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Effect of Posture on Oxygenation, Lung Volume, and Respiratory Mechanics in Premature Infants Studied Before Discharge

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ABSTRACT. *Objectives.* **To determine if the prone versus the supine posture was associated with higher oxygenation levels in prematurely born infants before discharge, whether any such effect was explained by alterations in lung volume or respiratory mechanics, and if the changes were greater in oxygen-dependent infants.**

Patients. **Twenty infants (10 oxygen-dependent), median gestational age 30 (range: 27–32) weeks, were studied at a median postconceptional age of 35 weeks (range: 32–38 weeks).**

Methods. **On 2 successive days, infants were studied both supine and prone; each posture was maintained for 3 hours. Oxygen saturation was continuously monitored and at the end of each 3-hour period; compliance and resistance of the respiratory system and functional residual capacity (FRC) were measured.**

Results. **Overall, the median oxygen saturation and FRC were significantly higher in the prone position; compliance of the respiratory system and resistance of the respiratory system were not significantly affected by posture. Differences in oxygen saturation and FRC were significantly higher in the prone posture in the oxygen-dependent, but not the nonoxygen-dependent infants.**

Conclusions. **Superior oxygenation in the prone posture in oxygen-dependent premature infants studied before discharge could be explained by higher lung volumes.** ***Pediatrics*** **2003;112:29–32;** ***prematurity, lung volume, oxygen saturation, lung mechanics.***

ABBREVIATIONS. Crs, compliance of the respiratory system; FRC, functional residual capacity; PCA, postconceptional age; Rrs, resistance of the respiratory system; SD, standard deviation.

Prematurely born infants with respiratory distress[1,2] and those in the recovery stage of respiratory disease[3] have higher levels of oxygenation when nursed prone compared with supine. The effect of posture on oxygenation has been less well investigated in older premature infants. The limited data available suggest that the prone posture may, in certain infants being considered for discharge, be associated with improved oxygenation even at 34 to 36 weeks postconceptional age (PCA).[4,5]

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In the perinatal period, higher oxygenation levels in premature infants nursed in the prone posture have been associated with superior respiratory mechanics,[4] higher lung volumes,[6] and less ventilation perfusion mismatch.[1] The mechanism of superior oxygenation in the prone posture in convalescent premature infants, however, has not been identified. We have demonstrated that the effect cannot be explained by superior respiratory muscle strength, as this is significantly lower in the prone compared with the supine position.[7] The aim of this study was to determine if the prone posture was associated with superior oxygenation in prematurely born infants being prepared for discharge, and if such an effect might be explained by higher lung volumes or better respiratory mechanics. We also wished to test the hypothesis that any posture-related effects would be most marked in oxygen-dependent rather than nonoxygen-dependent infants.

METHODS

Protocol

Infants born before 33 weeks of gestational age who were being prepared for discharge home were eligible for entry into the study. An audit had demonstrated that once infants achieved 3-hourly feeding they were usually discharged from the hospital within 1 to 2 weeks. Thus, parents were approached and the study design explained to them once their infant was tolerating 3-hourly feeds. If informed, written, parental consent was obtained, their infant was included in the study.

Infants were studied on 2 successive days. On each day, infants were examined both supine and prone, each posture being maintained for 3 hours. The order in which postures were examined on the first day was randomized between infants and reversed on the following day for each individual. Oxygen saturation was continuously monitored using the same pulse oximeter (Ohmeda Biox 3740; BOC Health Care, Louisville, CO) and a reusable infant saturation probe (Flex II). The accuracy of the Ohmeda Biox oximeter is ±2.1% between oxygen saturation levels of 80% to 89.9% and ±1.5% between 90% and 100%. The mean saturation for each 3-hour period was obtained using a software program (Oximeter Download for Windows; Stowood Scientific Instruments, Oxford, United Kingdom). The neonatal unit's policy was to keep the oxygen saturation of oxygen-dependent infants at a minimum of 94%. To achieve this, the nurses adjusted the amount of supplementary oxygen the infant received through their nasal cannula. As a consequence, the inspired oxygen flow delivered to each oxygen-dependent infant during each 3-hour period was recorded. To determine the infant's supplementary oxygen requirement, the serial 15-minute oxygen flow recordings over the last 2 hours of each 3-hour period were meaned. The results in each posture were then meaned for the 2 successive days. Oxygen was delivered through a low flow meter (Therapy Equipment Ltd, Potters Bar, United Kingdom).

At the end of each 3-hour period, lung volume and respiratory

system compliance (Crs) and resistance (Rrs) were measured. Lung volume was assessed by measurement of functional residual capacity (FRC) using a helium gas dilution technique and a specially designed infant circuit (total volume 95 mL).[7] The FRC system (Equilibrated Biosystems Inc, Series 7700, Melville, NY) contained a rebreathing bag as the system reservoir. A facemask (Rendell Baker, Laerdal, Norway) was held snugly over the infant's nose and mouth; silicone putty was used around the mask to achieve a tight seal. The facemask was connected to the rebreathing bag via a 3-way valve. The FRC system contained a helium analyser (Equilibrated Biosystems Inc, Series 7700) with a digital display. During the measurement, if there was no change in the helium concentration over a 15-second period, equilibration was deemed to have occurred. The initial and equilibration helium concentrations were used in the calculation of FRC, which was corrected for oxygen consumption (assumed to be 7 mL/kg/minute)[8] and to body temperature, pressure and water vapor-saturated conditions. FRC was measured twice in each position and the results of the paired measurements were meaned. The FRC results in each posture were then meaned for the 2 successive days and related to body weight. The mean intrasubject coefficient of variation of the measurement of FRC was 8%.

Crs and Rrs were assessed by using a single occlusion technique.[9] Airflow was recorded using a pneumotachograph (Mercury F10L; G M Engineering, Kilwinning, United Kingdom), inserted into the facemask, and differential pressure transducer (range: ±2 cm H_2O, MP45; Validyne Corporation, Northridge, CA). Airway pressure was measured from a side port on the pneumotachograph using a differential pressure transducer (range: ±100 cm H_2O, MP45; Validyne Corporation). The signals were amplified (Validyne CD280; Validyne Corporation) and displayed in real time on a computer running Labview software (version 4.0; National Instruments, Austin, TX) with 100 Hz analog to digital sampling (DAQ 16XE-50; National Instruments, Austin, TX). Tidal volume was obtained by digital integration of the respiratory flow signal using the Labview software. Occlusions were performed at end inspiration, which was identified from the flow signal. The distal end of the pneumotachograph was briefly occluded and only breaths with a pressure plateau of at least 100 ms were used in the calculation of Crs and Rrs. The mean Crs and Rrs in each posture were calculated from at least 5 technically acceptable occlusions and the results for a particular posture from the 2 days then meaned. The mean intrasubject coefficients of variation of the Crs and Rrs measurements were 14% and 19%, respectively.

Statistical Analysis

Differences were assessed for statistical significance using the Wilcoxon-paired signed sum rank test. Spearman's rank correlation coefficient was calculated to determine the strength of the relationship between the change in FRC and change in oxygenation.

Sample Size

Prematurely born, convalescent infants previously cared for on the neonatal unit had a mean oxygen saturation of 93.8% (standard deviation [SD] ±3.8%)[4] and a mean FRC of 27.2 mL/kg (SD ±7.3 mL/kg).[10] Recruitment of 20 patients allowed detection of differences in oxygen saturation and FRC of the equivalent of 1 SD with 85% power at the 5% level.

Patients

Twenty preterm infants, median gestational age 30 (range: 27–32) weeks, birth weight 1312 (range: 940-1940) g, PCA 35 (range: 32–38) weeks and postnatal age 4 (range: 2–10) weeks were examined. All had had respiratory distress syndrome. Ten of the infants were oxygen-dependent at the time of the study and had a median gestational age of 30 (range: 28–32) weeks, birth weight 1175 (940–1580) g, PCA of 35 (33–37) weeks, and postnatal age of 5 (range: 3–8) weeks. Ten nonoxygen-dependent infants were also examined; they had a median gestational age 31 (range: 27–32) weeks, birth weight 1589 (range: 1120–1940) g, PCA of 35 (range: 32–38) weeks, and postnatal age of 4 (range: 2–10) weeks. The study was approved by Kings College Hospital National Health Service Trust Research Ethics Committee and the parents gave informed written consent.

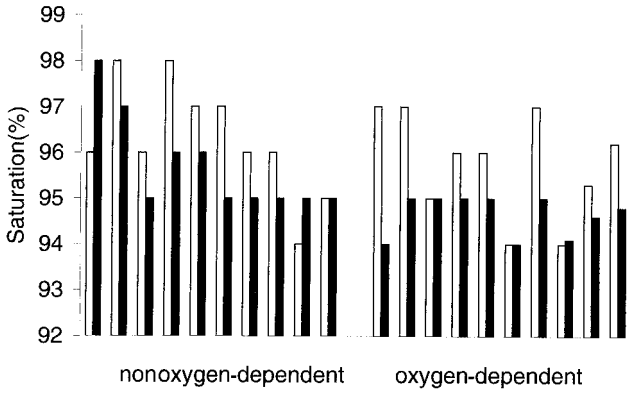

Fig 1. Oxygen saturation levels, individual data are shown. □, Prone posture; ■ supine posture. The oxygen-dependent infants are shown on the left hand side of the histogram.

RESULTS

Overall, the median oxygen saturation (P = .003; Fig 1) and FRC (P = .003; Fig 2) were significantly higher in the prone compared with supine posture. There were no statistically significant differences between the median Crs and Rrs in the 2 postures (Table 1).

In the oxygen-dependent infants, the median oxygen saturation (P = .015) and FRC (P = .019) were significantly higher in the prone compared with the supine posture, no significant differences related to posture were seen in the nonoxygen-dependent infants. The amount of supplementary oxygen given to the oxygen-dependent infants was significantly higher in the supine posture (median 80, range: 20–250 mL/min) compared with in the prone posture (median 65, range: 10–140 mL/min; P = .02; Table 2). A significant correlation (r = 0.672, P = .0034) was

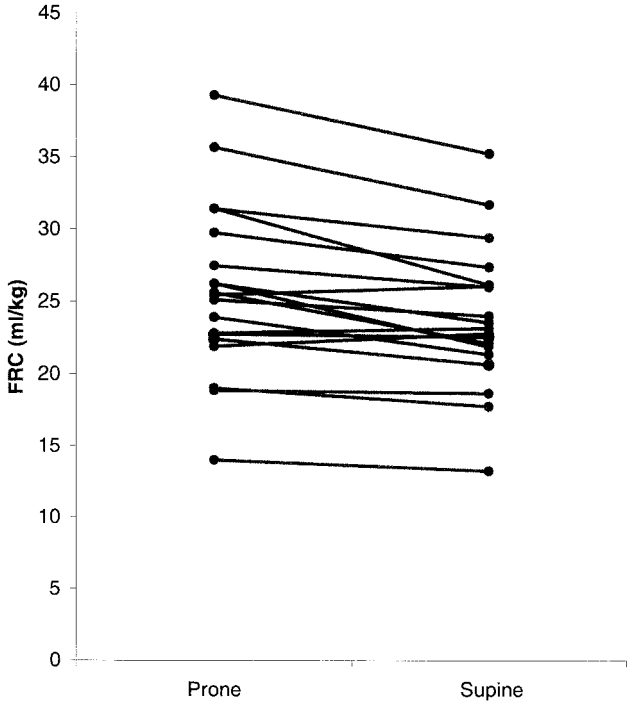

Fig 2. FRC results related to posture. Individuals are shown by linked data points.

TABLE 1. Comparison of Oxygen Saturation, FRC, and Respiratory Mechanics in the Prone and Supine Postures

	Prone	Supine	*P* Value
Oxygen saturation (%)			
Oxygen-dependent	96 (94–97)	95 (94–95)	.015
Nonoxygen-dependent	96 (94–98)	95 (95–98)	.25
FRC (mL/kg)			
Oxygen-dependent	25 (14–36)	23 (13–32)	.019
Nonoxygen-dependent	27 (19–39)	26 (17.7–35)	.06
Crs (mL/cm H_2O/kg)			
Oxygen-dependent	0.8 (0.2–1.6)	0.6 (0.4–1.4)	.43
Nonoxygen-dependent	1.1 (0.7–1.4)	1.0 (0.4–1.5)	.37
Rrs (cm H_2O/L/sec)			
Oxygen-dependent	132 (98–195)	131.3 (87–195)	.62
Nonoxygen-dependent	119 (67–207)	120 (89–166)	1.0

The data are displayed as median (range).

TABLE 2. Oxygen Saturation and Supplementary Oxygen Levels of the Oxygen-Dependent Infants in the Prone and Supine Positions

Oxygen Saturation (%)		Oxygen Flow (mL/min)	
Prone	Supine	Prone	Supine
97	94	120	250
97	95	10	20
95	95	80	80
96	95	140	200
96	95	40	60
94	94	60	100
97	95	20	40
94	94	100	80
95	95	70	90
96	95	30	60

Individual data are given.

found between the change in FRC and the change in oxygen saturation. There were no significant differences related to posture in the median Crs or Rrs in either group.

DISCUSSION

We have demonstrated that in prematurely born infants being prepared for discharge from the neonatal unit, the prone compared with the supine posture was associated with superior oxygenation. The difference between the postures, however, was only statistically significant in the oxygen-dependent infants, and this was despite the nursing staff giving extra supplementary oxygen to the oxygen-dependent infants when they were in the supine posture. The difference in the magnitude of effect of posture between the oxygen- and nonoxygen-dependent infants is not explained by differences in maturity. The 2 groups were born at similar gestational ages and studied at similar PCAs. We also took care not to bias the results by studying the postures in the same order. Indeed, all infants were studied on 2 successive days, the order in which the postures were studied was reversed on the second day and the results expressed as the mean from the 2 days for each individual. The type of oxygen saturation monitor we used over the range of oxygen saturations monitored has an accuracy of ±2%. However, we used the same machine throughout the study and demonstrate in the oxygen-dependent infants a significant change in oxygen saturation related to posture.

The influence of posture on lung volume in prematurely born infants has been debated. It has been suggested that lung volume might be lower in the prone posture because of the compressing effect of the infant's bodyweight on the compliant chest wall.[11] In contrast, others[3] have suggested that lung volume would be higher in the prone posture, as there would be reduced cephalad stress by the abdominal organs allowing greater diaphragmatic excursion.[12] We demonstrate that the prone posture is associated with superior lung volumes.

No significant posture-related effects on compliance or resistance were seen in the infants overall or in either subgroup. FRC was significantly higher in the prone posture in the oxygen-dependent infants, but the absolute change in FRC was ~2 mL/kg and too small to affect compliance. The measurements of compliance and resistance were less reproducible than those of FRC, but the coefficients of variation are not dissimilar to those quoted by other studies.[13] We would also stress that our sample size was sufficient to detect a 15% difference in Crs and a 20% difference in Rrs. Therefore, we feel that in the population studied, there were no clinically important posture-related effects on lung mechanics.

Our results suggest that the improvement in oxygen saturation in the prone posture was attributable to higher lung volumes, particularly as in the oxygen-dependent infants; we saw a significant correlation between the change in FRC and the change in oxygen saturation. The impact of posture on both oxygen saturation and lung volume has rarely been examined. In a group of children and infants, prone positioning had no significant effect overall on FRC or oxygenation.[14] The patients, however, were all ventilated and receiving neuromuscular blocking agents, which may have masked any effects. In spontaneously breathing intubated neonates, the prone posture was associated with a significant improvement in oxygenation, but no significant change in lung volume.[3] Those results are not in conflict with our findings, as the infants studied[3] had mild lung disease. We have documented significant changes in oxygen saturation and lung volume only in infants with chronic lung disease, that is, those requiring

supplementary oxygenation. There are, however, other explanations for the superior oxygenation in the prone position which need to be considered. Thoracoabdominal synchrony has been shown to be improved in the prone compared with the supine position.[15] The preterm infants studied, however, had a mean PCA of 33 weeks[15] and whether at an older age, there remains a posture-related effect on thoracoabdominal synchrony remains to be tested. An alternative explanation for the improved oxygenation in the prone position could be improved ventilation perfusion matching. In models of lung injury, the prone compared with the supine position has been shown to reduce ventilation/perfusion heterogeneity[16] and reduce intrapulmonary shunting.[17] In the latter study,[17] the reduction in shunting was not associated with a significant change in FRC. It was suggested in that study[17] that the lack of attempt to support the shoulder girdle and pelvis so that the chest and abdomen hung freely[18,19] might explain the failure to see a change in FRC. In the present study, the infants were placed prone in their cot with no special measures to allow the abdomen to protrude, yet their median FRC was significantly higher in the prone position.

CONCLUSIONS

In oxygen-dependent, prematurely born infants being prepared for discharge home oxygen saturation and lung volume are higher in the prone compared with the supine posture. If home oxygen therapy is being considered, parents need to be warned that the level of supplementary oxygen required to maintain an adequate oxygen saturation level will vary according to the infant's posture. Importantly, these results also emphasize that oxygen-dependent infants should be monitored in the supine posture before supplementary oxygen is discontinued.

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REFERENCES

1. Lioy J, Manginello FP. A comparison of supine and prone positioning in the immediate postextubation period of neonates. *J Pediatr.* 1988;112:982–984
2. Baird TM, Paton JB, Fisher DE. Improved oxygenation with prone positioning in neonates: stability of increased transcutaneous PO_2. *J Perinatol.* 1991;11:315–318
3. Wagaman MJ, Shutack JG, Mommjian AS, Schwartz JG, Shaffer TH, Fox WW. Improved oxygenation and lung compliance with prone positioning of neonates. *J Pediatr.* 1979;94:787–791
4. Dimitriou G, Greenough A, Castling D, Kavadia V. A comparison of supine and prone positioning in oxygen dependent and convalescent premature infants. *Br J Intens Care.* 1996;6:254–259
5. Martin RJ, Hernell N, Rubin D, Fanaroff A. Effect of supine and prone positions on arterial oxygen tension in the preterm infant. *Pediatrics.* 1979;63:528–531
6. Hutchinson AA, Ross KR, Russell G. The effect of posture on ventilation and lung mechanics in preterm and light-for-date infants. *Pediatrics.* 1979;64:429–432
7. Dimitriou G, Greenough A, Pink L, McGhee A, Hickey A, Rafferty GF. Effect of posture on oxygenation and respiratory muscle strength in convalescent infants. *Arch Dis Child.* 2002;86:F147–F150
8. Hey EN. The relation between environmental temperature and oxygen consumption in the newborn baby. *J Physiol.* 1969;200:589–603
9. Gappa M, Colin AA, Goetz I, Stocks J, ERS/ATS Task Force on Standards for Infant Respiratory Function Testing, European Respiratory Society/American Thoracic Society. Passive respiratory mechanics: the occlusion techniques. *Eur Respir J.* 2001;17:141–148
10. Yüksel B, Greenough A, Chan V, Ross-Russell RI. Comparison of helium dilution and nitrogen washout measurements of functional residual capacity in premature infants. *Pediatr Pulmonol.* 1993;16:197–200
11. Aiton NR, Fox GF, Alexander J, Ingram DM, Milner AD. The influence of sleeping position on functional residual capacity and effective pulmonary blood flow in healthy neonates. *Pediatr Pulmonol.* 1996;22:342–347
12. Bryan AC. Conference on the scientific basis of respiratory therapy. Pulmonary physiotherapy in the pediatric age group. Comments of a devil's advocate. *Am Rev Respir Dis.* 1974;110:143–144
13. Anonymous. Respiratory mechanics in infants: physiologic evaluation in health and disease. American Thoracic Society/European Respiratory Society Statement. *Am Rev Respir Dis.* 1993;147:474–496
14. Numa AH, Hammer J, Newth CJL. Effect of prone and supine positions on functional residual capacity, oxygenation and respiratory mechanics in ventilated infants and children. *Am J Respir Crit Care Med.* 1997;156:1185–1189
15. Wolfson MR, Greenspan JS, Deoras KS, Allen JL, Shaffer TH. Effect of position on the mechanical interaction between the rib cage and abdomen in preterm infants. *J Appl Physiol.* 1992;72:1032–1038
16. Lamm WJE, Graham MM, Albert RK. Mechanism by which the prone position improves oxygenation in acute lung injury. *Am J Respir Crit Care Med.* 1994;150:184–193
17. Albert RK, Leasa D, Sanderson M, Robertson HT, Hlastala MP. The prone position improves arterial oxygenation and reduces shunt in oleic-acid-induced acute lung injury. *Am Rev Respir Dis.* 1987;135:628–633
18. Moreno F, Lyons HA. Effect of body posture on lung volumes. *J Appl Physiol.* 1961;16:27–29
19. Agostoni E, Mead J. Statics of the respiratory system. In: Fenn WO, Rahn H, eds. *Handbook of Physiology.* Washington, DC: American Physiological Society; 1964:387

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