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THE EFFECT OF BED POSITION
ON ARTERIAL OXYGENATION
IN THE PRETERM INFANT WITH
RESPIRATORY DISTRESS SYNDROME

BY

BRENDA BISSELL

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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ABSTRACT

Ten preterm infants with respiratory distress requiring supplemental oxygen were studied to evaluate the impact of a head-up tilt of 12^0 as compared to a bed-flat position on arterial oxygenation. Both transcutaneous arterial tension (TcP_aO_2) and hemoglobin saturation ($TcSaO_2$) were monitored. A cross-over design was used and the infants were randomly allocated to the order of positioning. Infants were prone lying on a mattress for the study period. A twenty minute stabilization period was provided after positioning and prior to monitoring. The measurements were recorded every 30 seconds over a 10-minute period in each position. In two infants monitoring was continued during the stabilization period after the position change. Each infant was studied once.

An initial two-way ANOVA revealed no significant order or position effects and no significant interaction. The data of all 10 subjects were analyzed together. Dependent t-tests failed to show statistically significant positional differences for either the TcP_aO_2 or the $TcSaO_2$. The powers of the t-tests were high (.78 and .84).

Time series analyses were performed on two subjects. In one subject there was a statistically significant difference between positions for both outcome measures. The head-up position had a positive impact on arterial oxygenation. There was no difference between positions for the other subject.

The results of this study reject the hypothesis that a head-up tilt of 12^0 as compared to a bed-flat position results in an increase in arterial oxygen levels, as measured transcutaneously, in the preterm infant with RDS. However, individual responses to position may vary. The use of "routine" positioning is not supported.

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INTRODUCTION

A. Background of the Problem

Neonatology is a dynamic field specializing in providing care to newborns, in general, and to high risk infants, in particular. Preterm infants represent such an "at risk" group. Although they may be faced with any of a number of health problems, premature infants are frequently admitted to the Neonatal Intensive Care Unit (NICU) with respiratory disorders (Nikiforuk, 1989).

Respiratory distress syndrome (RDS) is a respiratory disorder commonly encountered in the NICU. RDS is a reflection of an immature pulmonary system and results from inadequate levels of surfactant. Surfactant first appears at approximately 20 weeks of gestation coinciding with the presence of the lamellar bodies in the Type II pneumocytes. However, lung maturity and adequate surfactant production are not assured until after 36 weeks' gestation (Mellins & Jobe, 1988). Infants born before this time are at an increased risk for developing RDS. Hutchison et al. (1979) as well as Mellins & Jobe (1988) acknowledge an inverse relationship between gestational age and the severity of RDS.

The lack of surfactant in the infant with RDS has three physiologic sequelae: an increase in alveolar surface tension, a decrease in lung compliance, and an increase in the transudation of fluid into the alveoli (Mellins & Jobe, 1988). Clinically, the deficiency in surfactant leads to: reduced lung volumes and atelectasis, increased elastic work of breathing, and pulmonary edema.

As well as the preterm infant, infant males, second born of twins, infants born to diabetic mothers, and those delivered by cesarian section are more likely to develop RDS (Mellins & Jobe, 1988).

Infants with RDS have clinical signs of respiratory distress. They have increased respiratory rates, indrawing, retractions, cyanosis, and grunting expirations resulting in hypoxemia , which may be partially refractory to supplemental oxygen (Hand et al., 1990). A metabolic and/or respiratory acidosis may exist. Chest X-rays show low volume lungs, a reticulo-granular pattern, and air bronchograms (Mellins & Jobe, 1988). The natural course of RDS is one of worsening status during the first 48 hours, stabilization by 72 hours and subsequent improvement.

Glucocorticoids such as dexamethasone are often prescribed if a premature delivery is anticipated. Given to the pregnant mother, these drugs prompt maturation of the fetal lungs by stimulating the production of phosphatidylcholine, one of the main components of surfactant (Brown et al., 1978). However, these drugs have a less positive impact on the male than the female fetus (Mellins & Jobe, 1988).

Until recently treatment of infants with RDS has been largely supportive. Surfactant has become a viable treatment for the preterm infant with RDS. The maintenance of adequate arterial oxygen levels continues to be a primary goal in the treatment program and may necessitate the use of supplemental oxygen, distending pressures and/or assisted ventilation.

B. Need for the Study

Hypoxemia is a symptom of RDS. One of the ongoing goals in caring for the preterm infant with RDS is to optimize the arterial oxygen levels. Dellagrammaticas et al. (1991) reported a direct relationship between vertical tilt and arterial oxygen tension (P_aO_2) in healthy, very low birth weight neonates. Little work has been done to evaluate the impact of vertical body position on arterial oxygenation in the preterm infant with RDS. However, it is common practice to nurse these infants in the head-up position (Klassen, 1990; Molesky, 1990). It is conceivable that a head-up tilt may affect the P_aO_2 and the hemoglobin saturation (SaO_2) through its influence on static lung volumes, ventilation, the work of breathing, and/or rib cage mechanics.

In the preterm infant with RDS, high recoil properties of the lung and a highly compliant chest wall result in a decreased end-expiratory lung volume or a decreased functional residual capacity (FRC). This decrease in FRC predisposes to basal atelectasis, shunting of blood and hypoxemia.

Does vertical tilting as compared to horizontal positioning alter the FRC of the preterm infant? Research reports on the effect of head-up positioning on lung volumes have not been consistent. Thoresen et al. (1988) reported an increase in the transcutaneously measured P_aO_2

(TcP_aO_2) in their healthy infants when they were positioned in a head-up 30° as opposed to a bed-flat position. They found the effect to be greatest in their sub-group of preterm infants. These researchers hypothesized that the increased oxygenation in the head-up position was a result of an increase in the FRC. They suggested that the vertical tilt opened alveoli in the lower zones, increased the $\dot{V}/\dot{Q}$ matching and enhanced the arterial oxygen tension. Wagaman et al. (1979) reported an increase in P_aO_2 when their intubated preterm infants were in prone as compared to supine lying. They attributed this, in part, to an increase in the ventilation-perfusion ($\dot{V}/\dot{Q}$) ratio. Specifically, they cited the decreased number of alveoli being placed in the dependent position as being instrumental in improving the oxygenation status. A change in position towards a head-up tilt would further decrease the number of dependent alveoli, decrease the extent of atelectasis, decrease the shunting, and enhance oxygenation.

In other studies the effect of a vertical tilt on the resting lung volumes was not clear. Waldemar et al. (1989) assessed a group of preterm infants in supine and semi-sitting at 45°. They reported a lower pulmonary resistance and a greater compliance in their infants when they were in the semi-sitting position. Although these researchers suggested that an increased FRC would explain these changes they did not measure the resting lung volumes of their sample in the two positions. Nor did they assess the effect of the more upright position on tidal volume (V_T) or the arterial oxygenation. Avery and O'Doherty (1962) recorded inconsistent changes in lung volumes with a head-up tip of 45° in their sample of healthy neonates. Stark et al. (1984) evaluated newborn infants. They found that the lung volumes in their sample were variously affected but were generally increased when the infants were in an upright posture of 80° as compared to a horizontal position. The resting lung volume of the preterm infant, particularly one with RDS, could be more sensitive to the effects of vertical positioning than the FRC of the healthy term infant.

Hand et al. (1990) studied the oxygen, carbon dioxide and nitrogen differences between alveoli and arteries in the preterm infant with RDS in order to determine which specific $\dot{V}/\dot{Q}$ abnormalities existed. They acknowledged the presence of shunting and diffusion problems but concluded that decreased $\dot{V}/\dot{Q}$ matching was the major source of the hypoxemia that they observed in their sample.

Can vertical positioning prompt an increase in the $\dot{V}/\dot{Q}$ matching? To do so it would have to cause a decrease in the pulmonary perfusion or an increase in the ventilation. Perfusion, being influenced by gravity, increases from the top to the bottom of the lung (West, 1985). However, perfusion is more evenly distributed throughout the lungs of the preterm infant than it is in the adult. This is due to the high pulmonary artery pressures in the neonate and the relatively small "height" of the preterm infant's lungs. West (1985) suggested that the presence of low static volumes in the dependent lung zone of the preterm infant with RDS prompts narrowing of the extra-alveolar vessels and a reduction in the regional blood flow. A head-up tilt as compared to a bed-flat position would decrease the **extent** of the dependent region. This would result in a small increase in the FRC as well as in the regional blood flow. The overall impact on the $\dot{V}/\dot{Q}$ ratio and, subsequently, on the arterial oxygenation would be minimal given the small vertical tilt involved.

An increase in static lung volumes in the head-up position may result in an increase in ventilation. At low lung volumes ventilation is preferentially distributed to the upper or non-dependent lung zones. An increase in the resting volumes opens basal alveoli. These basal lung units shift their position from the lower, flatter, non-compliant portion of the dynamic pressure-volume curve to the steeper, more compliant section of the curve (Cherniack, 1977). This increase in alveolar size and compliance may have one of two effects. There may be a greater change in lung volume per unit change in intrapleural pressure or there may be a decrease in the pressure required to produce a given V_T breath. In the first case there would be an increase in V_T. This would result in an increase in alveolar ventilation, an increase in the partial pressure of oxygen in the alveoli (P_AO_2) and, subsequently, in the arteries (P_aO_2). In the second situation a decrease in the inspiratory work of breathing would occur. The result would be a decrease in the energy expenditure and an increase in the arterial oxygen levels.

Avery and O'Doherty (1962) recorded an increase of 2 - 4 ml in the V_T's of their group of infants when they were tilted to 45°. They did not report any statistical analysis of this change but suggested that it would not be significant. This assumption may be challenged. The mean V_T for their sample in the horizontal position was 16 ml. It would seem that an increase of 2 - 4 ml may be clinically if not statistically significant. Stark et al. (1984) also reported a small but significant increase in V_T when their term infants were inclined from a horizontal position to 80° in their carrier seats. Although these researchers did not report on the oxygenation, they did record a small but significant increase in the end-tidal carbon dioxide (CO_2) in the upright position. Due to the inverse relationship between the alveolar partial pressures of O_2 and CO_2, this increase in the end-tidal CO_2 would tend to decrease the alveolar and arterial PO_2's.

In evaluating prone versus supine lying, Wagaman et al.(1989) reported a greater V_T in the prone position. They attributed this to an improved mechanical advantage of the diaphragm. Recognizing that the posterior portion of the diaphragm has the greatest radius of curvature, they suggested that the anterior displacement of the abdominal contents in prone freed the posterior diaphragm and allowed it to optimize its excursion. It is possible that a slight upward bed tilt would further increase the freedom of excursion of the diaphragm.

An upward tilt may cause a reduction in the work of breathing. Waldemar et al. (1989) reported an increased compliance and a decreased pulmonary resistance in their group of preterm infants in the semi-sitting as compared to the supine position. Carlo et al. (1989) also reported a decrease in pulmonary resistance in their neonates when they were in a head-up as compared to a bed-flat position. Neither of these studies evaluated the effects of a head-up tilt on V_T or oxygenation. Hutchison et al. (1979) suggested that changes in the pulmonary mechanics may decrease the inspiratory work of breathing. Kravitz (1975) argued that raising the head of the bed would effect a downward displacement of the abdominal contents and minimize the work of breathing. A decrease in the work of breathing would reduce the energy expenditure and enhance arterial oxygen levels. The impact of position on the work of breathing would be anticipated to be more pronounced in the ventilator-independent infant (Thoresen et al., 1988).

Vertical position may affect a preterm infant's rib cage mechanics. Stark et al. (1984) reported changes in the chest wall movements of their healthy infants when they were in an 80° upright as compared to a horizontal position. A decrease in the transverse diameter and an increase in the synchronous movement of the rib cage were noted when the infants were in the upright position. These researchers did not evaluate the effects of upward tilting on oxygenation. Other researchers (Martin et al., 1979) have suggested that there is a direct relationship between synchronous chest wall movement and arterial oxygenation.

Optimal arterial oxygen levels are essential for the proper functioning of body systems. Supplemental oxygen is often administered to infants with respiratory disease, although it is closely monitored to ensure that the P_aO_2 or the SaO_2 is maintained within a designated range. The risks of exposure to high concentrations of inspired oxygen are well documented (Slonim & Hamilton, 1987) and necessitate the consideration and use of interventions which may enhance arterial oxygen levels and thereby minimize the need for supplemental oxygen. Head-up bed positioning may be one such intervention. A head-up tilt of 12° is small. Dellagrammaticas et al. (1990) reported a consistent increase in oxygenation in the healthy preterm infants when an upward tilt of 10° was used. The impact of a 12° vertical tilt on arterial oxygen levels in preterm infants with RDS has not been investigated. It is possible that these infants respond differently to positioning than do healthy infants. Singularly or in combination, changes in static lung volumes, ventilation, the work of breathing or rib cage mechanics could effect a change in the arterial oxygen levels of the preterm infant with RDS.

C. Purpose of the Study

It was the purpose of this study to compare the effects of two bed positions - bed-flat and head-up 12° - on the SaO_2 and the P_aO_2 in the preterm infant with RDS.

D. Research Questions

1. Is there a significant difference in the SaO_2, as measured by a transcutaneous monitor ($TcSaO_2$), in the preterm infant with RDS when (s)he is nursed in the head-elevated 12° as compared to the bed-flat position?
2. Is there a significant difference in the P_aO_2, as measured by a transcutaneous monitor (TcP_aO_2), in the preterm infant with RDS when (s)he is nursed in the head-elevated 12° as compared to the bed-flat position?

E. Hypotheses

1. There is a significant increase in the $TcSaO_2$ in the preterm infant with RDS when (s)he is nursed in the head-up 12° as compared to the bed-flat position.
2. There is a significant increase in the TcP_aO_2 in the preterm infant with RDS when (s)he is nursed in the head-up 12° as compared to the bed-flat position.

F. Definition of Terms

1. **Neonate**: an infant who has not yet reached his/her 28th day of life (Hasselmeyer, 1963).
2. **Gestational age**: actual time, from conception to birth, that the fetus remains in the uterus (Thompson, 1987).
3. **Preterm Infant**: a baby born before 37 weeks gestation (Gorman, 1984).
4. **Deep sleep**: one of the two sleep states described by Brazelton (1973) in which the infant's eyes are closed, there is no spontaneous activity, and the respirations are regular.
5. **Light sleep**: the second of Brazelton's (1973) sleep states in which the infant's eyes are closed, rapid eye movements are present, and the breathing is irregular.
6. **Partial pressure of oxygen (P_aO_2)**: a measurement of the arterial oxygen tension, expressed in mm Hg (Cherniack et al., 1983).

7. **Transcutaneous partial pressure of oxygen in the arterial blood (TcP_aO_2):** a measurement of the P_aO_2 as obtained from a heated skin electrode. This is expressed in mm Hg.

8. **Oxygen saturation (SaO_2):** the amount of oxygen actually combined with hemoglobin (Hb), expressed as a percentage of the oxygen capacity of the Hb (Slonim & Hamilton, 1987).

9. **Transcutaneous saturation of oxygen ($TcSaO_2$):** a percentage measurement of oxygen saturation as obtained from a transcutaneous probe or monitor.

10. **Fractional inspired oxygen (FIO_2):** a measure of the proportion of oxygen in the inhaled air, expressed as a fraction of one or as a precentage.

11. **Tidal volume (V_T):** the volume of gas that is either inspired or expired during one ventilatory cycle, measured in ml. (Slonim & Hamilton, 1987).

12. **Minute ventilation ($\dot{V}_E$):** the volume of gas that is expired in one minute (Slonim & Hamilton, 1987).

13. **Compliance (C):** a measure of the distensibility of the lungs (Slonim & Hamilton, 1987).

14. **Functional residual capacity (FRC):** the volume of gas in the lungs after a normal expiration (West, 1979).

G. Clinical Significance of the Study

The care provided to the neonate is under ongoing scrutiny and continual evolution. It is necessary, in providing this care, to assess not only the impact of newly proposed interventions but to scientifically examine the effect of traditionally accepted practices. Positioning of the preterm infant with RDS in a head-up position is one such common practice. By comparing the effect of the head-up and bed-flat positions on arterial oxygen levels clinically relevant information on positioning the preterm infant with RDS in order to maximize respiratory function will be obtained.

II. LITERATURE REVIEW

In caring for the preterm infant with respiratory disorders, one of the aims of therapeutic intervention is the maintenance of optimal oxygenation. Recent studies have investigated the impact of prone versus supine body position, neck posture, handling and suctioning on an infant's arterial oxygenation. Relevant articles will be discussed under these headings.

A. Factors Affecting Oxygenation and Lung Mechanics

1. Horizontal Body Position

Brackbill et al. (1973) studied the psychophysiologic responses of 30 full-term healthy infants to prone and supine lying. They reported that, when prone, their infants moved less, slept more and cried less. They acknowledged that crying is an energy-consuming activity and speculated on the impact that an infant's body position could have on his/her energy consumption.

Masterson et al. (1987) examined the effect of supine versus prone lying on energy expenditure in a group of 42 preterm infants. They calculated a significantly higher energy expenditure in their infants when they were nursed in the supine as compared to the prone position. Citing the direct relationship between energy expenditure and the requirement for gas exchange, these researchers suggested that prone lying may be the position of choice for infants with cardiorespiratory insufficiency.

Martin et al. (1979) argued that a decrease in metabolic rate was not solely responsible for the improved oxygenation which they recorded in their preterm infants in the prone versus supine position. When they analyzed only periods of active sleep, they continued to record significantly higher P_aO_2's in their infants when they were nursed in prone as compared to supine lying. They attributed this to the increase in synchronous chest wall movement which they noted in their infants in the prone position.

Hutchison et al. (1979) supported these findings and also suggested that the rib cage stabilization in prone lying permitted improved diaphragmatic function in the preterm infant.

Wagman et al. (1979) evaluated the effect of body positioning (prone with the abdomen both free and restricted versus supine) on P_aO_2's and lung mechanics in their sample of 14 intubated preterm infants in the recovery phase of respiratory disease. They recorded higher P_aO_2's in the prone position and attributed this to both an enhanced diaphragmatic excursion and an improved ventilation to perfusion ($\dot{V}/\dot{Q}$) matching within the lung.

Fox and Molesky (1990) studied the effect of prone versus supine positioning on P_aO_2's in a group of 25 preterm infants with RDS. They reported a statistically higher P_aO_2 in their group of infants when they were nursed in the prone position. Although Fox and Molesky did not attempt to explain the basis for the noted differences in P_aO_2, they did provide insight into the role that body position can play in the oxygenation status of the acutely ill preterm infant.

Prone as compared to supine positioning resulted in a significant increase in oxygen saturation and a significant decrease in heart rates in intubated infants with chronic lung disease. A significant decrease in the pulmonary resistance during mechanical breaths was also noted when the subjects were prone lying (Mendoza et al., 1991).

Citing the technical difficulties often encountered in prone positioning of the ill neonate, Bozynski et al. (1988) examined the effect of side lying versus supine on the TcP_aO_2's of 18 mechanically ventilated neonates. They did not find any significant difference in the median TcP_aO_2 values when the lateral positioning was compared with the supine. However, they acknowledged that lateral positioning as compared to supine may have a positive developmental impact in facilitating mid-line behavior in the preterm infant.

The literature shows that positioning, and specifically prone lying, can have a positive impact on oxygenation in the preterm infant.

2. Vertical Body Position

Kravitz (1975) recognized the need for evaluating the impact of vertical as compared to horizontal positioning on neonates. He documented the incidence of abnormal clinical signs (cyanosis, choking and gagging, regurgitation, vomitting, and apnea) in 134 healthy, full-term infants who were nursed in either a horizontal or head-elevated 20° position. He found no statistically significant difference between the positions when either the number of infants displaying abnormal signs or the incidence of abnormal signs were compared. Kravitz stated the need for studies which would examine the physiologic and clinical effects of position on infants with respiratory distress.

Thoresen et al. (1988) examined the impact of vertical positioning on three groups of neonates: healthy term, healthy preterm and sick neonates. These researchers reported an increase in the TcP_aO_2 in the healthy term and, to a greater extent, in the healthy preterm infants when they were nursed in the head-up 30° as compared to the bed-flat position. There was no positional effect on the TcP_aO_2's in the neonates receiving mechanical ventilation.

Dellagrammaticas et al. (1991) examined the effect of progressive body tilting on oxygen tensions in 23 very low birthweight (<1500 grams) healthy neonates. They monitored P_aO_2 using a transcutaneous electrode at bed elevations of 0°, 10°, 20°. 30°, 45°, and, again, at 0°. All infants were prone lying and were monitored during quiet sleep as determined by visual assessment. All infants were being orally fed, although monitoring was scheduled 2 hours after the last feed. This study showed a direct relationship between bed tilt and mean TcP_aO_2 in each infant. There was a mean increase in the TcP_aO_2 of 13.5 mm Hg ($p<.05$) from the bed-flat to the head-elevated 45° position. The mean increase in TcP_aO_2 in the head-up 10° versus the horizontal position was 5 mm Hg. This difference was not statistically analyzed.

3. Neck Posture

Spoelstra and Srikasibhandha (1973) used dynamic pressure-volume loops to evaluate the effect of prone versus supine lying and of neck position on pulmonary mechanics in the healthy neonate. They found that neck posture has a significant impact on pulmonary mechanics with rotation causing a decrease in the dynamic compliance and flexion prompting an increase in the airway resistance. These researchers recommended that attention should be paid to the position of the head in relation to the body when monitoring pulmonary mechanics. Carlo et al. (1989) also reported an increase in airway resistance with neck flexion in infants.

Although the impact of neck posture on arterial oxygen status has not been documented, its effect on pulmonary mechanics is apparent. An increase in the pulmonary elastic or non-elastic resistance will affect the driving pressures and/or flow rates (Slonim & Hamilton, 1987) and, ultimately, the oxygen expenditure/status of the infant.

4. Handling

Nursing procedures can cause a significant decrease in the neonate's P_aO_2. Norris et al. (1981) examined the impact of three nursing procedures (suctioning, repositioning, and performing a heelstick) on TcP_aO_2 levels in a sample of 25 preterm infants. They reported significant decreases in blood oxygen tensions with suctioning and repositioning. Danford et al. (1983) monitored TcP_aO_2's during ten routine care-giving procedures in a group of 36 preterm infants. All ten procedures produced initial hypoxia in some infants. Five minutes after the intervention, there was an almost equal incidence of increased and decreased TcP_aO_2's as compared to the pre-intervention level.

5. Suctioning

Suctioning is needed to maintain patency of artificial airways (Redding et al., 1979; Truog, 1986). However, it is a noxious intervention. The documented adverse effects of endotracheal tube suctioning in the preterm infant include altered heart rates, increased blood pressure (Fanconi & Duc, 1987; Gunderson et al., 1986; Simbruner et al., 1981), tracheal damage (Friedberg & Forte, 1987), and hypoxemia (Fanconi & Duc, 1987; Fox et al., 1978; Murdoch & Darlow, 1984; Perlman & Volpe, 1983; Simbruner et al., 1981; Zmora & Merritt, 1980). The recovery time, the time required to return to the pre-suctioning level of oxygenation, varies with the specific suctioning procedure but can be a matter of one to five minutes with conventional endotracheal suctioning (Graff et al., 1987; Norris et al., 1981; Simbruner et al., 1981; Walsh et al., 1987).

6. Surface

The impact of various bed surfaces on arterial oxygen levels has not been studied. However, the possibility of an effect does exist. Scott and Richards (1979) evaluated the effect of a lambswool versus a cotton surface on weight gain and activity levels in six low birthweight infants. They recorded a significantly larger weight gain in their infants when they were nursed on the lambswool as compared to the cotton surface. They suggested that a reduction in the infants' radiant heat loss may have accounted for the larger weight gain recorded when the lambswool surface was used. The impact of the specific bed surface on arterial oxygenation must be considered.

7. Feeding

Yu (1975) studied the effects of prone, supine, and lateral positioning on the rate of gastric emptying in 48 neonates. His sample of infants included healthy term, preterm and small-for-gestational-age (SGA) infants as well as infants with RDS. He reported a delay in gastric emptying in the infants with RDS and alluded to the inverse relationship between the volume of food in the stomach and ventilatory function. It is recognized that poor ventilatory function (reductions in the resting and tidal volumes) may impact negatively on arterial oxygen levels.

8. Summary

A preterm infant's arterial oxygen level is primarily determined by the $\dot{V}/\dot{Q}$ ratio (Hand et al., 1990). The literature shows that body position, handling, and suctioning can also have a significant impact on a neonate's arterial oxygenation. Preterm infants are routinely nursed in the head-up position. It is clinically important that the effect of bed position on the preterm infant's arterial oxygenation be examined.

B. Transcutaneous Monitor of Arterial Oxygen Tension (TcP_aO_2)

The TcP_aO_2 monitor was developed in the early 1970's. It met the demands for continuous monitoring of P_aO_2's and decreased the need for repeated arterial blood gas sampling (A Huch et al., 1973).

1. Validity

Lafeber et al. (1987) studied four normoxemic neonates, simultaneously recording transcutaneous and sampled PO_2's. Their linear regression equation was $y = .87x + 10.96$ ($y = TcP_aO_2$, $x = P_aO_2$) and their correlation .91.

Fanconi (1987) reported a similar correlation co-efficient (.95) between his measurements of transcutaneous and sampled arterial oxygen tensions. His analysis included 178 data sets from 54 patients (mean age of 2.4 years). The linear correlation equation he calculated ($y = .876x - 1.04$: $y = TcP_aO_2$, $x = P_aO_2$) had a slope which was similar to Lafeber et al.'s (1987). The findings of these studies indicate that the TcP_aO_2 is a valid measurement of the partial pressure of arterial oxygen in the pediatric age group.

The difference in the y intercepts between the two studies may be explained, in part, by the different samples sizes. It is conceivable that Fanconi's (1987) larger sample provides a more accurate representation of the relationship between the two measures. The difference in the ages of the subjects between the studies may contribute to the noted difference in the y intercepts. The ranges of P_aO_2's studied may have also been a factor. Krauss et al. (1978) noted that the accuracy of transcutaneous measurements of P_aO_2 was dependent on whether the sampled P_aO_2 was in a range considered to be hypoxemic, normoxemic or hyperoxemic.

2. Reliability

Lafeber et al. (1987) reported that the TcP_aO_2 is a valid measure of the arterial oxygen tension in the normoxemic range. They suggested that, due to the shape of the oxy-hemoglobin dissociation curve, P_aO_2 is the outcome measure of choice in hyperoxemic situations. This conclusion was supported by Severinhaus (1987) who also reported that the TcP_aO_2 is a more dependable measurement tool than the $TcSaO_2$ in the presence of poor circulation.

3. Accuracy

Fanconi (1987) reported that sampled P_aO_2's were, on average, 7.43 ± 8.57 mm Hg higher than transcutaneously measured P_aO_2's. It may be that the TcP_aO_2 is more important as a trend indicator than as an accurate representation of the arterial oxygen tension. The large standard deviation may be the result of the large range of P_aO_2's which were monitored (Krauss et al., 1978).

4. Practical Considerations

In the continuous transcutaneous monitoring of arterial oxygen tension, a heated electrode is applied to the skin (R Huch et al., 1973) in order to produce local vasodilation and arterialization of the underlying capillary blood. Transcutaneous measurement of the oxygen tension is best carried out at an electrode temperature of 44 °C - 45 °C (Friis - Hanson et al., 1987; R Huch et al., 1973). However, after a three to four hour monitoring period this temperature is prone to produce a reddened and, sometimes, blistered spot on the skin (Friis - Hanson et al., 1973). In the present study the electrode temperature was set at 43 °C - 44 °C (as determined by an infant's size) for the period that each infant was in the study. The short time (approximately one and one-quarter hours) that the electrode was in place eliminated the risk of burns.

C. Pulse Oximeter

The pulse oximeter is a non-invasive continuous monitoring device for SaO_2. Its use with the adult patient to monitor oxygen levels intra-operatively (Edmonds-Seal, 1988; Tytler & Seeley, 1986), in critical care units (King & Simon, 1987; Tytler & Seeley, 1986), during the oxygen-weaning process (Acosta, 1988), and as a diagnostic tool (Bardakjian et al., 1988), has been documented and recommended. More recently the pulse oximeter has been used in monitoring the high-risk infant.

In reviewing the literature which examines the pulse oximeter as a measurement tool, only those articles testing the Nellcor oximeter were considered as this was the oximeter that was used in this study.

1. Validity and Reliability

Mihm and Halperin (1985) studied the Nellcor oximeter in an elderly population. They reported an excellent correlation ($r = .96$) between their concurrent measurements of transcutaneous ($TcSaO_2$) and directly measured saturations. Their linear regression equation ($y = .97x + 1.51$: $y = TcSaO_2$, $x = SaO_2$) showed a high degree of linearity and accuracy.

Fanconi et al. (1985) documented a similar correlation ($r = .95$, $p < .01$) between oximeter and sampled measurements in their pediatric subjects. Their linear regression equation ($y = .973x + .97$: $y = TcSaO_2$, $x = SaO_2$) also showed a high degree of linearity and accuracy. These findings support the claim that the Nellcor pulse oximeter is a valid and reliable measure of saturation.

Swedlow and Stern (1983) also evaluated the Nellcor oximeter in a pediatric population. They obtained simultaneous transcutaneous and sampled saturation readings on 23 children ranging in age from 1 day to 16 years under a variety of conditions. They reported a strong linear relationship ($r = .95$, slope $= .99$) between the data pairs.

Barrington et al. (1988) evaluated pulse oximetry as a continuous monitoring device in the neonatal intensive care unit. They reported a significant correlation ($r = .8$, $p < .0001$) between their concurrent measures of transcutaneous and sampled saturations. Their regression equation ($y = .71x + 27.1$: $y = TcSaO_2$, $x = SaO_2$) showed a moderate linearity but a low accuracy. Their regression equation differed notably from those of Mihm and Halperin (1985) and Fanconi et al. (1985) and may be explained by the different samples studied. Fetal hemoglobin has a higher affinity for oxygen than the hemoglobin of children and adults. Thus, transcutaneously measured saturations underestimated blood sample measurements in preterm infants (Peabody et al., 1987).

Lafeber et al. (1987) examined the pulse oximeter (Nellcor N-101) as a tool for measuring saturation in hypoxemic (low P_aO_2's), normoxemic (normal range P_aO_2's), and hyperoxemic (elevated P_aO_2's) neonates. They concluded that the pulse oximeter is a reliable indicator of hemoglobin saturation in the normoxemic range and is the tool of choice for continuous monitoring in the hypoxemic range.

2. Accuracy

Peabody et al. (1987) examined the accuracy of transcutaneous saturation measurements in the presence of fetal hemoglobin. They analyzed 177 paired arterial blood and $TcSaO_2$ measurements and reported that, in the presence of large amounts of fetal hemoglobin, the transcutaneous monitor consistently recorded less than the actual SaO_2.

In their study on a pediatric sample, Swedlow and Stern (1983) found the transcutaneous monitor to be accurate within 2% of the simultaneous in vitro oxyhemoglobin concentration.

The effect of pigmentation on the accuracy of the monitored saturation level has been studied. Several researchers (Griffiths et al., 1988; Shippy et al., 1984; Yelderman & New, 1983) have found the oximeter readings to be unaffected by variations in skin pigmentations.

METHODOLOGY

A. Sampling

The sample of infants included in this study consisted of preterm infants admitted to the NICU at the Royal Alexandra Hospitals (RAH) or the University of Alberta Hospitals (UAH). All infants with the exception of Subjects 1 and 11 had a primary diagnosis of RDS. The gestational age of each infant was determined by the mother's last menstrual period and/or clinical examination. The diagnosis of RDS was made by the attending neonatologist. It was based on XRay and clinical findings and negative blood cultures.

The investigator became aware of the presence of a potential candidate through on-site visits, telephone calls to the respective NICU's, and the help of the research nurses at the RAH.

The use of two neonatal units as a source of subjects facilitated achievement of the sample size.

A goal of twenty (20) subjects was set to provide ten infants for each the bed-flat-first and the head-up-first groups. After an nine month period a sample of ten infants had been obtained and was used in the descriptive and statistical analysis.

1. Inclusion Criteria

An infant was considered as a potential candidate for this study provided:

1. (s)he was a preterm infant,
2. (s)he had a primary diagnosis of RDS,
3. (s)he was receiving supplemental oxygen via a hood, a headbag, an isolette, nasal cannula, or an endotracheal tube,
4. (s)he was being nursed on a mattress,
5. it was within one week of his/her birth,
6. the attending neonatologist provided consent, and
7. informed consent for inclusion was obtained from the parent(s).

2. Exclusion Criteria

An infant was excluded from the study if:

1. (s)he did not meet the inclusion criteria,
2. there was any secondary medical or surgical condition that contra-indicated his/her being included (ie. unstable medical status),
3. (s)he was receiving medications such as bronchodilators which may have had an impact on ventilation and ultimately oxygenation. Infants receiving surfactant were considered as potential candidates provided the medication had been given more than six hours before the study period, and
4. (s)he had poor peripheral perfusion as this could have resulted in decreased accuracy of the pulse oximeter readings (Severinhaus, 1987).

B. Research Design

This research project was a prospective, clinical, randomized by order study in which the infants were used as their own controls. A crossover design facilitated the use of a relatively small sample size.

Once the inclusion criteria were met, each infant was stratified by hospital and gestational age (≤ 29 weeks/> 29 weeks) and randomly assigned, in blocks of two, to the bed-flat or head-up position first. Infants were stratified on the basis of gestational age in order to control for placement of infants at risk for more severe RDS. Twenty - nine weeks was chosen as it was one standard deviation below the mean gestational ages of the samples of preterm infants included in recent studies (Crane et al., 1990; Fox & Molesky, 1990). Group A was randomly allocated to the bed-flat position first and Group B to the head-up position first. Prior to the beginning of the study a random numbers table was used to determine the allocation of order of bed positioning for each pair of subjects.

1. Internal and External Validity

By using the infants as their own controls, balancing of all but the independent variable (bed position) was maximized. This decreased the possibility for **confounding** biases and increased the study's internal validity. To reduce the risk of **historical** or **maturation** biases, the time span between the two monitoring sessions was minimized. The randomization process balanced the impact of **maturation** and/or **historical** biases and eliminated the potential for **selection** bias. Internal calibration of the pulse oximeter at the factory eliminated the need for manual calibration of this measurement tool. The TcP_aO_2 probe was calibrated prior to each application.

C. Inservicing

A series of inservice lectures for both day and night staff was provided to each of the participating NICU's prior to the commencement of the data collection period. The inservices were held to familiarize the staff with the investigator, to inform them of the study's purpose, hypotheses and methodology, and to prepare them for their anticipated involvement in the study. An information sheet was posted in each NICU in order to reinforce the details of the study (Appendix A).

D. Treatment

Entry into the study was co-ordinated with suctioning so that an infant who was on a protocol of routine suctioning was monitored a minimum of twenty minutes after a suctioning intervention. Infants who were being fed at specified intervals entered the study one hour after a scheduled feeding.

Upon entry into the study, descriptive data were collected for each infant (Appendix B). A pulse oximeter probe was placed on the infant's foot (Barrington et al., 1988) and the TcP_aO_2 probe on his/her thorax (Huch et al., 1973). The presence of an oxygen analyzing device, for monitoring the supplemental oxygen, was assured for all subjects with the exception of the two infants (Subjects 10 & 11) receiving oxygen via nasal cannula. Each infant was positioned in prone lying with his/her head rotated to the side. The bed was placed in the horizontal position and the infant was allowed to settle into a sleep state. The infant's supplemental oxygen was adjusted to provide a baseline saturation in the middle of the range specified as acceptable for the infant (Krauss et al., 1978). The bed was subsequently adjusted to the position established by the randomization process. A 20 minute rest period followed to allow for heating and stabilizing of the TcP_aO_2 monitor. Once the arterial oxygen level had stabilized and the infant was visually assessed to be in one of Brazelton's two sleep states, a 10 minute monitoring period began. The $TcSaO_2$ and the TcP_aO_2 were recorded every 30 seconds (Appendix C). Upon completion of the first monitoring session, the bed was changed to the alternate position. A second 20 minute rest period and 10 minute monitoring session followed for Subjects 1 - 9. The TcP_aO_2's and $TcSaO_2$'s were continuously recorded in Subjects 10 and 11. Each infant was in the study for a total of 75 minutes unless additional stabilization time was required due to infant arousal or nursing intervention during the study period.

E. Co-interventions

Nursing and medical interventions were timed, as possible, to occur before or after the study period. If an infant required care during the study period, the intervention was documented and assessed as to its impact on oxygenation. If it was decided that the intervention's impact on the infant's oxygen levels was minimal and of short duration (ie. a diaper change), the arterial oxygen levels were permitted to stabilize before monitoring was re-commenced. If it was felt that the intervention may have had an ongoing impact on the arterial oxygen levels (ie. with feeding) the infant's data was excluded from the data analysis process.

Only the data of those subjects whose ventilatory support parameters (ie. supplemental oxygen, peak inspiratory pressure, positive end expiratory pressure/continuous positive airway pressure and/or ventilator rate) remained constant during the study period were used in the analysis.

F. Measurement Tools

The use of non-invasive monitoring of arterial oxygen levels in the study was deemed desirable for ethical reasons. The Nellcor pulse oximeter (N-100 or N-200, Nellcor Inc., Hayward, California) was used. It appears to be a valid and reliable tool for the continuous monitoring of hemoglobin saturation levels. In contrast to the TcP_aO_2 monitor it has numerous advantages:

1. a shorter response time,
2. the possibility of being used for a prolonged period of time,
3. no risk of burning the patient, and
4. no need for calibration (its internal calibration mechanism is set at the factory) (Barrington et al., 1988; Severinhaus, 1987).

An electrocardiogram (EKG) heart rate measurement was used as a cross-check of the oximeter's registered pulse rate. If the difference between the two heart rate measurements was less than five beats/minute, the oximeter's registered saturation was accepted as valid (Barrington et al., 1988). If there was a difference of five or more beats/minute the measure was considered invalid and the saturation that was recorded was an average of the preceding and succeeding values.

A TcP_aO_2 monitor (820, Kontron Scientific Ltd., Calgary, Alberta) was used, in addition to the oximeter, to permit comparison of the data with existing literature on the impact of position on the arterial oxygen tension in the neonate with RDS. The TcP_aO_2 electrode is a non-invasive monitor which provides a continuous read-out of the arterial oxygen tension. It appears to be a valid tool for the monitoring of P_aO_2's. It is theoretically a more sensitive outcome measure than saturation in the normoxemic range. Although it has a longer response time than the oximeter, the stabilization period and the ten minute monitoring session enhanced the ability of this monitor to register the effect of bed position on the arterial oxygen status.

During this study the range of acceptable saturations and TcP_aO_2's was in compliance with the protocol of the respective NICU's.

G. Data Analysis

1. Descriptive statistics (means and standard deviations) were calculated for the gestational ages for each group of infants (ie. those assigned to the bed-flat position first and those allocated to the head-up). An independent Student's t-test ($p<.05$) was used to establish if there was any significant difference between the two groups.
2. Descriptive statistics (means and standard deviations) were calculated for the oxygen saturations and oxygen tensions for each group of infants in each of the bed positions.
3. Two-way ANOVAs with repeated measures (group versus bed position) were used to determine if there was a significant difference ($p<.05$) in the dependent variables based on group (ie. an order effect).
4. As there was no significant difference between the groups, all 10 subjects were considered as one group for further analyses. A dependent t-test was utilized to determine if there was any significant difference ($p<.05$) in the mean $TcSaO_2$ or the mean TcP_aO_2 based on the bed position.
5. Time-series analyses (model 1,0,1) (SPSS/PC + Trends ™) of the data for two subjects (10 and 11) were conducted to evaluate the impact of bed position on the trend of TcP_aO_2's and $TcSaO_2$'s in these infants.

H. Ethical Considerations

The consent and co-operation of the Directors of the respective NICU's was obtained. The approval of the Ethics Review Committee for Human Experimentation at the UAH and of the Investigational Review Committee at the RAH was obtained prior to commencing this study.

It is common clinical practice to nurse infants in the head-up position. However, scientific information on the impact of head-up versus bed-flat positioning on arterial oxygenation in the preterm infant with RDS was not available prior to the commencement of this study. It was hoped that this study would help to establish substantiated guidelines on the preferred bed position for nursing these infants.

If an infant met the eligibility criteria for inclusion in this study, the infant's parent(s) or legal guardian(s) was approached by the investigator and asked to sign an informed consent (Appendix D). This consent explained the purpose of the research, the risks involved and guaranteed confidentiality. The parents were reassured that refusal to include their child in this study or the decision to withdraw the infant at any time was theirs to make and would in no way compromise the care that the child would receive.

IV. RESULTS

A. Introduction

Eleven infants were studied. One infant (7) was not included in the analysis because of difficulties in settling this infant and the resultant marked fluctuations in his transcutaneous oxygen readings. Data from the remaining ten subjects (five allocated to each group) provided the basis for the analyses and discussion presented.

B. Subjects

All infants, with the exception of Subjects 1 and 11, had an established diagnosis of RDS. The first subject had a final diagnosis of transient tachypnea of the newborn. The eleventh infant displayed signs of respiratory distress and required supplemental oxygen but did not have radiologic signs of RDS. All infants were nursed in neutral thermal environments under overhead radiant warmers or in isolettes.

The clinical characteristics, transcutaneous oxygen tensions and saturation readings of the infants studied are presented in Table 1. Tocolytic drugs were administered to the mothers of three of the infants studied (Subjects 4, 8, and 10). Subjects 8 and 10 also received surfactant as did Infants 2 and 6. Four of the infants (2, 3. 5, and 8) were delivered via cesarian section. Five of the infants were twins, Subjects 2 and 4 being the first-born and Subjects 3, 5 and 9 the second-born of twins. The mother of Subject 1 had gestational diabetes. All infants were studied within one week of birth (range of 6 to 164 hours of age with a mean of 64.3 ± 53.4 hours).

The result of an independent t-test evaluating the difference in the groups' gestational ages is presented in Table 2.

C. Effect of Bed Position on TcP_aO_2 and $TcSaO_2$

Table 3 shows the means (± SD) of both the transcutaneous oxygen tensions and hemoglobin saturations by group for the bed-flat and head-up positions.

The two-way ANOVAs (Tables 4 & 5) showed no significant group, position or interaction effects. The results of the dependent t-tests performed on all 10 subjects are presented in Table 6.

Table 7 shows the results of the time series analyses of the data for Subjects 10 and 11. Figures 1 and 2 show the scattergrams for Subjects 10 and 11 respectively.

The raw data for all subjects is presented in Appendices E and F. The scattergrams of the P_aO_2's and SaO_2's for Subjects 1 through 9 are in Appendix G.

Appendix H shows the lag 1 auto-correlation coefficients between sequential measurements for each dependent variable for individual subjects in each bed position.

Table 1: Characteristics of individual infants.

Infant	Group	G.A. (weeks)	Birth Weight (grams)	Sex	Birth Age (hours)	Oxygen Application	Inspired O_2	TcP_aO_2: bed-flat (mm Hg)	TcP_aO_2: head-up (mm Hg)	$TcSaO_2$: bed-flat (%)	$TcSaO_2$: head-up (%)
1	A	34	3905	M	6.0	head bag	24%	63.6 (0.50)	64.5 (0.76)	93.0 (0.56)	91.8 (1.59)
2	A	31	1745	M	79.5	hood	22%	67.6 (1.57)	62.4 (0.75)	95.2 (1.28)	92.2 (0.59)
5	A	32	1870	F	37.5	head bag	43%	69.4 (0.61)	69.0 (1.26)	96.8 (0.37)	95.0 (0.69)
7	A	28	1230	M	54.5	endotube	23%	72.6 (3.36)	74.6 (5.98)	93.2 (3.32)	92.6 (6.23)
8	A	29	1565	F	143.0	hood	31%	58.2 (0.67)	61.2 (2.40)	90.1 (0.85)	92.3 (1.38)
9	A	28	1120	M	39.0	endotube	37.5%	66.6 (0.61)	64.8 (0.62)	90.3 (0.80)	91.2 (1.04)
3	B	30	1895	M	19.5	head bag	24%	57.0 (2.52)	56.5 (2.06)	93.2 (1.09)	93.0 (1.17)
4	B	31	1600	M	18.5	isolette	37%	60.2 (4.45)	70.4 (1.50)	93.8 (1.62)	97.5 (1.32)
6	B	37	2870	F	93.0	hood	26%	61.7 (1.84)	59.8 (1.67)	93.2 (1.09)	92.6 (1.47)
10	B	29	1420	M	164.0	nasal cannula	75 cc/min.	60.1 (1.15)	71.4 (1.73)	89.5 (0.61)	92.7 (0.47)
11	B	31	1720	M	53.0	nasal cannula	5 cc/min.	50.8 (0.70)	49.6 (0.75)	92.1 (1.45)	92.0 (1.05)
Sample		**31.2 (2.5)**	**1971 (775)**		**65.3 (51.2)**			**61.5 (1.76)**	**63.0 (2.10)**	**92.7 (0.73)**	**93.0 (0.59)**

Group A = infants positioned in bed-flat first; Group B = infants positioned in head-up first; G.A.= gestational age; TcP_aO_2 = transcutaneous arterial oxygen tension; $TcSaO_2$= transcutaneous saturation. P_aO_2's, SaO_2's and sample values are expressed as the mean (± standard deviation).

Table 2: Independent t-test to evaluate the statistical significance of the difference in the mean gestational ages between Group A and B infants.

DF	Independent t Value	Prob. (2-tail)
8	-.454	.6616

Group	Count	Mean	Std. Dev.	Std. Error
A	5	30.8	2.39	1.07
B	5	31.6	3.13	1.40

Table 3: Mean's (± SD) of TcP_aO_2's and $TcSaO_2$'s for each group of infants in each bed position.

		Bed-flat	Head-up
Group A (n = 5)	TcP_aO_2	65.1 (4.38)	64.4 (2.98)
	$TcSaO_2$	93.1 (2.97)	92.5 (1.46)
Group B (n = 5)	TcP_aO_2	58.0 (4.35)	61.5 (9.31)
	$TcSaO_2$	92.3 (1.69)	93.6 (2.21)

Table 4: Two-way ANOVA with repeated measures for TcP_aO_2's for each group in each bed position.

Source	**DF**	**Sum of Squares**	**Mean Square**	**F-test**	**P value**
Group	1	124.002	124.002	2.310	.167
Subjects within Groups	8	429.526	53.691		
Position	1	10.368	10.368	.787	.401
Group x Position	1	22.898	22.898	1.738	.224
Position x Subjects within Groups	8	105.374	13.172		

Table 5: Two-way ANOVA with repeated measures for $TcSaO_2$'s for each group in each bed position.

Source	**DF**	**Sum of Squares**	**Mean Square**	**F-test**	**P value**
Group	1	.144	.144	.020	.891
Subjects within Groups	8	57.778	7.222		
Position	1	.481	.481	.221	.651
Group x Position	1	3.960	3.960	1.822	.214
Position x Subjects within Groups	8	17.394	2.174		

Table 6: Mean's (± SD) and results of dependent t-tests of TcP_aO_2's and of $TcSaO_2$'s for all infants (n = 10) in each bed position.

Variable	**Position**		**Dependent t value**	**Prob. (2-tail)**
	Bed-flat	**Head-up**		
TcP_aO_2	61.5 (1.76)	63.0 (2.10)	-.853	.4158
$TcSaO_2$	92.7 (0.73)	93.0 (0.59)	-.450	.6633

Table 7: Time-series analyses to evaluate the significance of the position change over time on the TcP_aO_2's and $TcSaO_2$'s in Subjects 10 and 11.

Subject	**Variable**	**DF**	**T-ratio**	**Prob. (2-tail)**
10	TcP_aO_2	74	-4.084	.0001
	$TcSaO_2$	74	-2.329	.0226
11	TcP_aO_2	74	.396	.6930
	$TcSaO_2$	74	.838	.4045

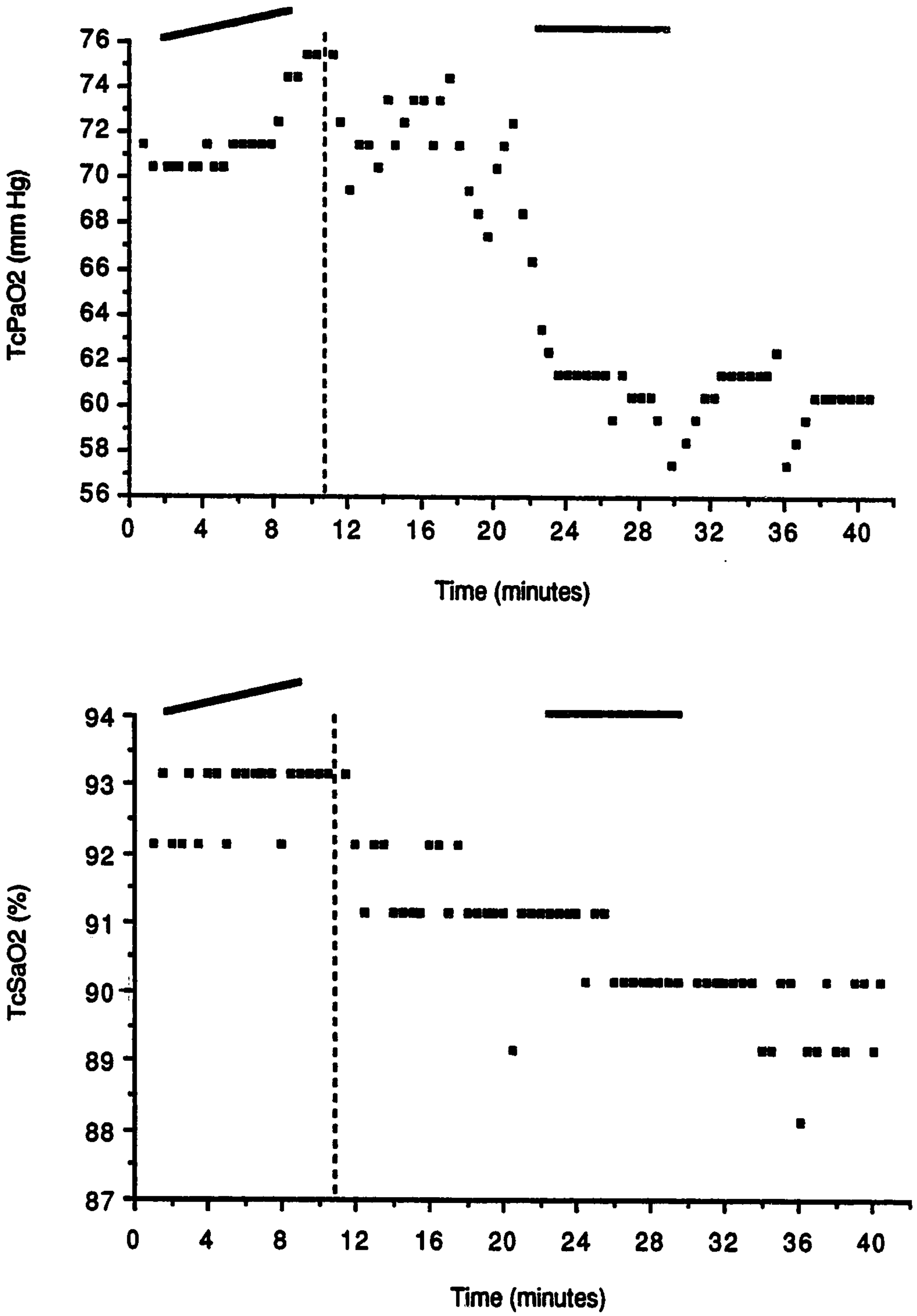

Figure 1: Scattergrams of the TcP_aO_2's and $TcSaO_2$'s for Subject 10 in the head-up and bed-flat positions.

⟋ = head-up position; ¦ = position change; — = bed-flat position

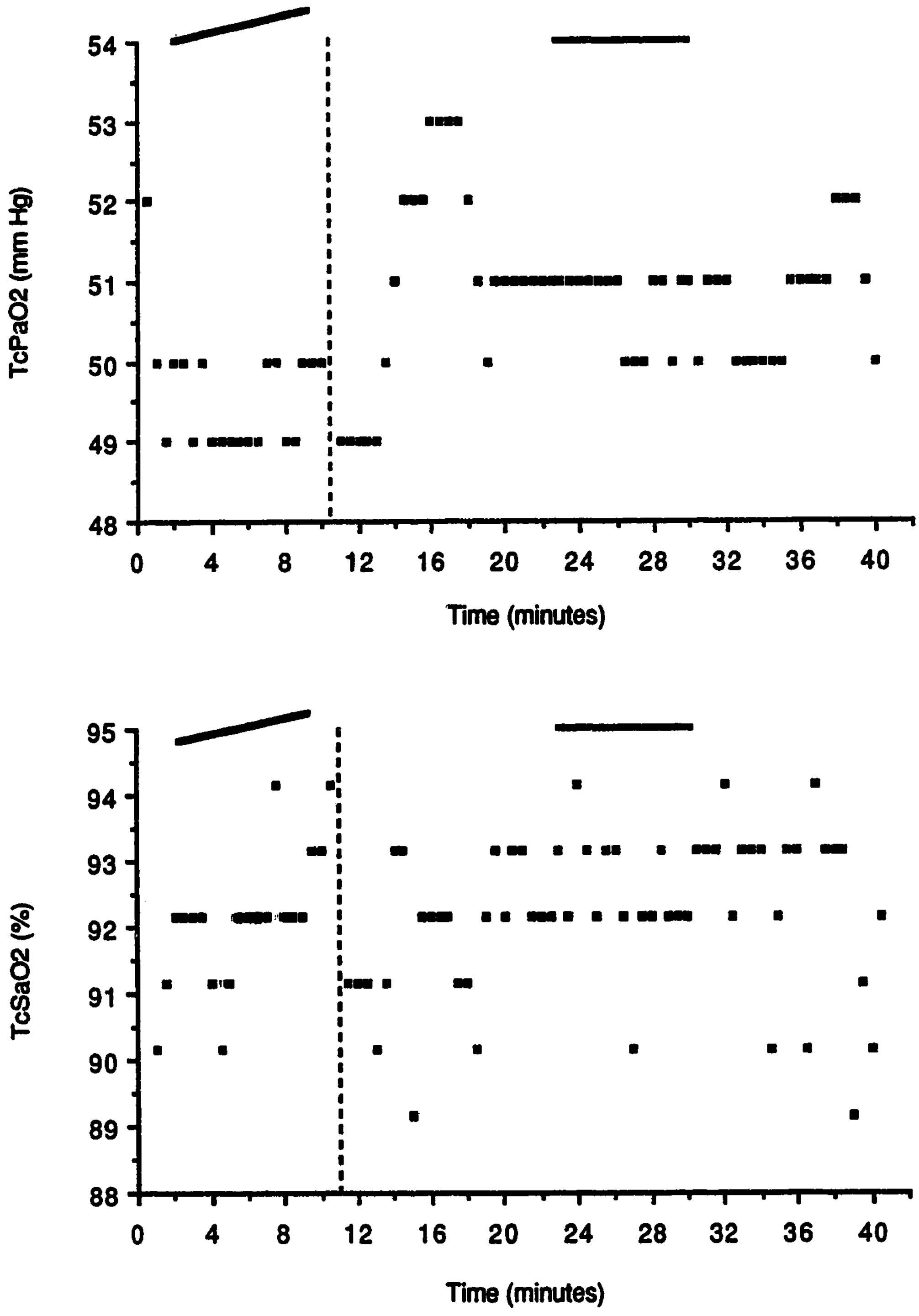

Figure 2: Scattergrams of the TcP_aO_2's and $TcSaO_2$'s for Subject 11 in the head-up and bed-flat positions.

╱ = head-up position; ⁞ = position change; — = bed-flat position

V. DISCUSSION

A. Introduction

It is important to optimize arterial oxygenation through non-invasive techniques such as positioning in preterm infants with RDS. There is a lack of data on the effect of body tilting on gas exchange in this group. This study was designed to evaluate the short term effect of head-up versus bed-flat positioning on oxygenation as measured non-invasively by the pulse oximeter and the TcP_aO_2 electrode. The discussion initially considers the sample as a group representative of the population of preterm infants with RDS. The importance of both the group and individual statistical analyses is discussed. The limitations and delimitations of the study are presented. Recommendations for future research are made. Lastly, the conclusions are outlined.

B. Subjects

1. The Sample as Representative of the Population

The sample of the present study was representative of the population of infants with RDS. Prematurity is the primary risk factor for the development of RDS. All infants included in this study were, by definition, preterm. Other cited risk factors include sex, cesarian section, and second-born of twins (Mellins & Jobe, 1988). The study's ratio of males to females was 7:3 and is supportive of the reported higher incidence of RDS in males as compared to females (Mellins & Jobe, 1988). Three of the subjects were the second-born of twins. Four of the infants were delivered by cesarian section.

The mean gestational age of the subjects (31.2 ± 2.5 weeks) was comparable to that of other studies involving preterm infants with RDS. The mean gestational age of infants in the study by Crane et al. (1990) was 31 ± 3 weeks and in Fox and Molesky's study (1990) 30.6 ± 2.4 weeks.

The mean birth weight of the infants in this study (1971 ± 775 grams) was greater than that (1633 ± 460 grams) of the sample studied by Fox and Molesky (1990) or by Crane et al.(1485 ± 645 grams) (1990). In the present study one infant (Subject 1) who was large-for-gestational-age was included in Group A. This infant's birth weight (3905 grams) was notably greater than that of the largest infant included in the studies of either Fox and Molesky (2390 grams) (1990) or Crane et al. (3120 grams) (1990). The mean birth weight and standard deviation of the sample in the present study was strongly influenced by the presence of this outlier.

The inverse relationship between gestational age and the severity of RDS, insofar as it is represented by oxygen requirements, was exemplified by the infants included in the present study. A correlation between the gestational ages and FiO_2 requirements of -.317 was calculated. This indicates the presence of an inverse, though weak, relationship between gestational age and FiO_2. It will be noted that the infants in this study entered at different post-birth ages (Table 1) and at different stages in the natural history of their RDS. This lack of control for the stage of RDS upon entry could have influenced the correlation between FiO_2 and gestational age within the sample.

2. The Sample of Infants within Groups

The independent t-test showed that there was no significant difference between the mean gestational ages of Group A and B infants. The power of the test to detect a significant difference was reduced by the small number of infants in each group ($n = 5$). However, the actual mean gestational ages of Group A and Group B infants were similar (Table 2). Gestational age is inversely related to the severity of RDS. The lack of a significant group difference in gestational ages suggested that there was no difference in the severity of RDS between the groups.

C. Effect of Bed Position on TcP_aO_2 and $TcSaO_2$

1. Groups

There was a clinically significant (> 5 mm Hg) difference between the groups for the TcP_aO_2's in the bed-flat position. Other between group differences were not clinically significant (clinical significance for differences between $TcSaO_2$ measures was defined as > 2%). Two-way ANOVAs with repeated measures failed to show statistically significant main (group or position) or interaction effects. As there was no interaction effect (ie. order had no effect on the response to position), the sample was considered as one group for further analyses.

2. Sample

The dependent t-test failed to show a significant positional difference in either the TcP_aO_2's or the $TcSaO_2$'s. Given the number of subjects and the standard deviations noted for the outcome measures, the power of the paired t-test to detect a change of 5 mm Hg in the TcP_aO_2 was .84. Its power to detect a change in the $TcSaO_2$ of 2% was .78 (Cohen, 1977). The decision regarding clinical significance was based on the reported accuracies (Fanconi, 1987), recent research (Dellagrammaticas, 1990), and known clinical guidelines for the control of oxygenation. The results of the sample analysis reject the hypothesis that a head-up tilt of 12^{o} results in a statistically significant increase in the arterial oxygen levels, as measured transcutaneously, in the preterm infant with RDS.

The findings of the present study are not in agreement with the findings of Dellagrammaticas et al. (1991). These researchers studied the impact of progressive bed tilting (10^{o}, 20^{o}, 30^{o}, and 45^{o}) on the TcP_aO_2's in 23 very low birth weight neonates. They reported a direct relationship between the tilt and the TcP_aO_2 in each of their infants. They documented a 5 mm Hg increase in the mean TcP_aO_2 when their infants were tilted 10^{o} as compared to horizontal. In the present study there was great individual variability in the response to the head-up tilt with some infants showing a decrease in their TcP_aO_2 in the head-up position. There was an increase in the mean TcP_aO_2 for the sample of only 1.5 mm Hg in the head-up as compared to the bed-flat position.

The study by Dellagrammaticas et al. (1991) and the present study had very similar methodologies but there were two notable differences in the inclusion criteria of the subjects. The first difference related to the respiratory status of the subjects. Infants in the study by Dellagrammaticas et al. (1991) did not have respiratory disorders. In the present study all infants had signs of respiratory distress and required supplemental oxygen. It may be that preterm infants with RDS respond differently than do healthy infants to position changes. The second difference pertained to the birth weights of the infants. Dellagrammaticas et al. (1991) looked at the effect of position on very low birth weight (< 1500 grams) infants. In the present study only 2 infants (Subjects 9 and 10) were < 1500 grams. Both infants had RDS. Subject 10 showed a large and clinically significant increase (10.3 mm Hg) in the TcP_aO_2 in the head-up as compared to the bed-flat position. The difference in mean TcP_aO_2's between the positions in this subject was larger than the mean difference reported by Dellagrammaticas et al. (1991). In contrast Subject 9 registered a mean TcP_aO_2 that was less (1.8 mm Hg) in the head-up position than it was in the bed-flat position. The reason for this difference in response is not explained by a review of individual characteristics. However, the mechanical ventilation of Subject 9 may have attenuated this infant's response to position. Although Subjects 9 and 10 differed in their birth age and FiO_2 requirements, it did not appear that the stage of RDS or the FiO_2 requirements were consistent predictors of response to position within the sample.

The use of nasal cannula by two of the subjects (Subjects 10 and 11) in the present study could have influenced the results. It is not possible to monitor the FiO_2 with this application of supplemental oxygen. This is not a significant problem when the flow rate of oxygen and the V_T are constant. In the present study the flow rate was constant but tidal volume may have been affected by the position change. There is an inverse relationship between the V_T and FiO_2 when the flow rate is constant (Shapiro et al., 1982). An increase in the V_T such as may occur in the head-up position (Hutchison et al., 1979) would decrease the inspired oxygen concentration, the partial pressure of oxygen in the alveoli and the arterial oxygen levels. Maintaining a constant FiO_2 may have resulted in higher arterial oxygen levels in the head-up position. This might have effected a small change in the mean readings for each infant (Subjects 10 and 11), for Group B and for the total sample. It is doubtful that the change would have been large enough to alter the findings of the ANOVA or the dependent t-test.

One subject (Subject 4) had two $TcSaO_2$ readings of 100% in the head-up position. There may have been a greater positional difference in the mean $TcSaO_2$ readings in this subject if this ceiling effect had not occurred. However, the impact of two altered values on the individual mean would have been small given that 20 readings were used to calculate each position mean. The effect on the group and sample means would have been less and would not have been enough to make a difference in the results.

3. Individual Subjects

The lack of significant positional differences in the dependent variables may be explained in part by the variation in individual responses (see Table 1). There are other possible explanations for the lack of a significant treatment effect within the sample. Vertical tilt may not affect arterial oxygenation in the preterm infant with RDS. The specific tilt used may have been too small to affect the arterial oxygen levels.

In two of the ten subjects there were opposite changes in the TcP_aO_2 and $TcSaO_2$ readings in the head-up as compared to the bed-flat positions. This finding is not compatible with known physiology as there is a direct relationship between hemoglobin saturation and arterial oxygen tension. Inaccuracies in the measurement tools may account for these unexpected results. The slow response time of the TcP_aO_2 monitor may have resulted in an inaccuracies in the means for this outcome measure.

It appeared that in some cases individual infants responded in a clinically significant manner to a change in vertical bed position. This observation prompted the use of time-series analyses of the responses of two subjects (10 and 11).

Ottenbacher (1986) recommends that the process for analyzing single subject data should include graphic representation, visual analysis and, finally, statistical analysis. Visual inspection examines the pre- and post-intervention data with respect to the **variance** or range in responses, the **level** or magnitude of the measures, and the **trend** or direction of the data over time.

The scattergrams (Figures 1 and 2) of the TcP_aO_2's and $TcSaO_2$'s for Subjects 10 and 11 show large variances in the outcome measures for each subject in each bed position. There is no immediate impact of the position change on the level of the dependent variables in Subject 10 although a decrease in the mean values for both outcome measures appears to be the result of the position change. The immediate effect of the position change on the dependent variables in Subject 11 can not be assessed visually because of the instability of the pre-intervention (baseline) data in this infant. Nor does there appear to be any clinically significant change in the mean level of the outcome measures over time. The trends of both outcome measures appear to be affected by the position change in Subject 10. The pre-intervention trend for the TcP_aO_2 values is an accelerating one while the post-intervention trend is a downward or decelerating one. The direction of the pre-intervention $TcSaO_2$ values appears to be level and the post-intervention trend assumes a downslope. There are no visually significant changes in the trends for either outcome measure in Subject 11.

The time-series analyses of the data for Subjects 10 and 11 utilized an ARIMA model (1,0,1) (SPSS/PC + Trends ™) with an autoregressive (AR1) and a moving average (MA1) component. This model acknowledges that the value of a variable response is determined, in part, by the magnitude of the previous response in the time series as well as present and past random error. The analysis evaluates whether a defined intervention (position change) produces a difference in the outcome measure which is greater than can be explained by chance. The statistical analysis involves the calculation of a T-ratio which compares the difference in the mean values of the dependent variables pre- and post-intervention to the standard error of the mean. A greater difference in an outcome measure pre- and post-intervention will produce a T-ratio which is larger and more likely to be statistically significant. The degrees of freedom are calculated from the number of observations minus the sum of the levels of transformations performed and the number of independent variables. The statistical analysis for Subject 10 showed that position change was a statistically significant predictor of both TcP_aO_2 and $TcSaO_2$ values. The statistical analysis of the data for Subject 11 failed to show significance. The clinical significance of the individual responses is tempered by the fact that the effects were tested over a limited period. Long term effects were not evaluated.

The failure to replicate results across subjects in the time-series analyses supports the findings of the group analyses and rejects the hypothesis that a head-up tilt of 12^o will effect an increase in arterial oxygen levels in the preterm infant with RDS.

4. Physiologic Consideration

Position change may have an effect on minute ventilation ($\dot{V}_E$). Stark et al. (1984) reported a significant decrease in $\dot{V}_E$ and increase in end-tidal partial pressure of carbon dioxide (PCO_2) when their group of newborns were elevated from a horizontal to an almost upright position. According to Dalton's Law, an increase in the P_ACO_2 would cause a decrease in the partial pressure of oxygen within the alveoli (P_AO_2). This would result in a decreased diffusion gradient for oxygen and, subsequently, a decreased P_aO_2. $\dot{V}_E$ was not monitored in this study and definitive conclusions can not be drawn. It is acknowledged that the effect of the position change on $\dot{V}_E$ and P_AO_2 in the present study would have been small.

5. General Observations

a. Measurement Errors

An oxygen analyzer was used to monitor the FiO_2 of those infants in a head bag or hood (n = 6). The distance between the analyzer and infant's mouth was not standardized and may have changed with the alteration in bed position. Nor was the analyzer consistently positioned in front of each infant's mouth. Although in each case the analyzer registered a constant FiO_2 during the study period, it may not have accurately reflected the FiO_2 in the infant's immediate ambient environment.

There were 22 instances when the difference between the heart rate measurements obtained from the EKG and the oximeter were greater than four beats/minute. The incidence of occurrence was fairly equally distributed between positions: 12 were recorded in the head-up and 10 in the bed-flat positions. Nineteen episodes involved single measurements and one involved a run of three measures. In all instances the recorded saturation was an average of the preceding and succeeding values. The impact of these averaged measurements on the positional means would have been minimal given the number of measurements used to calculate each mean.

b. Recruitment of Subjects

There was a high incidence of parental refusals. The reason most frequently given was of concern for the infant and a desire not to further disturb him/her. The fact that the investigator was not a member of the neonatal team may have been a predisposing factor for refusal. It is possible that involving a member of the neonatal team in the recruitment process may have decreased the number of parental refusals.

6. Limitations

The limitations of the present study include:

1. a lack of strict control for sleep state. Visual assessment of sleep state has been used in some studies (Dellagrammaticas et al, 1991). However, other researchers (Martin et al., 1979) have used electro-oculograms as an objective method of monitoring the behavioral state of their subjects. The use of a cardiopulmonary monitor would provide a more sensitive assessment of the regularity of an infant's respirations and lead to a more accurate decision regarding sleep state.
2. the inclusion of two individual infants who did not meet the criteria for RDS.

7. Delimitations

The study was delimited to:

1. the observation of each infant on only one occasion in each of two positions.
2. the observation of each infant in a head-up position of only 12^{o}.
3. observation over a short period of time (approximately 60 minutes).

8. Recommendations

The present study failed to show a significant difference in the transcutaneously measured arterial oxygen levels in preterm infants with RDS when they were placed in a head-up 12° as compared to a bed-flat position. This failure may be reflective of measurement and methodology errors and future research should direct itself to minimizing these factors. Recommendations for future studies on the impact of bed position include:

1. the study of infants at a specific stage in the natural course of RDS.
2. the use of an electro-oculogram or cardiopulmonary monitor in order to accurately monitor the sleep states of the infants. Control for sleep state during the monitoring phases of the study would ensure that altered arterial oxygen levels were not simply a reflection of an altered behavioral state.
3. the use of an indwelling umbilical arterial line in order to minimize measurement error.
4. the use of a baseline-intervention-baseline (ABA) design (Ottenbacher, 1986) for single-subject studies.

Subsequently, it would be recommended that research be directed to:

5. the evaluation of the impact of increased vertical tilts on arterial oxygenation in the infant with RDS.
6. monitoring the infants' heart rates, respiratory rates, and tidal volumes in order to obtain more comprehensive insight into the impact of vertical tilting on physiologic parameters.

VI. CONCLUSIONS

The purpose of this study was to determine if nursing the preterm infant with respiratory distress syndrome in a head-up 12° position as compared to a bed-flat position would have a significant impact on transcutaneously measured arterial oxygen levels. It was hypothesized that there would be a significant increase in both the TcP_aO_2 and the $TcSaO_2$ in the head-up as compared to the bed-flat position.

Within the limitations of this study, the following conclusions may be drawn:

1. There is no support for the routine positioning of an infant with respiratory distress syndrome in a head-up 12° position in order to improve arterial oxygenation.
2. Individual responses to a head-up tilt of 12° vary and may be clinically significant.

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Appendix A:

Information Sheet

THE EFFECT OF BED POSITION ON ARTERIAL OXYGENATION IN THE PRETERM INFANT WITH RESPIRATORY DISTRESS SYNDROME

This research project will be conducted in the NICU by Brenda Bissell, physiotherapist and graduate student. It is tentatively scheduled to run from February, 1991 through March, 1991.

PURPOSE

This research project proposes **to examine the impact of two bed positions (bed-flat and head-elevated) on the arterial oxygen levels in the preterm infant with RDS.**

Although the effect of **body position** on the arterial oxygen levels has been well documented, the impact of the **head-up bed position** on arterial oxygenation has not been scientifically recorded. It is felt that this is a clinically relevant study that will provide further information on positioning the preterm infant with RDS in order that arterial oxygenation may be maximized.

METHODOLOGY

An infant will be considered as a potential subject for this study provided:

1. (s)he is a preterm infant,
2. (s)he has a primary diagnosis of RDS,
3. (s)he is receiving supplemental oxygen via a hood apparatus, in an isolette, or by means of an endotracheal tube,
4. (s)he is being nursed on a mattress,
5. it is within 72 hours of his/her birth, and
6. consent is obtained from both the neonatologist and the parent(s)/guardian(s).

Entry into the study will be timed to co-ordinate with scheduled nursing procedures (ie. feeding, suctioning, CXR's, etc). Upon entry into the study, the infant will be placed in the bed-flat, prone lying position. A pulse oximeter and transcutaneous oxygen tension electrode will be applied. The FiO_2 will be adjusted to provide a saturation of 90%. The initial, randomly determined bed position (either bed-flat or head-up) will be set. A rest period will follow. Once the arterial oxygen levels have stabilized and the infant is assessed to be in a sleep state, a ten minute monitoring period will begin. Upon completion of the first monitoring session, the bed position will be changed to the alternate position. A second rest period and monitoring session will follow. The infant will then exit the study.

It is anticipated that each infant will be in the study for a period of approximately 1 1/4 hours.

This study will occur at both the NICU at the RAH and the UAH.

NURSING INVOLVEMENT

It is anticipated that this will include:

1. positioning each infant in prone lying at the beginning of the study, and
2. input regarding the best timing for the study. It would be ideal if the timing was such that nursing/medical interventions were not anticipated during the study period.

QUESTIONS ?????

Please ask......**Brenda Bissell**

THANK YOU !!! YOUR HELP IS TRULY APPRECIATED !!!

Appendix B:

Infant Identification Form

Infant Identification Form

NAME	I.D.#	SEX
BORN:	GESTATION	B.W.
AGA/SGA	DIAGNOSIS	FEEDS
MEDS: 1. TOCOLYTIC DRUGS PRE-NATALLY: Y N 2. EXOSURF: Y N		
DATE & TIME OF ENTRY INTO STUDY		
	POSITION 1	POSITION 2
FIO_2		
O_2 APPLICATION VIA...		
IMV		
PIP		
PEEP/CPAP		
TEMP.		
PCO_2		
pH		
STATE		
STATUS AT BIRTH AGE OF 28 DAYS		

Appendix C:

Data Collection Form

Data Collection Form

Subject # ___

POSITION 1:			POSITION 2:		
FiO_2	TcP_aO_2	$TcSaO_2$	FiO_2	TcP_aO_2	$TcSaO_2$

Appendix D:

Consent Form

Consent Form

The Effect of Bed Position on Arterial Oxygenation in the Preterm Infant with Respiratory Distress Syndrome

I, ____________________, freely and voluntarily consent to the participation of my child, ____________________, in the above-named research project under the direction of Brenda Bissell, physiotherapist, and graduate student in the Department of Physical Therapy, University of Alberta, to be conducted in the Neonatal Intensive Care Unit at the Royal Alexandra Hospitals.

The purpose of this study is to examine the effects of two bed positions (lying flat and with the head-end slightly elevated) on my child's blood oxygen levels. This may help to determine which position is better for routine positioning of preterm infants.

I understand that my child will be in this study for ~one and one-quarter hours of which three-quarters of an hour will be spent in the horizontal and one-half hour in the head-up position. For ten minutes in each position my child's blood oxygen level will be monitored. This will done by applying a skin monitor to his/her foot and a second monitor to his/her back. These devices are used routinely in the care of infants like mine and are not expected to pose any risks to my child.

The risks of the two positions have been explained to me. These include a change in my child's blood-oxygen levels and/or a change in his/her heart rate. I understand that the occurrence of these signs may necessitate that a change be made in the amount of oxygen which (s)he is receiving.

I may withdraw my child from this study at any time without compromising the care that (s)he will receive.

I understand that if I have any questions regarding my child's participation in this study I can call Brenda Bissell at 492-7459 or Dr. N. Finer, the unit's medical director, at 477-4644.

I authorize Dr. N. Finer, B. Bissell and the Department of Neonatology to keep, use and dispose of the findings of this research with the provision that my name or my child's name will not be associated with the results.

I have been given the right to ask questions concerning the procedures to be used during this research. All my questions have been answered to my satisfaction.

I have read and understand the contents of this form and have received a copy of it.

____

Parent(s)/Guardian(s) Date

____

Principal Investigator Date

____

Witness Date

I have explained and defined in detail the research procedures to which the infant will be subjected and have answered all questions raised by his/her parents(s)/guardian(s).

____

Investigator Date

Appendix E:

Raw Data -

TcP_aO_2 Readings

GROUP A										GROUP B									
Bed-flat					**Head-up**					**Head-up**					**Bed-flat**				
Subject #					Subject #					Subject #					Subject #				
1	2	5	8	9	1	2	5	8	9	3	4	6	10	11	3	4	6	10	11
64	68	69	58	68	65	64	70	66	65	58	73	62	71	52	62	68	61	59	51
64	68	69	59	67	65	63	70	64	65	59	73	63	70	50	60	66	61	60	51
64	67	69	58	67	65	63	71	63	64	58	72	63	70	49	60	67	61	60	51
64	66	69	57	67	65	63	71	63	64	58	72	62	70	50	60	65	61	61	50
64	65	70	57	66	65	63	70	62	64	57	72	61	70	50	59	65	61	61	50
63	65	70	58	66	64	62	69	62	64	59	71	60	70	49	59	66	63	61	50
64	65	70	58	66	66	62	69	62	65	59	71	60	70	50	57	62	65	61	50
63	66	70	59	66	65	62	68	61	65	59	71	60	71	49	59	62	65	61	50
63	68	70	59	66	64	61	66	61	65	57	70	60	70	49	56	60	64	61	50
64	70	70	59	66	63	63	67	63	65	57	70	60	70	49	57	59	64	62	51
64	69	70	58	67	63	63	68	62	65	56	71	58	71	49	56	58	64	57	51
64	69	70	57	67	64	63	68	62	66	56	70	58	71	49	56	57	62	58	51
63	69	70	58	67	64	62	69	60	66	56	69	57	71	49	56	57	62	59	51
63	69	69	58	67	65	62	69	61	65	56	68	58	71	50	56	56	61	60	51
63	69	69	58	67	65	62	69	58	65	55	69	59	71	50	57	56	60	60	52
63	69	69	58	67	64	62	70	55	64	56	70	59	72	49	54	56	60	60	52
64	69	69	58	66	65	63	70	61	64	54	68	59	74	49	54	56	60	60	52
64	67	69	58	66	64	62	69	61	65	54	69	59	74	50	54	56	60	60	51
64	67	68	59	66	64	61	68	59	65	52	70	59	75	50	53	56	59	60	50
63	67	[illegible]	59	66	65	62	68	58	65	53	69	59	75	50	54	56	60	60	51

Appendix F:

Raw Data -

TcSaO_2 Readings

GROUP A										GROUP B									
Bed-flat					**Head-up**					**Head-up**					**Bed-flat**				
Subject #					Subject #					Subject #					Subject #				
1	2	5	8	9	1	2	5	8	9	3	4	6	10	11	3	4	6	10	11
93	94	96	90	90	90	92	95	90	91	94	98	94	92	90	95	97	93	90	93
92	94	96	91	90	88	92	95	92	90	95	97	97	93	91	94	92	94	90	94
94	94	96	90	90	89	91	96	94	90	94	100	95	92	92	94	95	94	90	92
93	94	97	89	90	90	92	95	92	90	93	100	94	92	92	95	96	93	90	93
93	94	97	89	89	92	92	95	94	90	93	98	93	93	92	93	97	92	90	93
93	94	97	91	91	92	92	96	92	90	94	98	92	92	92	94	96	95	89	93
93	94	97	90	89	93	92	95	91	92	95	97	91	93	91	94	93	94	89	90
93	94	97	91	90	94	92	94	93	91	93	97	91	93	90	94	94	94	90	92
93	94	97	89	90	92	91	94	93	92	93	98	92	92	91	93	93	94	90	93
93	95	97	90	91	93	93	95	94	91	93	96	92	93	92	93	93	94	88	93
93	95	97	88	92	94	92	95	93	92	94	97	91	93	92	92	92	94	89	90
93	96	97	90	91	93	93	95	93	92	93	98	92	93	92	93	94	93	89	94
94	96	97	91	91	91	93	95	92	93	93	96	92	93	92	93	92	93	90	93
92	97	97	90	91	91	92	95	94	90	93	97	92	93	94	93	93	92	89	93
93	97	97	91	90	92	92	96	92	91	92	99	92	92	92	94	94	92	89	93
92	97	97	90	91	92	92	95	94	90	93	98	93	93	92	92	93	93	90	89
93	97	97	90	89	91	93	95	90	92	91	95	92	93	92	92	93	93	90	91
93	97	97	91	91	93	93	94	92	93	92	96	92	93	93	91	93	91	89	90
94	96	97	91	90	92	92	94	91	92	91	96	93	93	93	92	92	91	90	92
93	95	97	90	90	93	92	94	90	91	91	98	92	93	94	92	93	94	89	91

Appendix G:

Scattergrams of TcP_aO_2 and $TcSaO_2$ Readings for Subjects 1 - 9

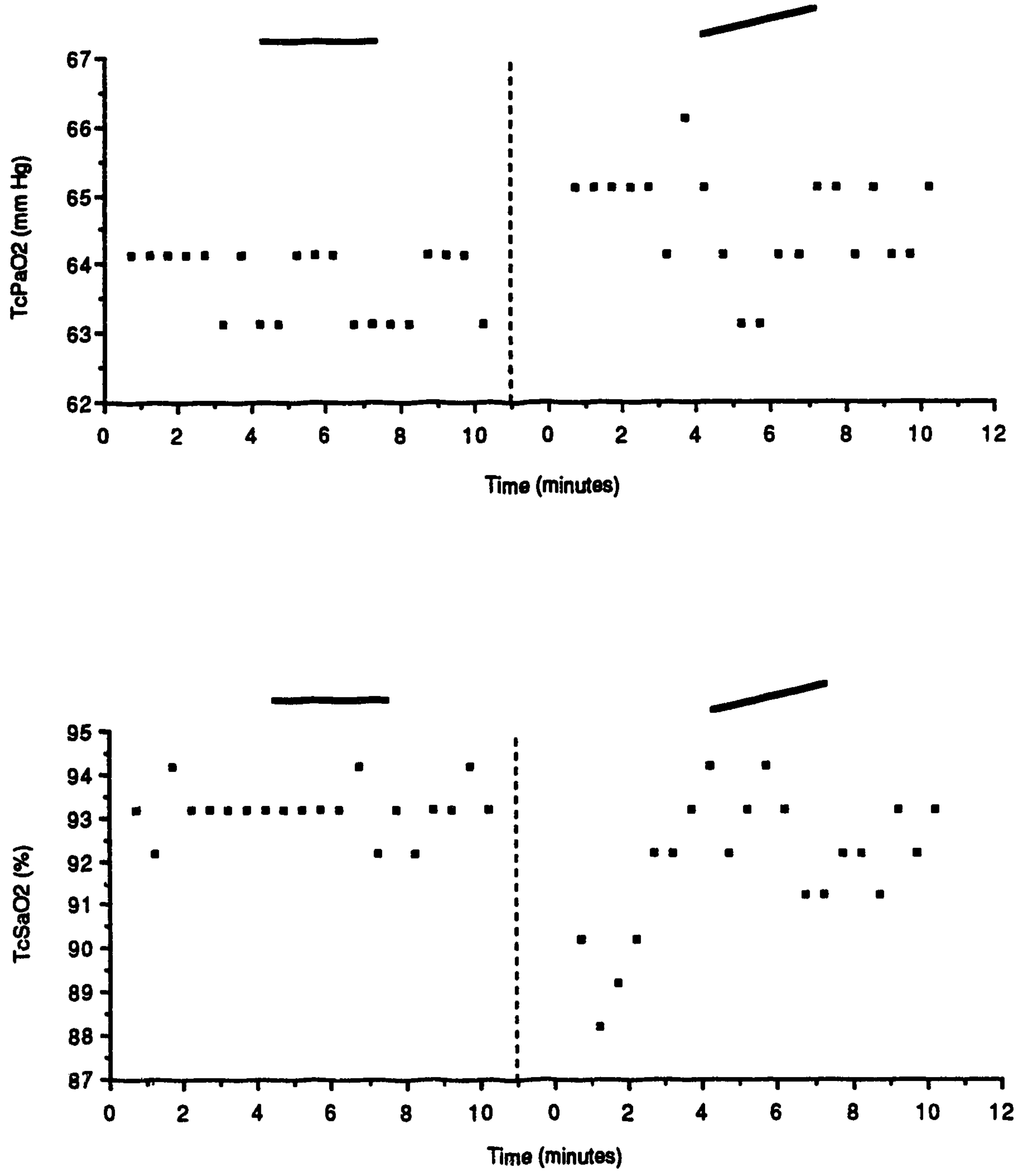
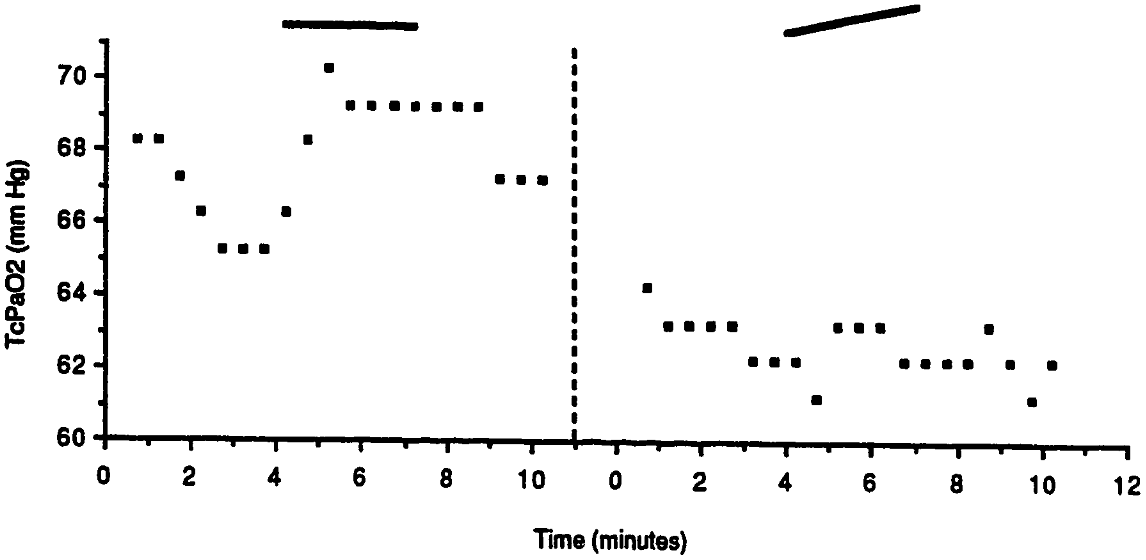


Figure G.1: Scattergrams of the TcP$_a$O$_2$'s and TcSaO$_2$'s for Subject 1 in the bed-flat and head-up positions.

— = bed-flat position; ⋮ = position change; ╱ = head-up position



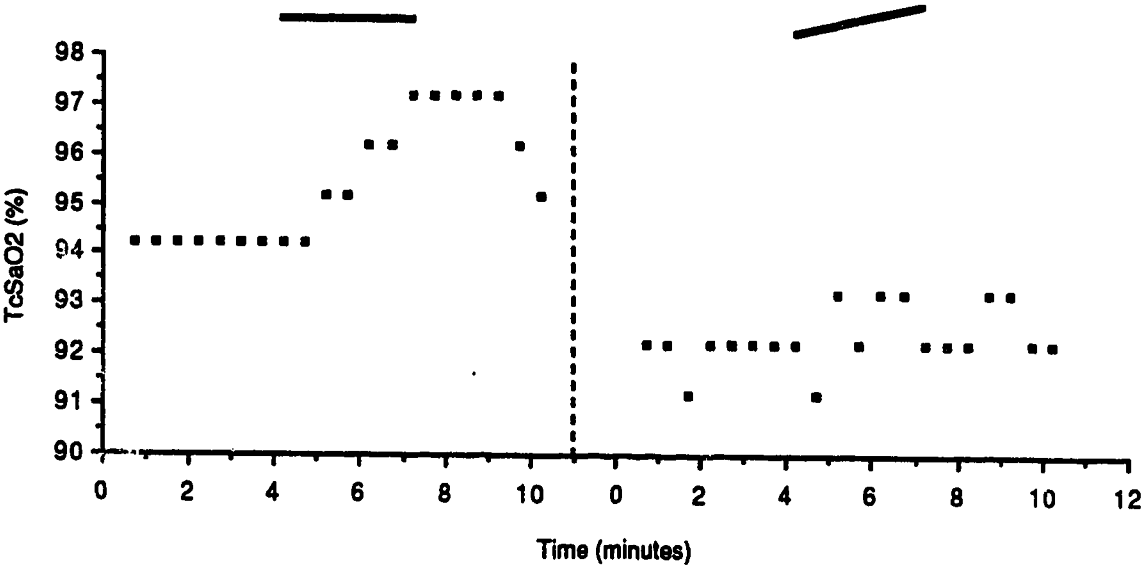


Figure G.2: Scattergrams of the TcP_aO_2's and $TcSaO_2$'s for Subject 2 in the bed-flat and head-up positions.

▬ = bed-flat position; ¦ = position change; ⟋ = head-up position

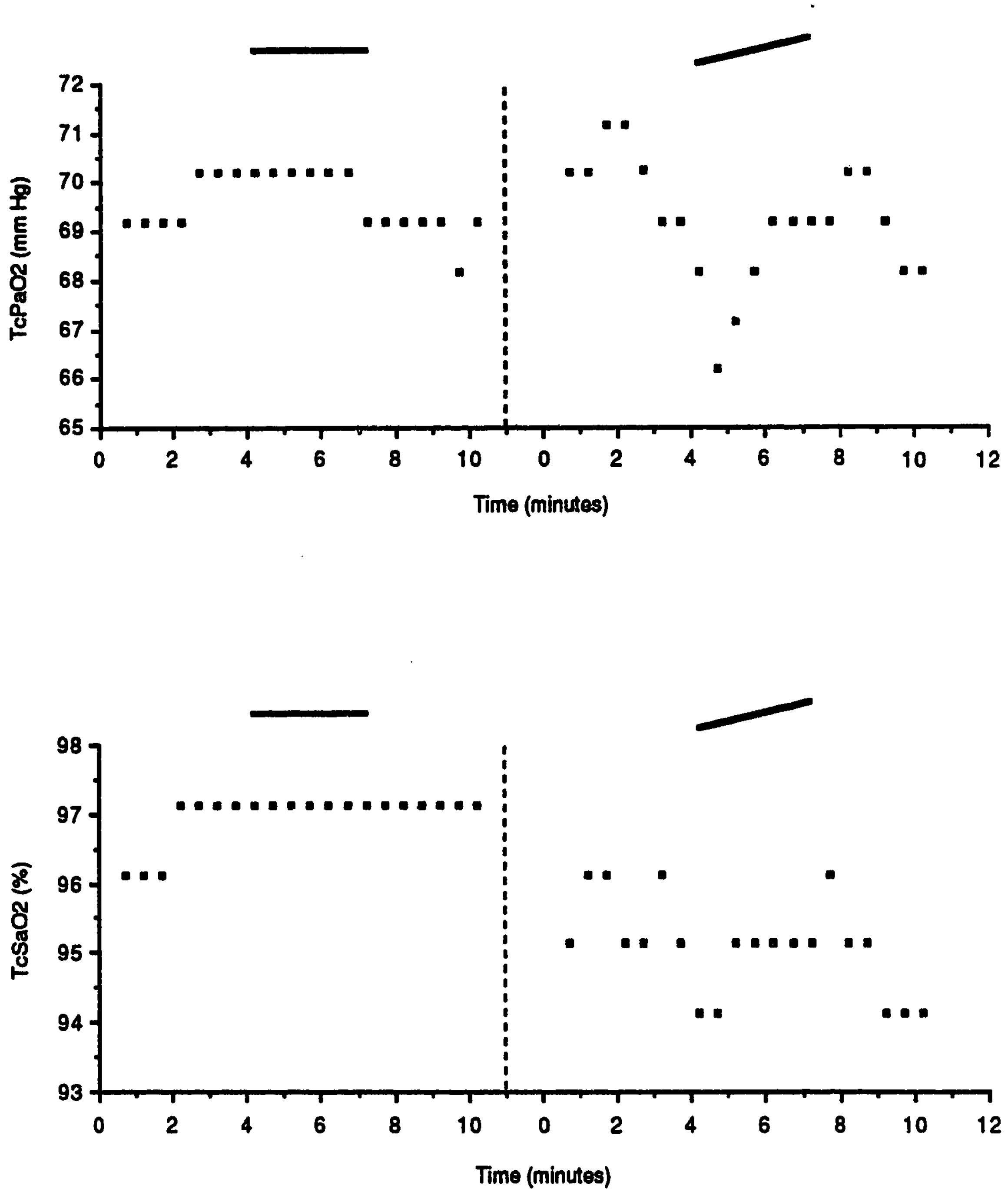
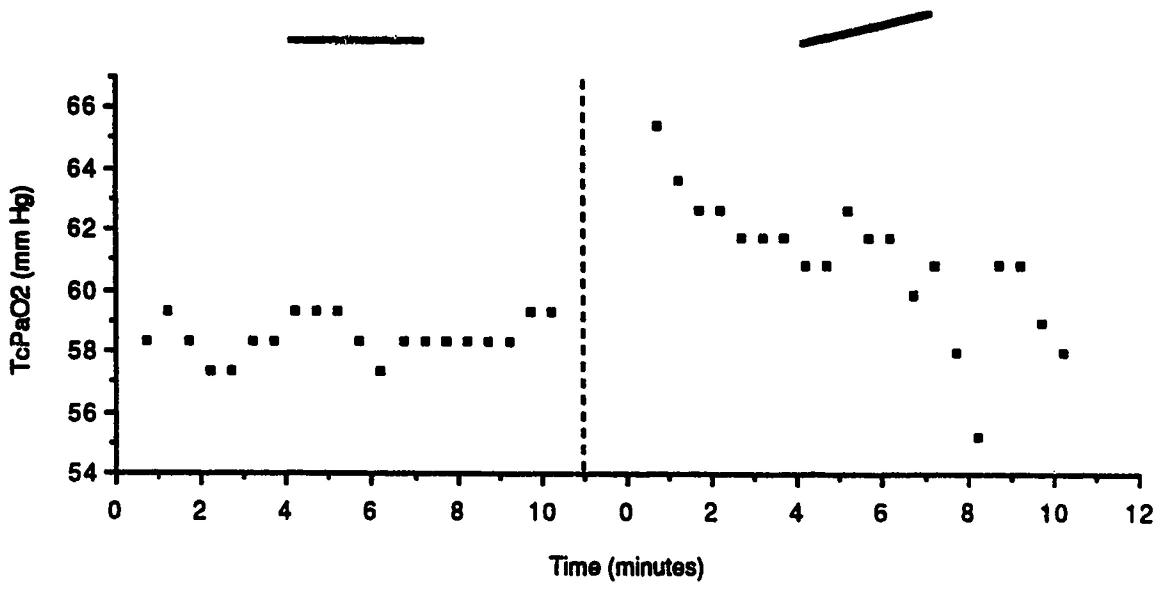


Figure G.3: Scattergrams of the TcP_aO_2's and $TcSaO_2$'s for Subject 5 in the bed-flat and head-up positions.

▬ = bed-flat position; ⁞ = position change; ⟋ = head-up position



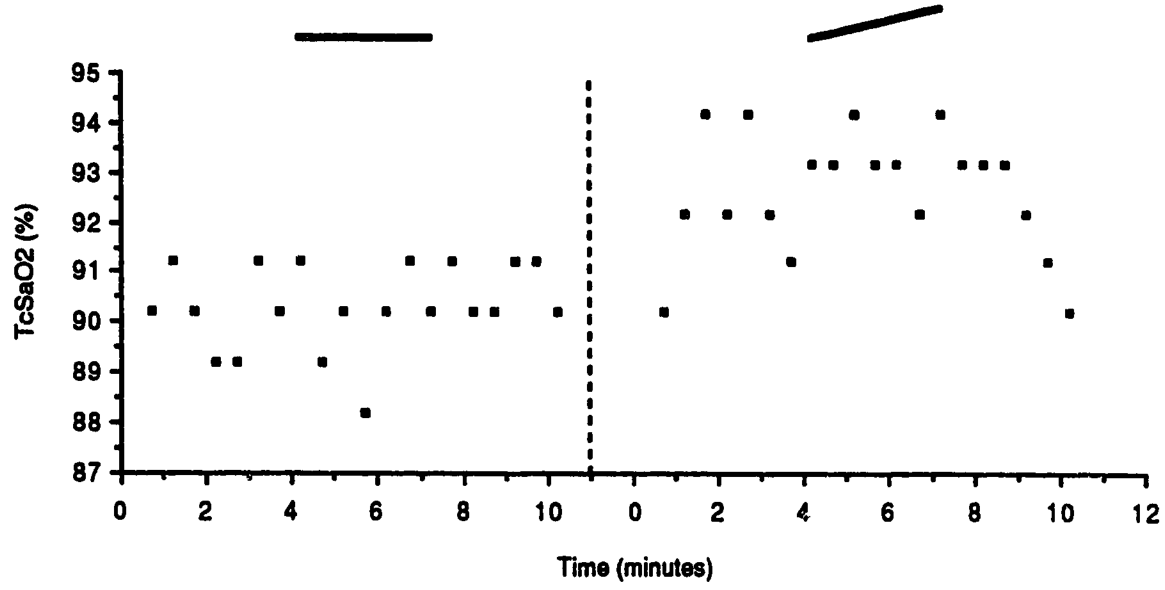


Figure G.4: Scattergrams of the TcP_aO_2's and $TcSaO_2$'s for Subject 8 in the bed-flat and head-up positions.

— = bed-flat position; ⁞ = position change; ⁄ = head-up position

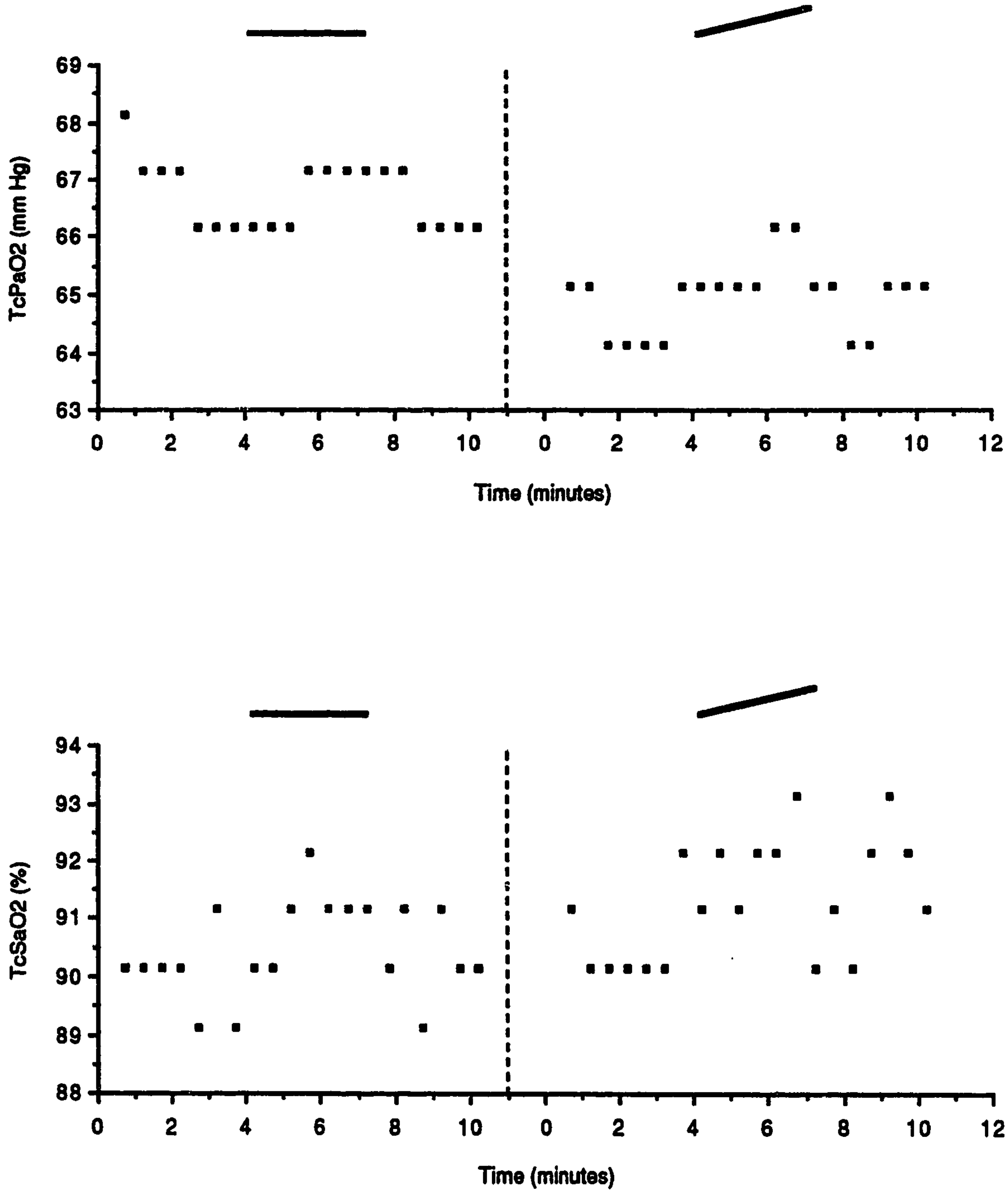
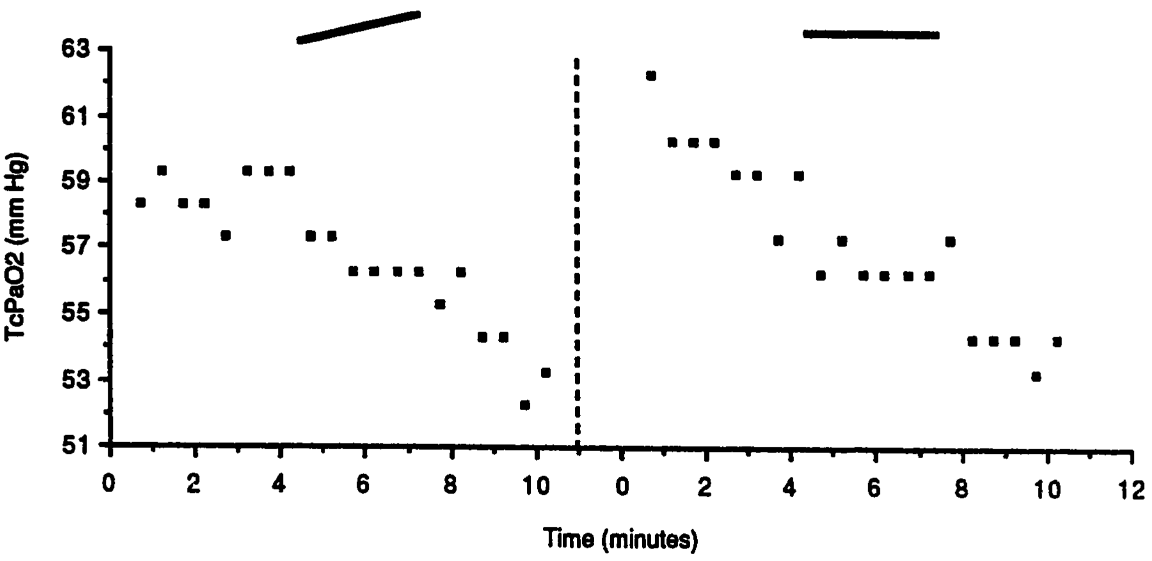


Figure G.5: Scattergrams of the TcP_aO_2's and $TcSaO_2$'s for Subject 9 in the bed-flat and head-up positions.

▬ = bed-flat position; ¦ = position change; ⁄ = head-up position



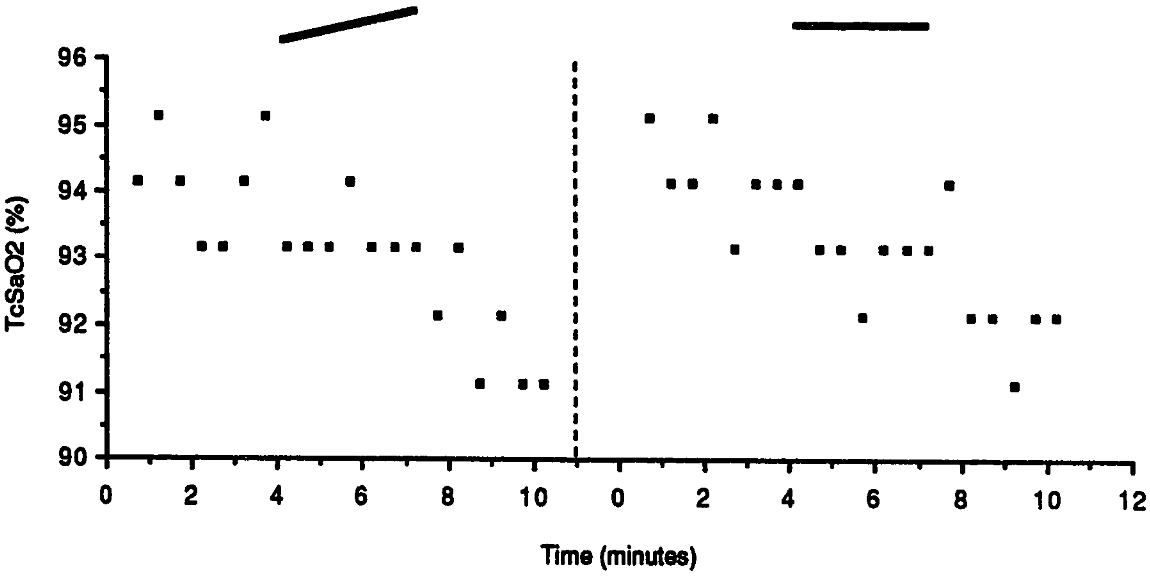
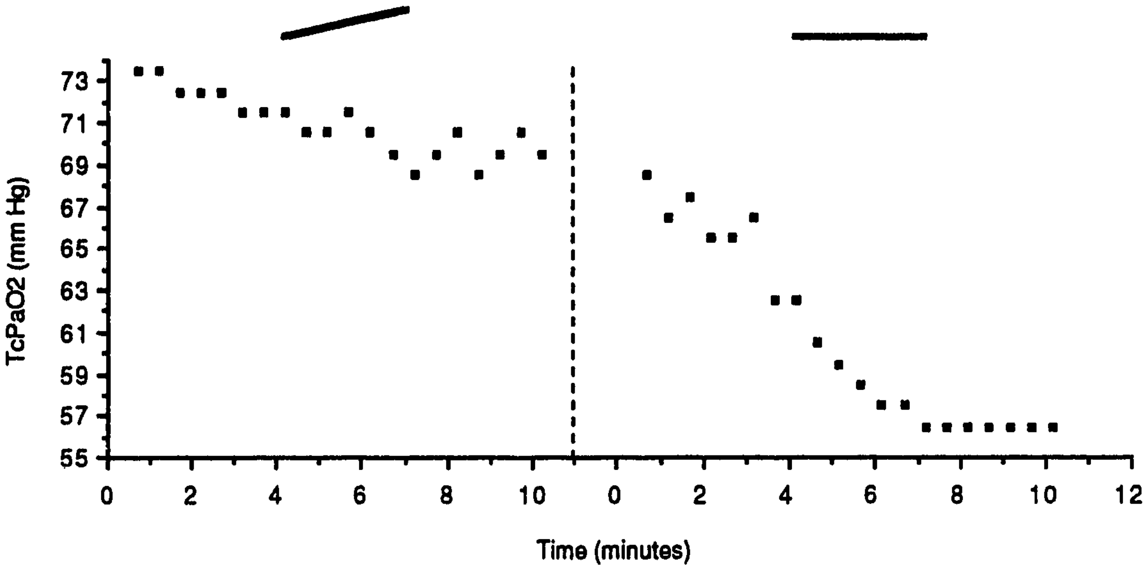


Figure G.6: Scattergrams of the TcP_aO_2's and $TcSaO_2$'s for Subject 3 in the head-up and bed-flat positions.

▬ = head-up position; ¦ = position change; ▬ = bed-flat position



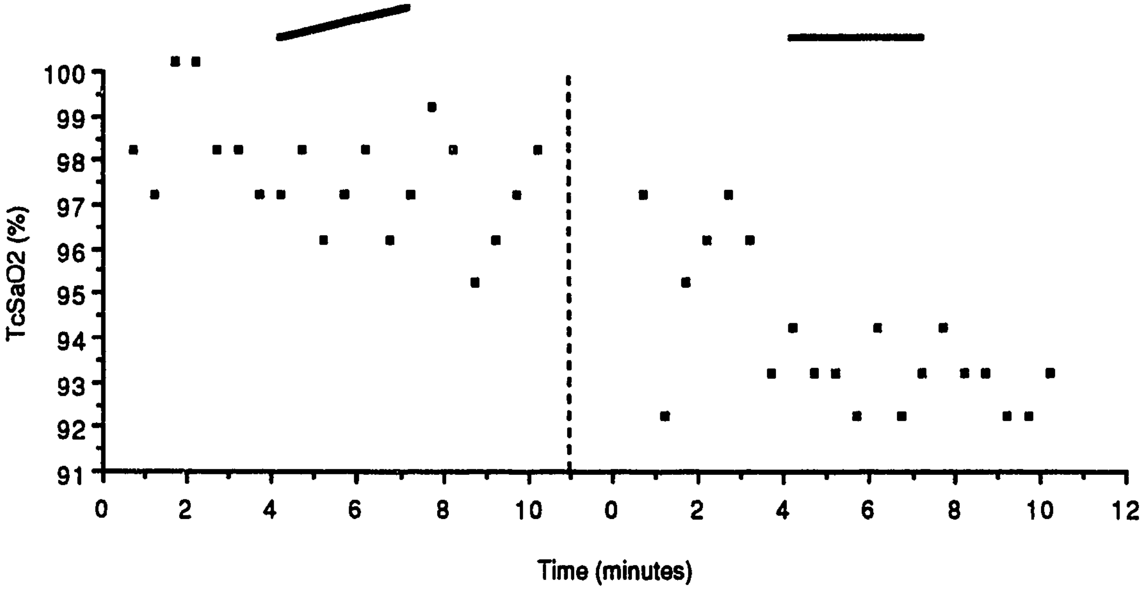


Figure G.7: Scattergrams of the TcP_aO_2's and $TcSaO_2$'s for Subject 4 in the head-up and bed-flat positions.

╱ = head-up position; ⋮ = position change; ▬ = bed-flat position

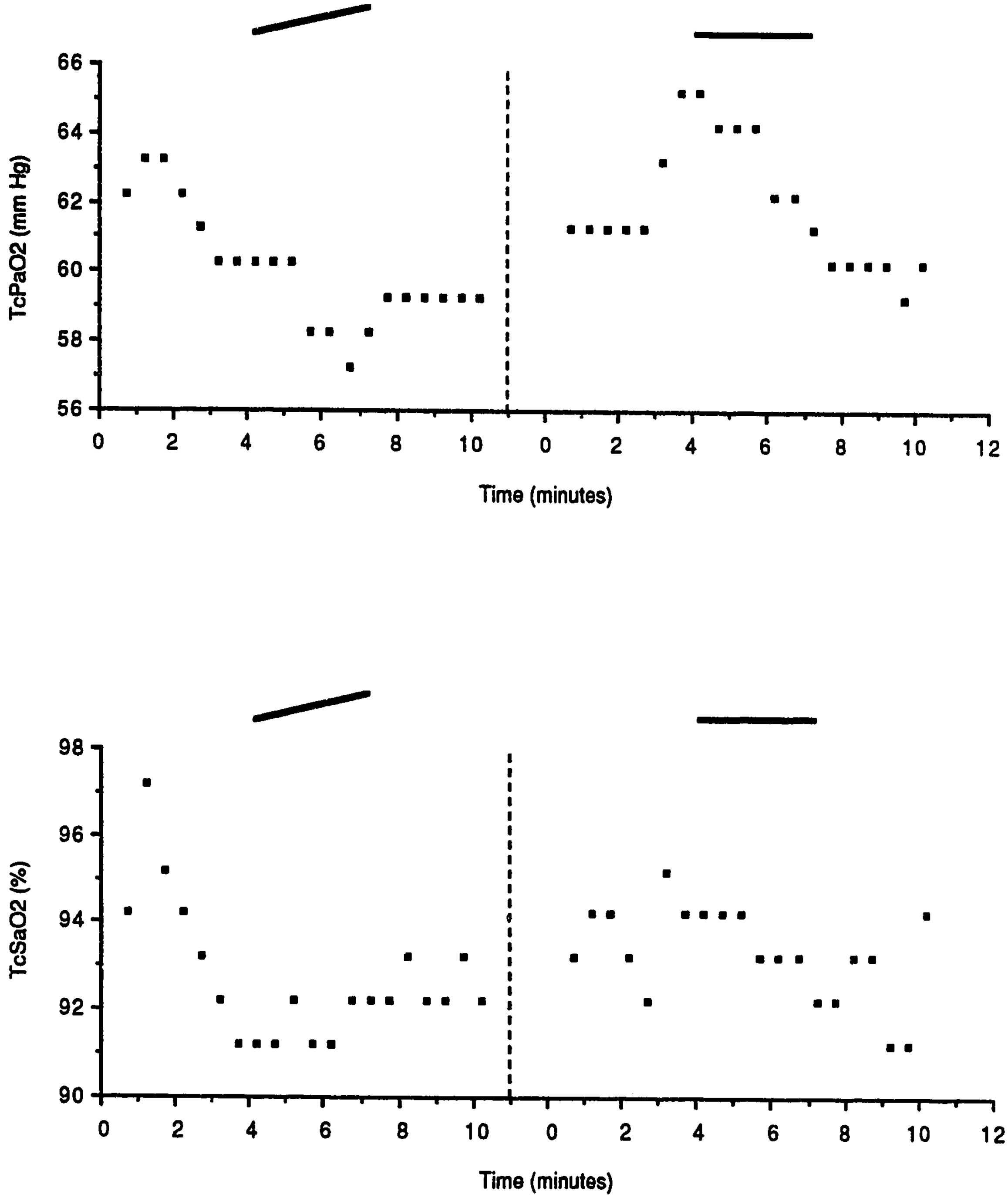


Figure G.8: Scattergrams of the TcP_aO_2's and $TcSaO_2$'s for Subject 6 in the head-up and bed-flat positions.

╱ = head-up position; ¦ = position change; ▬ = bed-flat position

Appendix H:

Lag 1 Auto-correlation Coefficients

Infant	Group	Variable	Bed-flat	Head-up
1	A	P_aO_2	.500 *	.562 *
		SaO_2	.333	.633 *
2	A	P_aO_2	.820 *	.429
		SaO_2	.906 *	.143
5	A	P_aO_2	.800 *	.733 *
		SaO_2	.667 *	.445
8	A	P_aO_2	.444	.500 *
		SaO_2	.000	.333
9	A	P_aO_2	.727 *	.625 *
		SaO_2	.143	.333
3	B	P_aO_2	.711 *	.770 *
		SaO_2	.522 *	.539 *
4	B	P_aO_2	.849 *	.717 *
		SaO_2	.333	.389
6	B	P_aO_2	.848 *	.852 *
		SaO_2	.318	.723 *
10	B	P_aO_2	.375	.780*
		SaO_2	.416	.167
11	B	P_aO_2	.700*	.429
		SaO_2	.077	.429

*$p < .05$