Effect of prone sleeping on circulatory control in infants

Angeline Chong, Nuala Murphy, Thomas Matthews

Abstract

***Background*—The mechanism of death in sudden infant death syndrome (SIDS) remains unclear. Progressive bradycardia is the pre-eminent terminal event, suggesting that circulatory failure might be a crucial factor. Vasomotor tone regulates the circulatory system by controlling blood volume distribution while maintaining venous return and blood pressure.**

***Aim*—To examine whether prone sleeping, the most consistently identified risk factor for SIDS, has a measurable influence on vasomotor/circulatory control.**

***Methods*—44 full term infants (mean age, 7.9 weeks) were studied during an overnight sleep. Recordings were made while the infants were horizontal and asleep in the supine and prone positions, and repeated after a head up tilt to 60°, maintained for 30 minutes, while in both sleep positions. Blood pressure, heart rate, anterior shin, and anterior abdominal wall skin temperatures were measured.**

***Results*—Systolic blood pressure was lower, but peripheral skin temperature and heart rate were higher during sleep, while horizontal, in the prone rather than the supine position. After tilting, there was a greater reduction in blood pressure and a greater increase in peripheral skin temperature and heart rate when in the prone position. Anterior abdominal wall skin temperature did not vary in either sleeping positions while horizontal or tilted.**

***Conclusion*—Prone sleeping has a measurable effect on circulatory control, with a reduction in vasomotor tone resulting in peripheral vasodilatation, a higher peripheral skin temperature, a lower blood pressure, and a higher resting heart rate. Because vasomotor tone is crucially important in circulatory control this could be a factor in increasing the risk of SIDS.**

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Department of Paediatrics, Rotunda Hospital, Dublin 1, Republic of Ireland
A Chong
N Murphy
T Matthews

Correspondence to:
Professor T Matthews

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Recent epidemiological studies have shown that both the prone sleeping position and overheating increase the risk of sudden infant death syndrome (SIDS), although the mechanism is unknown.[1 2] Prone sleeping has been shown not to affect adversely respiratory control, airway patency control, transcutaneous oxygen saturation, the frequency of gastro-oesophageal reflux, or rectal temperature control in infants.[3–6] A report of infants dying from SIDS while attached to a cardiorespiratory monitor, with a built in memory, showed a progressive bradycardia with continued breathing movements to be the most frequent terminal event.[7] Analysis of the data from these deaths suggests that cardiovascular/circulatory failure is important in the sequence of events leading up to SIDS. The vasomotor system plays an important role in circulatory control by regulating and altering blood volume distribution to meet the needs of different organs and tissues while maintaining a normal blood pressure, an adequate central venous return and cardiac output. The aim of our study was to determine whether sleeping in the prone position has a measurable effect on vasomotor/circulatory control in healthy infants.

Patients and methods

Full term, healthy infants were recruited from the postnatal ward at the Rotunda Hospital (Dublin, Republic of Ireland) (between days 1 to 5 of life). Of the 88 infants that were initially recruited, 61 returned to be studied. No infant was on medication and they were admitted electively into the paediatric unit and studied during unsedated overnight sleep (between the hours of 22:00 and 02:00). Because of the difficulty in keeping some of the infants asleep for the duration of the study period, complete data are available for only 44 of the infants. There were 21 boys and 23 girls, and the mean age at study was 7.9 weeks (range, 6–9 weeks). Seventeen of the babies were breast fed, whereas the others were fed formula milk. After being fed, infants were put to sleep in a plastic bassinet on a mechanically controlled tilt table in the supine position, wearing a vest, a "babygro", and a cardigan, with two small single blankets (tog 10). Resting measurements of heart rate, blood pressure, anterior shin temperature, and anterior abdominal skin temperature were recorded for a minimum of 30 minutes of sleep time. The infants were then tilted head up to 60° over a period of three to four seconds and the tilt was maintained for 30 minutes. Measurements of heart rate, blood pressure, and anterior shin and abdominal skin temperatures were made for another 30 minutes, after which time the infant was returned to the horizontal position and the sleep position was changed to prone.

Physiological parameters were measured for a minimum of 30 minutes in the prone position, then the infants were again tilted head up to 60° and recordings were made for a further 30 minutes. All recordings were made during clinically staged quiet sleep (defined as:

eyes closed with no body or eye movements, and the cardiorespiratory tracing showing respiratory movements of uniform amplitude).[8] During periods of active sleep, recordings were discontinued and only restarted when quiet sleep was established again. Therefore, all recordings were made during quiet sleep. The room temperature was maintained at 23–25°C. Informed parental consent was obtained in all cases and no financial incentives were given to the families for participating in our study. Approval was given for our study by the hospital ethics committee.

MEASUREMENTS OF PHYSIOLOGICAL PARAMETERS

Heart rate

Continuous electrocardiographic (ECG) recordings, and respiratory and abdominal wall movements, were recorded on a Corometrics 552 neonatal cardiorespiratory monitor (Corometrics Medical Systems, Connecticut, USA) and stored on paper at a speed of 6.25 mm/s. The heart rate/min was then assessed by counting the number of R waves over a one minute period. The mean heart rates over 30 minutes while the infants were horizontal and tilted to 60° were used to compare the prone with the supine position.

Blood pressure

Blood pressure was measured by a neonatal blood pressure monitor (Spacelabs NIBP monitor; Spacelabs, Redmond, West Virginia, USA) using an appropriately sized cuff attached to the right upper arm. The mean blood pressure measurements of readings taken at five minute intervals for 30 minutes while the infants were in the horizontal position were used to compare the supine with the prone position. After tilting, readings were then taken one minute and five minutes after tilting and at five minute intervals for a total of 30 minutes. Differences between the mean blood pressure readings over the 30 minute period after tilting and the resting blood pressure, which was defined as the mean of five readings taken at one minute intervals immediately before tilting, were taken as a response to tilting. Systolic blood pressure was used to express the results.

Skin temperature

Skin temperature was measured by placing and taping a thermistor probe on the right anterior shin and a second probe on the left anterior abdominal wall. These were recorded continuously at one minute intervals by a Squirrel 1000 datalogger (Grant Instruments, Cambridge, UK) for a minimum of 30 minutes in each sleep position (supine, tilted in the supine position, prone, and tilted in the prone position). Ambient temperature was also recorded. Comparisons were made using the mean temperature measurements over each 30 minute period.

Table 1 Physiological parameters during 30 minutes of supine and prone sleep in the horizontal position

	Supine	*Prone*	*p Value*
Heart rate (bpm)	130.8 (7.9)	131.4 (7.5)	NS
Systolic blood pressure (mm Hg)	82.3 (8.8)	79.6 (8.9)	< 0.05
Peripheral skin temperature (°C)	33.3 (1.4)	33.7 (1.4)	< 0.05
Anterior abdominal skin temperature (°C)	35.7 (0.4)	35.8 (0.5)	NS

Values are means (SD).
bpm, beats/minute.

Table 2 The responses of the physiological parameters during 30 minutes' head up tilt in the supine and prone sleeping positions

	Supine	*Prone*
Heart rate (bpm)	129.7	132.9*
Systolic blood pressure (mm Hg)	−1.8%	−3.2%*
Peripheral skin temperature (°C)	+0.1	+0.3*
Anterior abdominal skin temperature (°C)	−0.1	+0.1

*p < 0.05.
bpm, beats/minute.

ANALYSIS

Statistical comparisons were made by the Student's *t* test.

Results

Systolic blood pressure was lower and peripheral skin temperature was higher in the prone than in the supine position while horizontal (table 1). The resting heart rate was slightly, although not significantly, higher in the prone position. In response to head up tilting to 60°, the infants developed a greater reduction in blood pressure and a greater increase in peripheral skin temperature and heart rate when in the prone position compared with the supine position (table 2). Anterior abdominal skin temperature did not vary with either position or head up tilting.

Discussion

The risk of SIDS increases dramatically in the 2nd and 3rd months of postnatal life, with most deaths occurring during the overnight sleep period.[9] Because circulatory control seems to be important in the sequence of events leading to death in SIDS the effect of sleep, especially overnight in the prone position, on circulatory control might provide some insight into the mechanism of death. Our results suggest that sleep in the prone position is associated with a reduction in vasomotor tone, with a lower resting blood pressure (79.6 mm Hg *v* 82.3 mm Hg) and a higher peripheral skin temperature (33.7°C *v* 33.3°C) in the prone position compared with the supine sleeping position. The lack of an effect of the prone or the supine sleeping position on anterior abdominal skin temperature (35.8°C *v* 35.7°C) makes it unlikely that lying on the probe, while prone, influenced the results. In addition, when circulatory control was stressed, by a 60° head up tilt for 30 minutes, the fall in resting blood pressure was greater while asleep prone than supine, and was matched by a greater increase in peripheral skin temperature, and an increased resting heart rate (table 2), indicating peripheral pooling of blood. These results are supported by two previous studies of peripheral skin temperature in similar aged infants during an overnight sleep. Skadberg and Markestad studied 32 infants aged 2.5 and 5 months and found that prone sleeping was associated with a higher peripheral (toe) skin temperature and a faster resting heart rate when compared with supine sleeping.[10] The peripheral

skin temperatures in this study were higher than in our study (36.3°C *v* 33.7°C); however, their infants were more heavily wrapped (15.5 togs *v* 10 togs) in a similar ambient temperature. The amount of clothing and bedding used in both studies is within the range normally used at home at this age.[11] Skadberg and Markestad concluded that the tachycardia associated with prone sleeping, seen in their study, was the result of heat stress, and occurred despite infants in the prone position having more settled sleep with less arousals, confirming the findings of previous studies that infants sleep "better" if prone (prone sleeping was previously recommended for this reason).[12–14]

These two studies give some insight into the circulatory effects of two differing, but normal, infant care practices, with heavier wrapping causing a higher peripheral skin temperature and a faster resting heart rate. Heavy wrapping, especially if sleeping prone, has been a consistent risk factor for SIDS,[15] and a faster resting heart rate has been one of the most consistent factors found in cardiorespiratory recordings of infants subsequently dying of SIDS.[16 17] Azaz *et al* studied 22 infants in the prone position during an overnight sleep in conditions very similar to our study and found similar anterior shin skin temperatures (33.7°C *v* 33.7°C).[18] Azaz *et al* also found that the anterior shin skin temperature during sleep increased significantly from 1–12 weeks of age, as does the resting heart rate,[19] suggesting an age associated reduction in vasomotor tone during sleep, with peripheral vasodilatation, a reduction in venous return, and a compensatory increase in resting heart rate. In our study, all infants were studied in the supine sleeping position first, because there were no regular prone sleepers in the group, and consequently the differences found between prone and supine sleep could reflect the fact that all the prone studies took place later during the night's sleep. However the peripheral skin temperature differences between prone and supine sleep in our study are very similar to those found in the study of Skadberg *et al*, where infants were allocated randomly to the prone or supine position initially, and where peripheral skin temperature was higher when prone both in active and quiet sleep at 2.5 and 5 months, whether studied early or late in an overnight sleep. Consequently, we feel that the differences shown in our study reflect an effect of sleep in the prone position.

The most consistent circulatory effect of sleep is a reduction in vasomotor tone, reflected by a fall in resting blood pressure and a decrease in peripheral vascular resistance.[20] This is associated with a reduced heart rate, a reduced central venous return, and a reduction in cardiac output, indicating a dramatic sleep induced alteration in baroreceptor function, because a similar combination of events while awake is associated with an increase in heart rate, with sympathetic activation and peripheral vasoconstriction.[20] Overheating and overwrapping increase the risk of SIDS, especially if sleeping prone,[12] and the normal response to heat is to increase skin blood flow and heat loss by a reduction in vasomotor tone and peripheral vasodilatation.[21]

Bundling (or tightly wrapping infants) has also been shown to increase the risk of SIDS in infants sleeping prone and also to increase skin temperature, implying peripheral vasodilatation.[12 22] In addition, co-sleeping has been reported to increase the risk of SIDS and is associated with a higher rectal temperature in infants, again implying a degree of heat stress.[23–25] Sleep is also associated with a fall in rectal temperature, which is absent during the first 2 weeks of postnatal life, a period of low risk of SIDS, and which becomes established and increases in magnitude by 8 weeks, a period of increased risk of SIDS.[26] This sleep induced fall in rectal temperature is associated with a maintained or rising peripheral skin temperature, which often exceeds rectal temperature, implying both peripheral vasodilatation and age associated changes in vasomotor control during sleep.[27] Vasomotor control has long been known to be poor in healthy full term infants, with a 15% reduction in circulating blood volume resulting in a 54% reduction in central venous return because of poor peripheral vasoconstrictor ability.[28]

The vasomotor system is controlled by the sympathetic component of the autonomic nervous system, which also regulates cardiac repolarisation. Recently, a prolonged QT interval has been shown to increase the risk of SIDS and inefficient cardiac repolarisation has been suggested to be the cause.[29] We have suggested previously that poor autonomic control, in particular the combination of a sleep induced reduction in vasomotor tone with a reduction in central venous return and cardiac distension, might trigger a brain stem mediated bradycardia in some infants via a neurocardiac reflex.[30 31] However, without invoking a specific neurocardiac reflex, a combination of circumstances, each of which reduce vasomotor tone, such as nocturnal sleep in the prone position at 2 months' postnatal age in a heavily wrapped infant, associated with an unresponsive baroreceptor controlling system, could render an infant vulnerable to inadequate central venous return, poor pulmonary perfusion, and hypoxia. Antemortem pulmonary thrombi have been described in SIDS, suggesting low pulmonary blood flow in some instances.[32] Prone sleeping might also impair the arousal response, perhaps because the infants are more deeply asleep, further disadvantaging infants with a down regulated baroreceptor response.[33] The peak age of occurrence of SIDS coincides with the nadir of the physiological anaemia that occurs in all infants and which would accentuate any sleep induced reduction in venous return. Physiological anaemia is exaggerated in preterm and low birth weight infants, who also have an increased risk of SIDS.[9] Our study suggests that the normal sleep induced reduction in vasomotor tone is greater in the prone sleeping position, perhaps simply because in this position infants are more deeply asleep, and that vasomotor control and its interaction with circulatory control and temperature control, deserve further study in infants.

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