.3	68.4	3.1	0.9	.01	62.4	64.4	2.0	1.4	.3	.03	67.1	68.4	1.3	1.1	.2	65.4	65.8	0.6	0.9	.6	.3
Oxygen saturation (%)	99.2	99.5	0.4	0.1	.005	99.3	99.4	0.2	0.2	.2	.6	99.0	99.1	0.1	0.2	.5	99.0	99.4	0.4	0.2	.05	.3

Abbreviations: DBM, differences between means; SE, standard error of differences between means; *P*, level of significance before vs after covering; P^1, level of significance between prone and supine at maximum mean CO_2 while the head was covered.

removed from the head. In one half—and relatively more pronounced the longer the head was covered with the duvet—the skin was wet with additional flushing of the face whereas the limbs felt cool. Four infants were generally wet and cool, and eight were pale instead of flushed. These findings did not differ with position or age.

DISCUSSION

In the present study covering the head with bedding resulted in accumulation of CO_2 around the face, significantly less apneas, and shorter duration of apneas after sighs, higher heart and respiratory rates, and higher peripheral skin temperature at 2½ and 5 months of age. At 2½ months the infants also had more frequent body movements after being covered. While covered, the prone position was associated with higher CO_2 levels close to the face, higher heart rates, peripheral skin temperatures, and slightly higher transcutaneous Pco_2 than the supine position, and the infants were less able to remove the cover when prone.

The infants in the present study slept on a firm mattress with the face to the side, and the duvet (fiber quilt) used to cover the head is the cover in common use in Norway. The study condition of totally covering the head was chosen to mimic the circumstances in which SIDS victims are commonly found.[14] The observed CO_2 concentrations at the face while the head was covered were similar to those observed by Chiodini et al[11] in uncovered infants sleeping face down on soft bedding, but greater than the levels of .3 to 2.0% observed by Malcolm et al[12] in prone infants whose heads were covered with a baby blanket. The higher CO_2 levels in the present compared with the latter study probably reflect a higher resistance to transport of gases through the duvet than a blanket, and possibly a greater difficulty in creating air channels to the surrounding air attributable to the heavier weight of the duvet. The range of CO_2 accumulation measured around the face during the first 15 minutes of the study was comparable to the values obtained during the first 5 minutes in an experimental CO_2 rebreathing model.[10] Lack of further rise probably reflected the establishment of channels from spontaneous lifting of the duvet with subsequent exchange of air to the surroundings. Hypercapnia is known to be a strong respiratory and arousal stimulant in normal infants.[23] In this study, the immediate increases in respiratory rate, number of body movements and arousals, and fewer apneas and shorter duration of apneas after sighs after covering the head, are consistent with such an effect of CO_2. Although not always significant, the rise in oxygen saturation and transcutaneous Po_2, and only a minimal rise in transcutaneous Pco_2 further indicate that normal infants are able to eliminate CO_2 immediately by hyperventilation.

An increase in CO_2 in the respiratory air is accompanied by a decrease in O_2. Although most infants will respond to both hypoxia and hypercarbia with hyperventilation, around two-thirds of normal infants may have an inappropriate response to mild and moderate hypoxia[24] and 2% may have a diminished response to hypercarbia.[25] Impaired alveolar ventilation and significantly higher arousal thresholds to high CO_2 have also been found in some infants with ALTE.[26] Ventilatory and arousal thresholds to hypercapnia and hypoxia are also increased during sleep and especially during REM sleep.[23,27] In adults, the common response to a single exposure of CO_2 seems to be an enhanced rather than a decreased sensitivity to CO_2,[28] but this condition has not been studied in infants. However, in adult divers, the ventilatory response to an increased CO_2 in inspiratory gases is commonly decreased, and it has been suggested that the blunted response may be caused by adaptation.[29] We speculate that a subgroup of normal infants may respond inappropriately to hypoxia and hypercarbia if repeatedly exposed to rebreathing which may occur with consistent untoward care-giving practices such as prone sleeping on soft bedding.

The mean peripheral skin temperature in the present study was higher in the prone than the supine position both before and after covering the head. The prone position is associated with reduced heat loss partly because a higher fraction of the body surface is in direct contact with the mattress, and partly because air exchange around the body is decreased,[19,30,31] (B.T. Skadberg and T. Markestad, personal observation). The additional rise in peripheral skin temperature observed after covering the head may reflect a combined effect from the cover itself because the head is the main route of heat loss in young infants,[32–36] and the increase in metabolic rate attributable to hyperventilation from CO_2 rebreathing. This is further supported by the circulatory response with a rise in heart rate. Most of the infants were sweating and the skin often felt cool. Therefore, the moderate rise in peripheral skin temperature may not fully reflect the increased thermal stress because sweating and evaporation of sweat may have limited the rise in temperature at the surface of the skin.

Subsequent to a change in body position or movements during sleep, infants may happen to slip under the bedding,[13,14,37,38] and a situation for CO_2 rebreathing and risk of overheating may occur.[10,13,19] Although most infants in the present study woke up when covered, there was a striking difference in subsequent behavior depending on the infants' body position. Only one prone infant of 5 months managed to remove the duvet from the head compared with 23% of the supine infants at 2½ months and 60% at 5 months. The inability of prone sleepers to remove the duvet may be explained by the age dependent neuromotor development. Coordination of head and body movements is still very limited at 5 months,[39,40] and the present study shows that the complex series of movements which is necessary to remove the bedding when prone, may be virtually impossible.

Victims of SIDS apparently die in close relationship to sleep. Infants' early crawling movements are reciprocal which may tend to bring them under the bedding while prone. It has also been shown that infants sleeping on the side may be able to pull the cover over the head,[13] and that they may roll from the unstable side position to prone.[13,14,37,38] The inability to remove the cover while prone and subsequent awakening and struggling may increase the likelihood of overheating, exhaustion, and a face down position with CO_2 rebreathing, all possible contributors to SIDS.

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