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The Effect of Prolonged Lateral Positioning During Routine Care on Regional Lung Volume Changes in Preterm Infants

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Summary. Introduction: During routine nursing care, preterm infants are often placed in lateral position for several hours, but the effect of this procedure on regional lung volume and ventilation is unknown. In our study we examined this effect during 3 hrs of lateral positioning in stable preterm infants. Methods: Preterm infants on non-invasive respiratory support were eligible for the study. Infants were placed in supine position and subsequently transferred to right or left lateral position, according to their individual routine nursing schedule. Changes in end-expiratory lung volume (EELV), tidal volume (V_T) and ventilation distribution were recorded using electrical impedance tomography (EIT), starting 10 min before and up to 180 min after the positional change. Additionally, oxygen requirement, transcutaneous oxygen saturation and respiratory rate were recorded. Results: 15 infants were included (GA 28.9 ± 2.0 wk, BW 1167 ± 290 g). EELV increased significantly after changing to lateral position, stabilizing at a median value of 40.8 (IQR 29.0–99.3) AU/kg at 30 min. This increase could almost be exclusively attributed to the non-dependent lung regions. Tidal volume, oxygenation, and respiratory rate remained stable. Changing to the right, but not the left, lateral position resulted in a rapid but transient shift in ventilation to the dependent lung regions. After 180 min there were no differences in ventilation distribution between lateral and supine positioning. Conclusion: This study shows that lateral position up to 3 hours, as part of normal nursing care of preterm infants, has no adverse effects on lung volumes and its regional distribution. **Pediatr Pulmonol. 2016;51:280–285.**

Key words: imaging; non-invasive ventilation; neonatal pulmonary medicine; positioning; electrical impedance tomography; continuous positive airway pressure; nasal cannula.

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INTRODUCTION

In daily clinical care, preterm infants are usually nursed in the supine, prone, left lateral, or right lateral position. Changing between these different positions is limited as much as possible in an attempt to reduce stress factors and allowing the infant to sleep between nursing care procedures. However, prolonged positioning also increases the risk of pressure ulcers and for this reason it is currently recommended to reposition infants at least every 4 hrs.[1]

Positioning may also have an effect on lung volumes and gas exchange. Several studies have shown that, compared with supine, prone positioning improves end-expiratory lung volume (EELV), tidal volume, and oxygenation.[2–4] Interestingly, data on lateral positioning are very limited. Only one study compared left lateral to supine positioning and reported a significant increase in EELV, tidal volume and gas exchange.[5]

The effect of positioning on lung volumes may not be homogenously distributed across the lungs.[6,7] Gravitational effects may result in regional differences in EELV changes and the distribution of (tidal) ventilation. Indeed, a recent

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report showed that the increase in EELV in prone positioning in preterm infants is primarily located in the non-dependent (uppermost) lung regions.[8] The effect of positioning on ventilation distribution in preterm infants is much less clear. Initially, studies indicated that ventilation in infants favored the non-dependent lung regions.[9,10] However, more recent studies have challenged this paradigm, suggesting that ventilation distribution is not affected by positioning and follows an anatomical rather than a gravitational pattern.[11–15] However, most of these studies only compared supine to prone positioning and assessed the effect on ventilation distribution after a stabilization period of less than one hour. The effect of lateral positioning for a period of several hours, as often used in daily clinical care of preterm infants, on ventilation distribution is unknown.

We therefore conducted an observational study, measuring (regional) lung volume changes before and during 3 hrs of right or left lateral positioning in stable preterm infants treated with non-invasive respiratory support, using electrical impedance tomography (EIT). EIT is a non-invasive, easily applicable, bedside tool, which measures regional changes in electrical bioimpedance in a cross-section of the lungs. These impedance changes correlate well with actual lung volume changes[16] and the cross-sectional image of the lungs has been shown to be representative for the total lung in preterm infants.[17] Based on previous reports comparing supine to prone positioning, we hypothesized that EELV changes would favor the non-dependent lung and ventilation distribution would not be affected by body positioning.

MATERIALS AND METHODS

This study was performed in the neonatal intensive care unit of the Emma Children's Hospital, Academic Medical Center (Amsterdam, the Netherlands). Infants were included in the study if they were <34 weeks gestational age and required non-invasive respiratory support by either nasal continuous positive airway pressure (nCPAP) or nasal cannula (1 L/min). Exclusion criteria were congenital anomalies of the chest and/or abdomen and a fragile skin condition. Written informed consent was obtained from both parents and the study was approved by the Institutional Review Board.

Study Protocol

Before the study all infants were nursed in either the left or right lateral positioning. At the start of the study, all infants were placed in supine position for 30 min with the head facing the side opposite to the previous lateral position. Next, the infants were placed in either right or left lateral position, depending on their position during previous nursing period. This position was maintained for 180 min and no nursing procedures were performed during the period.

EIT continuously recorded lung impedance changes, starting 10 min before and up to 180 min after the positional change. Sixteen hand-trimmed electrocardiography electrodes (Blue Sensor, BRS-50-K, Ambu Inc, Linthicum Heights, MD) were placed equidistantly on the thorax circumference, just above the nipple line and connected to the Goe-MF II EIT system (CareFusion, Yorba Linda, CA). Repetitive electrical currents (5 mA, 100 kHz) were applied cyclically (scan rate 13 Hz) through adjacent electrode pairs. Voltage changes were registered between all other passive adjacent electrode pairs. A back-projection algorithm generated a series of 32×32 pixel matrices of relative impedance changes (ΔZ) by comparing these voltage changes to a reference period. Impedance changes were registered using a custom designed Polybench-based software package (Applied Biosignals, Weener, Germany).

EIT Data Analysis

Data analysis was performed off-line with AUSPEX version 1.6 (VUmc, Amsterdam, The Netherlands). A stable 30-sec period was selected in the EIT recording during supine positioning, just before changing to the lateral position, and used as reference for all subsequent recordings. Next, the change in EELV (ΔEELV) was calculated by comparing the average ΔZ at the troughs of the breaths in the reference period to the average ΔZ at the troughs of 30-sec recordings at the time intervals $t = 0$, 30, 60, 120, 150, and 180 min after the positional change. ΔEELV was then normalized for body weight.

The same time points were used to calculate EIT-derived tidal volume (V_T) changes. However, the selected 30-sec periods were now referenced to the average ΔZ in that same interval. The EIT waveforms of relative ΔZ values were then band-pass filtered in the band of spontaneous breathing rate (10/min below the actual breathing frequency and 10/min above its second harmonic). The peak and trough values of the signal were identified and averaged over the selected period. The average amplitude was normalized for body weight.

Regional ventilation distribution was assessed by means of functional EIT (fEIT) images. fEIT images were generated by calculating the standard deviation (SD) of the impedance waveforms in each individual pixel within the 32×32 pixel matrix. A ventilation profile was derived from each fEIT image showing the distribution of ventilation in 32 slices in the region of interest, as previously described.[18] As the focus of this study was on lateral positioning, with either the left or right lung being non-dependent, the ventilation distribution in supine positioning (reference period) was assessed in the horizontal axis, i.e. the right and the left lungs. Subsequently, the areas under the curve (AUC) for the non-dependent (AUC_{nondep}) and dependent regions were calculated. The AUC_{nondep} describes the proportion of the total tidal impedance changes in the non-dependent lung regions. An AUC_{nondep} less than 50% indicates a dependent oriented and more than 50% a non-dependent oriented distribution of tidal ventilation. Finally, the geometrical center of ventilation (CoV) was determined as an additional measure describing the ventilation distribution.[18,19] The geometrical CoV represents the level in the dependent-nondependent axis (0–100%) where the AUC of tidal impedance changes is identical in the lung regions above and below this level. A geometrical CoV more than 50% indicates a dependent oriented and less than 50% a non-dependent oriented distribution of tidal ventilation.

Patient Data Collection

Patient characteristics including gestational age, birth weight, postnatal age, and Apgar scores were collected. Together with the EIT recordings, fraction of inspired oxygen (FiO_2) and transcutaneous oxygen saturation (SpO_2) were registered throughout the study.

Statistical Analysis

Statistical analysis was performed using GraphPad Prism 5.0 (GraphPad Software Inc, San Diego, CA) and SPSS version 20.0 (SPSS Inc, Chicago, IL). Data were expressed as mean with SD or median with interquartile range (IQR), as appropriate. Comparative analysis was performed using the Friedman repeated measures test for skewed data and one-way ANOVA for repeated measures for normally distributed data, followed by post-hoc testing. A *P*-value of less than 0.05 was considered statistically significant.

RESULTS

Fifteen infants were included in the study and all completed the study period without any complications. The patient characteristics are summarized in Table 1. Seven infants were placed in right and eight infants in left lateral position. The mean FiO_2 and SpO_2 in supine position was, respectively, 0.24 ± 0.07, and $94.6\% \pm 4.4\%$, and both parameters did not change during the 180 min of lateral positioning (Table 2).

EELV increased significantly after changing to lateral position, stabilizing at a median value of 40.8 (IQR 29.0–99.3) AU/kg at 30 min (Fig. 1A). At a regional level, this increase in EELV could almost be exclusively attributed to the non-dependent lung regions (Fig. 1B). The EELV in the dependent lung regions remained stable throughout the 180 min.

There were no differences between the infants on nCPAP or NC and no differences between left and right lateral positioning (data not shown).

Both V_T and breathing frequency did not change after the positional change (Table 2). In supine position, tidal ventilation was distributed more to the right than the left lung (Table 3). Changing to the lateral position resulted in an immediate ($t = 0$) shift in ventilation to the dependent lung regions, although only the CoV reached statistical significance (Table 3). This shift towards the dependent lung regions could almost exclusively be attributed to the right, but not the left, lateral position. Over time this effect on ventilation distribution stepwise decreased and was no longer statistically significant (Table 3). Again, there were no differences between the infants on nCPAP or NC.

TABLE 1—Patient Characteristics

Subject no.	GA (wk)	BW (g)	Postnatal age (d)	5′ Apgar score	Mode	FiO_2
1	31.0	1800	1	8	CPAP	0.21
2	31.0	1540	1	9	NC	0.21
3	29.1	1290	3	8	CPAP	0.21
4	29.7	1128	6	8	CPAP	0.21
5	28.9	1410	6	8	CPAP	0.28
6	27.9	850	22	7	CPAP	0.21
7	31.6	915	3	9	NC	0.21
8	27.0	895	7	6	CPAP	0.21
9	27.0	965	22	7	NC	0.21
10	29.0	1390	15	9	NC	0.21
11	28.9	1405	15	9	NC	0.21
12	26.9	1115	17	8	CPAP	0.21
13	26.9	890	18	9	NC	0.21
14	32.6	900	11	7	NC	0.21
15	25.7	1008	43	8	CPAP	0.44
Median	28.9	1115	12.7	8		0.23

GA, gestational age; BW, birth weight; FiO_2, fraction of inspired oxygen; CPAP, continuous positive airway pressure; NC, nasal cannula.

TABLE 2— Ventilatory Parameters

	Before	T = 0 min	T = 30 min	T = 60 min	T = 120 min	T = 180 min
RR (min-1)	58 ± 19	65 ± 15	59 ± 15	58 ± 15	65 ± 16	62 ± 17
V_T (AU/kg)[1]	11.5 (7.7–14.3)	7.6 (5.9–12.8)	10.1 (5.2–12.8)	8.8 (6.2–14.3)	9.6 (5.8–14.3)	10.9 (7.4–12.9)
MV (AU/kg/min)	735 ± 365	667 ± 310	631 ± 324	675 ± 328	689 ± 357	761 ± 336
SpO_2 (%)	94.6 ± 4.4	95.8 ± 3.7	95.8 ± 4.6	95.5 ± 3.9	94.2 ± 4.8	96.5 ± 2.3
FiO_2	0.24 ± 0.07	0.24 ± 0.07	0.24 ± 0.07	0.24 ± 0.07	0.24 ± 0.07	0.24 ± 0.07
SpO_2/FiO_2	417 ± 85	421 ± 85	415 ± 89	418 ± 83	417 ± 86	423 ± 82

Data are presented as mean ± SD or median (IQR 25–75) when stated differently[1]. Comparative analyses between groups are performed using one-way ANOVA for repeated measures or Friedman test for repeated measures when appropriate.
RR, respiratory rate; V_T, tidal volume; MV, minute volume; SpO_2, transcutaneous oxygen saturation; FiO_2, fraction of inspired oxygen.

DISCUSSION

This study shows that, compared to supine positioning, lateral positioning for 3 hrs in stable preterm infants results in an increased EELV in the non-dependent and a stable EELV in the dependent lung regions. Except for small transient changes, tidal volume and its distribution did not change over time.

To date, only one other study has investigated the effect of lateral positioning in stable preterm infants on EELV.[5] This study showed that changing from supine to left lateral position resulted in a significant increase in EELV. The results from our study are consistent with this observation, but also add important additional information. First, and most important, our study shows that this increase in EELV is not homogeneously distributed and only present in the non-dependent lung regions. It also shows that this increase occurs relatively quickly after the change in positioning and thereafter remains stable over time. This increase in EELV might be explained by the effect of gravity[6] or a decreased transmission of the weight of the abdominal content on the non-dependent lung.[20,21] It was interesting to observe that these possible changes in gravitational and abdominal forces did not result in a loss of EELV over the 3 hrs of lateral positioning in the dependent lung regions. This later finding suggests that there are no adverse effects in terms of collapse associated with prolonged lateral positioning. Second, our study shows that the increase in EELV is present in both right and lateral position. Finally, the effect on EELV was also present in infants supported by low flow nasal cannula.

Only few studies have assessed the impact of lateral positioning on oxygenation and showed conflicting results. Some reported an improvement[5] while others found no change in oxygenation[22] when transferring preterm infants from supine to lateral. In the present study we also observed no change in oxygenation when placing infants in lateral position. This suggests that the increase in EELV is mainly due to lung distension and not lung recruitment, as only the latter will reduce intrapulmonary right-to-left shunt and thereby improve oxygenation. The

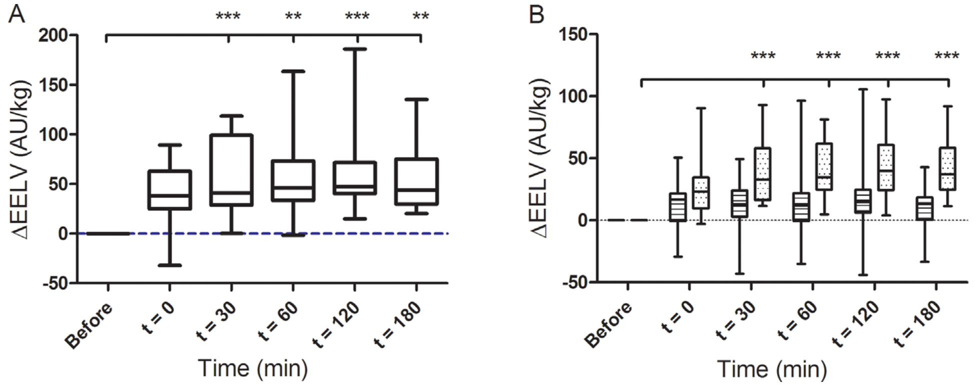

Fig. 1. End-expiratory lung volume. Changes in end-expiratory lung volume at time points 0, 30, 60, 120, and 180 min after the positional change, relative to supine position. Panel A: changes in global impedance, panel B: changes in impedance in the dependent (striped boxes) and non-dependent (dotted boxes) lung regions. The median, 25th and 75th percentiles, minimum, and maximum values of 15 patients are shown. **$P < 0.001$, ***$P < 0.0001$ compared to supine position.

TABLE 3— Ventilation Distribution

	Before	t = 0 min	t = 30 min	t = 60 min	t = 120 min	t = 180 min
$\text{AUC}_{\text{nondep}}$ total group(%)	52.4 ± 5.8	48.1 ± 10.5	50.2 ± 10.7	50.3 ± 9.8	51.1 ± 9.0	50.9 ± 7.5
$\text{AUC}_{\text{nondep}}$ left lateral posture (%)	56.5 ± 3.7	55.9 ± 7.7	57.9 ± 7.4	57.9 ± 6.5	56.6 ± 5.9	56.2 ± 5.8
$\text{AUC}_{\text{nondep}}$ right lateral posture (%)	48.3 ± 4.4	40.2 ± 6.0[1]	42.5 ± 7.5	42.7 ± 5.5	45.7 ± 8.4	45.7 ± 4.9
CoV total group (%)	47.9 ± 4.7	51.7 ± 8.1[1]	49.9 ± 8.0	49.9 ± 7.3	49.1 ± 6.3	49.8 ± 5.6
CoV left lateral posture(%)	44.6 ± 3.1	45.6 ± 53	43.9 ± 5.6	44.1 ± 4.5	45.0 ± 4.3	45.9 ± 4.0
CoV right lateral posture (%)	51.4 ± 3.3	57.8 ± 5.2[2]	55.8 ± 4.9	55.8 ± 4.0	53.2 ± 5.4	53.7 ± 4.0

Data are presented as mean ± SD. Comparative analyses between groups are performed using one-way ANOVA for repeated measures. $\text{AUC}_{\text{nondep}}$, area under the curve of the non-dependent lung region; CoV, geometric center of ventilation.

[1] Significant change compared to "Before" lateral positioning, $P < 0.05$.

[2] Significant change compared to "Before" lateral positioning, $P < 0.001$.

stable oxygenation over time also strengthens the assumption that prolonged lateral positioning is not accompanied by alveolar or airway collapse.

Compared to supine, lateral positioning did not have a significant effect on breathing frequency or tidal volume. Our finding on breathing frequency is consistent with previous studies.[5,22] However, the data on tidal volume are in contrast to a previous study that reported a significant increase in tidal volume after changing from supine to left lateral position.[5] It is unclear why our results are different, but factors that may play a role are differences in patient characteristics, study design and the method of measuring tidal volume changes. Future studies will have to explore the possible interactions between these variables and the positional effects on tidal volume.

In most previous studies the effect of changed body position on ventilation distribution in preterm infants were assessed after a relatively short stabilization period of less than 60 min.[11–14,23] In this study we measured the changes in ventilation distribution up to 3 hrs of lateral positioning as this is more in line with daily nursing care. Consistent with previous studies ventilation distribution was more prominent in the right lung compared with the left lung.[11,12] As previously suggested, this finding is probably best explained by the anatomical differences, that is, less lung tissue in the left hemi-thorax.[11] It was interesting to observe that immediately after changing from supine to lateral position, ventilation distribution was shifted to the dependent lung regions. However, this effect weaned off during the 180 min measurement period and therefore was no longer statistically significant at all subsequent analysis time points. More detailed analysis showed that this shift in ventilation distribution towards the dependent lung regions was almost exclusively seen in the infants placed in right, but not left, lateral positioning. It is unclear why this transient shift in tidal ventilation towards the dependent lung regions occurred and why it was only present during right lateral positioning. The increase in EELV in the non-dependent lung regions following lateral positioning may have resulted in regional overdistension and a reduction in (regional) compliance. However, this does not explain the fact that ventilation distribution only changed in right lateral positioning, as the regional increase in EELV was similar in both lateral positions. A gravitational effect, as described in some older studies[9,10] is also unlikely as this would probably need time to develop and would not be present directly after changing position. Future studies are needed to confirm and clarify our findings.

It is important to emphasize that our study did not show any major shifts in ventilation distribution over time, suggesting that nursing in lateral positioning for up to 3 hrs is safe in terms of ventilation distribution.

This study has several limitations that need to be addressed. First of all, for practical reasons infants were only measured in the right or left lateral positioning and not both. Although most of our results were similar during left and right lateral positioning, we cannot rule out small differences in treatment effects between these two positions. Second, the assignment to right or left lateral position was based on the previous position during routine nursing care. And although this procedure also involves a certain element of chance, it is not the same as true randomization and therefore may have resulted in some level of bias. Third, changes in positioning may also have impacted the distribution of blood and fluid in the lung. Although this may also have affected lung impedance measurements, the overall effect is probably small as blood has a 5-times lower resistance than lung tissue.[24] Fourth, this study only included stable preterm infants. The results may be different in infants with more severe lung disease or other modes of respiratory support. Finally, EIT is only capable of measuring relative and not absolute lung volume changes because calibration in preterm infants on nCPAP or nasal cannula is not yet feasible. However, this does not compromise the validity of our findings, because the focus of this study was not on the absolute but on the relative changes in lung volumes.

Despite its limitations, this study has important clinical implications. First of all, the results of this study indicate that 3 hrs of lateral positioning as part of normal nursing care is safe in terms of changes in lung volume and its distribution. The fact that it increases EELV compared with supine position could be interpreted as an additional advantage of lateral positioning as EELV is often compromised in preterm infants. Second, the increase in EELV in the non-dependent lung may also have a therapeutic potential in infants with unilateral atelectasis. Placing these infants in lateral position with the atelectatic lung non-dependent may improve lung expansion and aeration. Finally, the results of this study may also be helpful in positioning infants with unilateral pulmonary interstitial emphysema. These infants should probably be placed in lateral position with the affected lung dependent. This may prevent further distension of the already overdistended lung. This study cannot answer the questions whether lateral positioning is also effective in creating lung collapse and subsequent resolution of the interstitial emphysema in the dependent lung, as previously described.[25,26] It does suggest that this effect will probably not occur before 3 hrs of lateral positioning.

In conclusion, this study shows that lateral position up to 3 hrs, as part of normal nursing care of preterm infants is safe in terms of lung volume changes and its regional distribution.

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