Sleep States and Neonatal Pulse Oximetry

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Aim: Pulse oximetry is a quick, easy, noninvasive method widely used for monitoring oxygen saturation (SaO_2) in the neonatal period. The greatest recognized problem with SaO_2 readings measured from the oximeter is artifact, arising from an inability to record accurately during movement. The aim of this study was to determine the proportion of pulse oximeter readings affected by movement artifact during sleep in term and preterm infants.

Method: Polygraphic recordings were obtained from 11 term and 6 preterm infants at postconceptional ages (SD) of 39.8 (0.8) and 39.3 (1.5) weeks respectively. The polygraphic and computer recordings were divided into epochs of 30 seconds duration and identified as active sleep (AS), quiet sleep (QS), indeterminate sleep (IS), or wakefulness (AW), using electrophysiological parameters and behavioral observations. Movement artifact was identified by visual examination of polygraphic computer recordings using strict criteria. Signal containing artifact was removed from recordings and the percentage of artifact time present per recording calculated.

Results: Signal artifact was present in recordings of all infants studied, comprising an average state time of 19% during quiet sleep, 49% of active sleep, 49% of indeterminate sleep and 91% of wakefulness. A significant difference in the proportion of artifact present in recordings of term and preterm was observed only during quiet sleep.

Conclusion: Movement artifact during pulse oximetry recordings is dependent on behavioral state, and overall affects up to 50% of recorded traces. A reliable and more accurate noninvasive method of recording oxygen saturation is thus needed, for use in both neonatal nurseries and in sleep studies, to aid in accurate clinical decision-making.

Key words: Oximetry; signal artifact; neonate sleep state; term; preterm infant

PULSE OXIMETRY is a quick, easy, noninvasive method for monitoring oxygen saturation, and is now widely used in clinical medicine, especially during the neonatal period. However, signal artifact—that is, measurement that does not truly represent that of the patient—is a problem in both clinical interpretation and statistical summaries of recordings. In practice, artifact due to movement is a major cause of error in the measurement of SaO_2 readings using oximetry.[1-5]

Clinical researchers, through the use of various techniques,[2,4,6-8] have attempted to reduce the effects of motion artifact in an effort to exclude erroneous data from pulse oximetry readings in term and preterm infants during sleep study analysis (Table 1).

In clinical neonatal practice, the single greatest problem with SaO_2 readings measured by oximeters is the inaccuracy associated with movement artifact and the danger that this may not be appreciated by staff. The movement producing the artifact can be both physiological and nonphysiological. The most common cause of the latter is handling of the infant and interventions. Hence these criteria have been used by some authors to exclude artifact.[9,10] This, however, fails to account for the spontaneous physiological movement which occurs during wakefulness and sleep. The extent of the inaccuracies of pulse oximeters arising from physiological and nonphysiological signal artifact during different behavioral states has not been adequately quanti-

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fied for the neonate, where SaO_2 monitoring is so frequently used in clinical care.

This study was prompted by the frequency with which staff "ignore" oximeter alarms due to artifact, and the limitation that this places on accurately assessing whether a preterm infant at or near term is safe to send home. This study was designed to answer the following clinical questions: (1) what proportion of pulse oximeter readings contain signal artifact?; and (2) how dependent are accurate pulse oximeter SaO_2 readings on behavioral state?

METHODS

Subjects and Selection

(1) Term infants.—Eleven healthy full-term neonates, six males and five females, were selected from the maternity ward at King George V (KGV) Hospital between March and September, 1995. Entry criteria required that the infants were born vaginally at a gestational age of 37-42 weeks to mothers who had no complications of pregnancy such as drug or alcohol abuse, hypertensive disease of pregnancy, or diabetes. Additional criteria included a normal clinical examination with no evidence of a neurological abnormality, no evidence of asphyxia at birth, birth weight appropriate for gestational age according to Australian growth charts,[11] no treatment for jaundice, and age of 3-5 days at the time of study.

(2) Preterm infants.—Six preterm infants, two males and four females, were selected from the neonatal intensive care unit at KGV hospital. Entry criteria required that the infants were born between 24 and 32 weeks gestation, were at term-equivalent age (37-42 weeks post-menstrual age), did not require supplemental oxygen at the time of study, and had a normal head ultrasound at 1 week and 1month of age.[12]

Detailed information regarding the nature and purpose of the study was supplied verbally and in writing to parents. Written consent was obtained from all participating parents. The experimental protocol was approved by the Hospital Ethics Committee.

Polygraphic Recording of Sleep State

During sleep, physiological parameters were recorded continuously on a 12-channel pen recorder (Model 78D, Grass Instrument Co.) and a Macintosh computer (Quadra 700) using a data acquisition system (Model MP 100 Data Acquisition System, Biopac Systems Inc., Goleta, Calif) and software (AcqKnowledge881 version 3.1.2). All infants were lying supine in a cot with the head in a lateral position, in a quiet warm recording room. Sleep studies were recorded at a chart speed of 2 mm sec^{-1} and sample rate of 4 or 10 Hz.

Sleep state was determined from polygraphic recordings. An electroencephalogram (EEG) was obtained by the placement of silver cup electrodes on the forehead (ground electrode), A1 and C3 or A2 and C4 cranial positions according to the international 10-20 electrode montage.

Eye and gross body movements were detected by piezoelectric transducers placed on the upper eyelid and laryngeal prominence, respectively. Breathing was recorded by an abdominal pneumogram using a mercury-in-rubber strain gauge taped across the upper abdomen and connected to a plethysmograph (Model 270, Parks Electronics Laboratory, Ore) and by a nasal thermistor (Model 978 Premie Nasal Airflow Sensor and Model 3170 Sleep Lab Airflow Cable, Eden-Tec Corporation, Eden Prairie, Minn) placed under the external nares of the infant. Behavioral observations of head and body movements, cries, noises, grunts and groans were also recorded continuously on polygraph and computer recordings. In accordance with published criteria,[13-15] all variables were used to define sleep state. Following early morning feeding, sleep studies of at least 4 hours duration were obtained from all study participants.

Recording of Oxygen Saturation and Heart Rate

Oxygen saturation and heart rate were recorded using the Nellcor 200 pulse oximeter (Nellcor Incorporated, Pleasanton, Calif) sampling at 3 Hz and averaging over 3 seconds. The sensor probe (Nellcor Oxisensor II N-25 Neonatal/Adult O_2 transducer, Calif) was wrapped around the foot of the infant and covered with an opaque dressing to decrease interference from ambient light and maintain good contact with the skin. Beat-to-beat heart rate was obtained from amplification of the analog output signal of the oximeter via a tachograph. Synchronization of data acquisition from the pulse oximeter with the ECG R-wave was not used in this study, as the N200 pulse oximeters have been reported to synchronize with ECG artifact generated by motion.[1]

Analysis of Recordings

The polygraphic sleep recordings were divided into successive 30-second epochs in order to define sleep and awake states. State was assigned as either active, quiet or indeterminate sleep, or the awake state, according to preset criteria.[13-15] If a state occurred for greater than one-half of a 30-second epoch, that state was deemed to be present.

The computer files were separated according to state (ie, active sleep (AS), quiet sleep (QS), indeterminate sleep (IS) or awake (AW)). The total and percentage time spent in each state for each infant was measured and a mean time (SD) calculated.

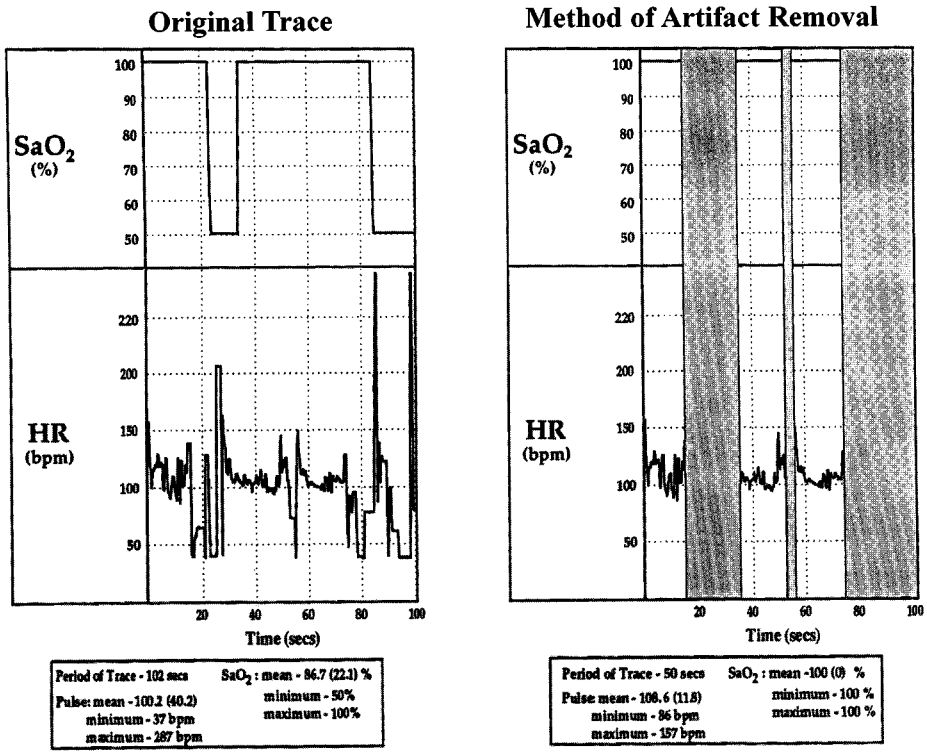

Figure 1.—Left panel: Illustration of the original computer traces of oxygen saturation (SaO_2) and heart rate (HR). Right panel: Visual identification of artifact (defined in methods) and computer deletion of artifact.
Boxed regions, containing the computer calculations, show the difference in readings when artifact is included in the computer analysis compared with artifact-free analysis.

Removal of Artifact and Analysis of Oxygen Saturation

Artifact was determined by visualization of the trace and defined as either: areas of heart rate trace showing rapid variability in pulse readings, and/or areas of oxygen saturation trace showing "lost signal" with saturation readings 50% or less. The duration of artifact time was calculated for each recording and the contaminated trace then removed from further analysis of recordings, as shown in Fig. 1. The proportion of total study period affected by signal artifact was then calculated.

A mean baseline SaO_2 for each sleep state was calculated by averaging all SaO_2 values of artifact-free recordings. Results of further analysis of oxygen saturation and desaturation episodes are not included due to the small number of infants in the study.

Statistical Analysis

Chi-squared analysis was used for the comparison of the amount of artifact present in the recordings of term and preterm infants. Statistical significance was defined as a p-value <0.05.

RESULTS

Subjects

Seventeen infants, eleven term and six preterm, were studied. The mean (SD) gestational age of term and preterm infants was 39.2 (0.8) and 27.5 (1.9) weeks respectively. Post conceptional ages at the time of the study were not significantly different, being 39.8 (0.8) weeks for term and 39.3 (1.5) weeks for preterm infants.

Sleep Staging

The mean (SD) duration of the study periods for term and preterm infants was closely matched, being 116.5 (4.5) and 116.2 (6.4) minutes respectively. The period of time spent in each state was variable for both groups of infants. Term infants spent, on average, 52% of recording time in active sleep (AS), 20% in quiet sleep (QS), 16% in indeterminate sleep (IS), and 12% in wakefulness. Preterm infants spent considerably less time in AS (40%) compared with term infants, the same proportion of time in QS (20%), and increased periods in IS (25%) and wakefulness (15%). The percentage of time spent within each state is comparable to previous studies in healthy newborn infants.[16-18]

Table 1.—Methods of removing signal artifact in previous sleep studies of term and preterm infants

Author & Journal	Babies Studied	In sleep	Method Used For Artifact Removal	Artifact Conclusions
Mok et. al. (1986) J. Pediatr **108**: 365-351	Infants: Healthy term n 55 GA: 37-42 weeks Age at Study: 1 week (6wks, 3&6 mths) Mean (SD) Study Period (min): 50.8 (16.2)	YES	Periods when baby was handled or crying were excluded	Nil
Mok et. al. (1988) J. Pediatr. **113**: 706-709	Infants: Healthy preterm n 28 GA: 29-36 weeks PCA at study: 39-46 weeks (and 6wks and 3, 6, 9 and 12 mths) Mean (SD) Study Period (min): 63.1 (16.7)	YES	Periods of trace when baby was crying, being held or in indeterminate sleep were excluded	Nil
Thilo et. al. (1991) AJDC **145**:1137-1140	Infants: Healthy term n 150 GA: 37-42 weeks Age at Study: 1-2 days (1mth & 3mths) Mean (SD) Study Period (min): 77.0 (1.3)	YES	Rejected if HR from pulse oximeter differed by > 5bpm from an independent bedside ECG	"Intermittant Artifact easily ignored" No other mention of artifact
Poets et. al. (1991) Arch. Dis. Child. **66**:574-578	Infants: Preterm n 66 GA: 25-36 weeks PCA at study: 37-46 weeks Study Period: 12 hr overnight	YES	SaO_2 values determined from plethysmographic (pulse) waveforms but definition of method not stated	Median duration of artifact-free signal reported as 8.1hrs. No other mention of artifact
Stebbens et. al. (1991) Arch. Dis. Child **66**:569-573	Infants: Healthy term n 69 GA: >37 weeks Age at study: 2 months Mean (SD) Study Period (hrs): 11.5 (1.1)	YES	SaO_2 values determined from plethysmographic (pulse) waveforms but definition of method not stated	Median duration artifact-free signal for regular breathing ~ 2.9/3.0 (1.1-5.4) hrs and Non-regular breathing ~ 4.6/8.8 (2.3-6.9) hrs.
Poets et. al. (1992) J. Pediatr. **120**: 447-454	Infants: Preterm at discharge n 160 GA: 32.8 ± 2.5 weeks PCA at study: 36.6 ± 2.1 weeks Mean (SD) Study Period (hrs): 12.2 (1.3)	YES	SaO_2 values determined from plethysmographic (pulse) waveforms but definition of method not stated	Nil
Masters et. al. (1994) J. Ped. Child Health **30**:423-428	Infants: Healthy term n 67 GA: >37 weeks PCA at study: 45-48 weeks Mean Study Period (hrs): 7.5	YES	Immediate removal based on observations of the baby, plethysmographic pulse and analogue output on computer data acquisition system	The edited and artifact free time reported as ~ 7.5 Hrs

Abbreviations: n = number studied; GA= gestational age; PCA = post conceptional age.

Artifact Removal

Signal artifact was present in the recordings of all infants studied, with wide intersubject variability in the amount of artifact time per recording. Recordings of term infants contained between 32% and 73% of signal artifact, with a mean (SD) duration of 56.6 (15.7) minutes of artifact from an averaged study period of 116.5 (4.5) minutes. Preterm infants were similar, with 24% to 73% of recordings containing signal artifact (mean (SD) duration of 51.9 (20.9) minutes of artifact from an averaged study period of 116.2 (6.4) minutes).

The percentage of artifact present per recording was largely dependent on state. A significant difference in the amount removed for corresponding states between the term and preterm infants was observed only during quiet. Quiet sleep, characterized by minimal body movement, contained 19% and 9% artifact per total study time for term and preterm infants respectively ($p = 0.02$), whereas during active sleep, the period during which infants spent most time, there was 49% and 44% artifact, respectively ($p = 0.9$). During indeterminate sleep there was 49% movement artifact in term and 47% in preterm infants ($p = 0.8$). For both groups of infants, most of the recording was associat-

Table 2.—Mean baseline saturation and range of saturation values for term and preterm infants.

Infants	Mean Baseline Saturation (Range)			
	AS	QS	IS	AW
Term Infants				
1	**92 (82 - 97)**	**92 (89 - 94)**	**91 (88 - 94)**	**94 (92 - 94)**
2	97 (85 - 100)	98 (92 - 100)	97 (91 - 100)	99 (97 - 100)
3	**94 (85 - 99)**	**93 (85 - 97)**	**94 (84 - 97)**	**94 (88 - 98)**
4	**90 (81 - 97)**	**92 (88 - 98)**	**92 (85 -100)**	**90 (89 - 93)**
5	96 (87 - 100)	96 (87 - 98)	96 (90 - 100)	-
6	99 (91 - 100)	99 (97 - 100)	99 (98 - 100)	-
7	98 (92 - 100)	97 (92 - 100)	96 (90 - 100)	96 (78 - 100)
8	98 (86 - 100)	99 (94 - 100)	99 (91 - 100)	-
9	**92 (86 - 94)**	**92 (86 - 95)**	**93 (83 - 96)**	**93 (83 - 98)**
10	98 (90 - 100)	98 (90 - 100)	99 (95 - 100)	-
11	99 (95 - 100)	99 (95 - 100)	100 (94 - 100)	-
Preterm Infants				
1	99 (90 - 100)	99 (96 - 100)	100 (97 - 100)	100 (98 - 100)
2	98 (90 - 100)	98 (94 - 100)	98 (92 - 100)	99 (88 - 100)
3	99 (97 - 100)	99 (98 - 100)	100 (95 - 100)	100
4	99 (87 - 100)	99 (87 - 100)	100 (93 - 100)	100 (94 -100)
5	99 (92 - 100)	99 (98 - 100)	100 (93 - 100)	-
6	96 (73 -100**)**	**94 (74 -100)**	97 (77 - 100)	**95 (83 -100)**

Four term infants, numbers 1,3,4,9 **(bolded)** and one preterm infant (number 6) had low baseline SaO_2.

ed with movement artifact during the awake state (91% of term and 89% of preterm recordings ($p = 0.6$)).

The mean baseline saturation values for all infants studied is shown in Table 2. Four of the eleven term infants exhibited low mean (≤95%) baseline saturations across all four sleep states, with only one preterm infant (infant number 6) exhibiting a low baseline saturation in the quiet and awake states. The four infants with low baseline saturation values did not differ from the remaining seven term infants in the percentage of time spent in individual sleep states, range of heart rates, or frequency of artifact. The four infants did, however, have more episodes of oxygen desaturation in association with short central apneas and swallowing. The remaining term and preterm infants all exhibited high (>95%) mean baseline saturations.

DISCUSSION

This study highlights several new aspects of monitoring oxygen saturation by pulse oximetry in term and preterm infants. First, there is a wide intersubject variability in the proportions of signal artifact, with 24% to 73% of recordings in all infants representing artifact, thereby making saturation values unreliable during this period. Second, the amount of signal artifact, and therefore artifact-free saturation readings, is dependent on behavioral state. Third, a small group of normal, healthy, term newborns have a low mean baseline saturation compared with healthy preterm infants at term equivalent age.

Recognition of movement-associated signal artifact is important to improve the accuracy of oxygen saturation measurements in infants.[5] In previous reports, the amount of recording time lost due to artifact is either not stated,[9,10,19,20] presented as edited and artifact-free time,[21] or summarized as the median (range) duration of artifact-free signal for all infants.[22,23] In contrast, in this study we have analyzed the amount of artifact removed for each infant. There was a wide intersubject variation for both term and preterm infants at term age, which emphasizes the need to collect SaO_2 data from artifact-free periods to improve clinical decisions based on saturation monitoring.

The amount of signal artifact varied with the infant's state. These findings are systematically assessed by sleep state in this study. As neonates spend the majority of time asleep in the active and indeterminate states,[16] then based on data in this study, up to 49% of SaO_2 readings will be invalidated by movement artifact. The effect of physiological movement during sleep will be greatest during the first few postnatal months, since active sleep comprises the major part of total sleep time.[16] From 2 months of age, the amount of active sleep decreases, which will significantly reduce the amount of artifact due to movement in sleep.

In the awake state of the neonate, saturation values from the pulse oximeter are largely uninterpretable (up to 91% of recorded values). Distinguishing true desaturation from artifact will therefore be difficult, especially in those pulse oximeters which do not detect artifact.[24] The possi-

bility also exists that within recordings contaminated by movement artifact there are true episodes of desaturation.[21]

The low mean baseline saturation observed in four of the eleven term infants in this study has been previously reported in a small number of term infants and preterm infants at discharge.[9,19,22,23,25] The term-infant studies of Mok and coworkers[9] observed baseline saturations as low as 86% in term infants at <1 week of age. However, by only removing movement artifact associated with periods of handling and intervention, these workers would have included in their analysis large amounts of artifact-affected recording.

CONCLUSION

We have found that signal artifact during pulse oximetry readings in the newborn period, whether in healthy term infants or preterm infants at term-equivalent age, is affected by behavioral state. Artifact occurs in more than 90% of recordings during wakefulness and 50% of recordings during active sleep. Since sleep and the active sleep state are predominant in the early postnatal weeks, this has a major effect on determining accuracy of saturation recordings. In addition we have found that some apparently healthy term infants, when studied in the first week of life, have low baseline oxygen saturation. An awareness of such findings is useful in clinical settings where decisions are based on oximetry readings. Clearly, a reliable and more accurate noninvasive method of recording oxygen saturation in these young infants is needed, for use in both neonatal nurseries and sleep studies, to aid in accurate clinical decision-making.

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