Decreased Incidence of Pneumothorax in VLBW Infants After Increased Monitoring of Tidal Volumes

abstract

BACKGROUND AND OBJECTIVE: Pneumothorax is common in very low birth weight (VLBW) infants. In our NICU, we noted an above average incidence of pneumothorax compared with similar NICUs based on Vermont Oxford Network benchmarking. The quality improvement project was designed to decrease the incidence of pneumothorax in VLBW infants in a tertiary care NICU.

METHODS: The project was divided into 2 periods. During period 1, all VLBW infants were followed for 6 months for the presence of pneumothorax. A multidisciplinary team met regularly to review cases of pneumothorax and identify potential causes. High tidal volumes (VT) (>6 mL/kg) were noted around the time of occurrence of pneumothorax. Guidelines were developed for improved monitoring and rapid feedback of VT and peak inspiratory pressure between nursing staff and clinicians. During period 2, these guidelines were implemented and VLBW infants were again followed for 6 months. The incidence of pneumothorax was tracked. Run charts were used to monitor changes.

RESULTS: The incidence of pneumothorax in VLBW infants decreased from 10.4% to 2.6% after the intervention (P = .04). By using process control, a reduction in pneumothorax was achieved in period 2.

CONCLUSIONS: Increased vigilance and real-time monitoring of VT and peak inspiratory pressure decreased the incidence of pneumothorax in our population of VLBW infants. These interventions can be considered in other NICUs with an above-average risk adjusted incidence of pneumothorax in VLBW infants. Our data illustrate the benefits of comparative benchmarking and organized quality improvement in advancing patient care outcomes. Pediatrics 2012;130:e1352–e1358

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KEY WORDS pneumothorax, tidal volume, peak inspiratory pressure, quality improvement, very low birth weight

ABBREVIATIONS

BPD—bronchopulmonary dysplasia
CLD—chronic lung disease
PIP—peak inspiratory pressure
QI—quality improvement
RDS—respiratory distress syndrome
S-TCPL—synchronized time-cycled pressure-limited ventilation
VLBW—very low birth weight
VT—tidal volume

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Pneumothorax remains a common morbidity in critically ill ventilated neonates despite treatment with antenatal corticosteroids, surfactant, and less aggressive ventilation. Pneumothorax during respiratory distress is associated with increased risk of intraventricular hemorrhage, chronic lung disease (CLD), and death. Symptomatic pneumothorax occurs in 0.08% of all live births and in 5.00% to 7.00% of all infants with birth weight <1500 g. The incidence of pneumothorax varies among NICUs, even with similar populations of infants. This may be because of different clinical practice guidelines, modalities of ventilation, and use of surfactant. The risk of pneumothorax is increased in infants with respiratory distress syndrome (RDS), has been investigated as a factor determining long term pulmonary outcomes, and may be related to timing of surfactant and resuscitation at birth. Continuous positive airway pressure and positive pressure ventilation also increase the incidence of pneumothorax. Surfactant replacement, use of synchronized volume ventilation, and high-rate, lower tidal volume (VT) ventilation are all clinical factors known to decrease the incidence of pneumothorax. Given all these factors, NICU process of care, including method of mechanical ventilation, timing of surfactant administration, and the interactions between these clinical practices may be important in determining individual NICU rates of pneumothorax.

In our NICU, we noted an above-average risk-adjusted incidence of pneumothorax in very low birth weight (VLBW) infants, when compared with similar NICUs, based on the Vermont Oxford Network benchmarking data. The objective of this quality improvement (QI) project was to identify clinical practices and factors associated with pneumothorax, and develop an intervention to decrease the occurrence of pneumothorax in VLBW infants in our NICU.

**METHODS**

**Human Subject Protection**

The study was approved by the Christiana Care Hospital Institutional Review Board.

**Setting**

The NICU at Christiana Care Hospital is a level III unit, with 60 beds and ~7000 live births per year. The NICU cares for both inborn (90%) and outborn (10%) infants.

**Resuscitation and Delivery Room Policies**

The delivery room and NICU are staffed by neonatologists, neonatal fellows, neonatal nurse practitioners, pediatric residents, and pediatric hospitalists. Neopuff (Irvine, CA) infant resuscitator is used in the delivery room. Self-inflating bags are used in the NICU when infants are disconnected from the ventilator for routine care, such as endotracheal tube suctioning.

**Surfactant Administration Policies**

Prophylactic exogenous surfactant (Beclomethasone, Survanta, Abbott Park, IL) is administered by the respiratory therapist for all infants of <30 weeks’ gestation who are intubated in the delivery room and suspected to have RDS. Additional doses (up to 4) are given at 6-hour intervals if needed. Surfactant is administered intratracheally by instillation through a 5-French end-hole catheter. The catheter is inserted into the infant’s endotracheal tube without interrupting ventilation by passing the catheter through a neonatal suction valve attached to the endotracheal tube. To ensure homogeneous distribution throughout the lungs, each dose is divided into 4-quarter doses and is administered in 4 positions (head and body up and to the left and right, head and body down and to the left and right).

**NICU Ventilation Policies**

After standard resuscitation, the decision to intubate the infant in the delivery room is made by the clinician based on clinical symptoms, including decreased air entry, chest retractions, need for high-inflating pressure during bag-mask ventilation, and/or need for increasing supplemental oxygen. VLBW infants not mechanically ventilated in the delivery room are started on mask continuous positive airway pressure and transported to the NICU. Those infants with high requirements of FiO₂ (>0.40 to maintain oxygen saturation 0.88–0.92), respiratory acidosis (Pco₂ >60 torr or pH <7.2), or worsening clinical symptoms of RDS are intubated and receive mechanical ventilation in the NICU. Surfactant rescue is provided to those infants initiated on mechanical ventilation in the NICU.

Infants are transported to the NICU in a transporter equipped with a Neopuff and a monitor with heart rate and pulse-oximetry. Dräger (Telford, PA) infant ventilators are used, and the initial mode of ventilation is either synchronized time-cycled pressure-limited ventilation (S-TCPL) or synchronized volume-targeted ventilation based on physician preference. The most common mode of initial ventilation is S-TCPL. Before the intervention phase of our QI project, ventilator setting adjustments were made based on physical examination and blood gas measurements.

**Inclusion Criteria**

All infants (inborn or outborn) with birth weight <1500 g were enrolled as part of the QI project. The project was divided into 2 periods: period 1 and period 2. Both periods were 6 months in duration. In period 1, infants were...
enrolled from June to December of 2009. In period 2, infants were enrolled from January to June of 2010. The incidence of pneumothorax was tracked prospectively in all enrolled infants. For the purposes of this study, tension pneumothorax was defined based on radiographic appearance of shift in the midline or flattening of the diaphragm and clinical symptoms requiring intervention, such as needle thoracotomy or chest tube placement. The clinical team caring for the infant determined the need for intervention. For the purpose of this study, high peak inspiratory pressure (PIP) alarm was set by respiratory therapy at 5 cm of H2O above the average PIP required to generate a desired \( V_T \) of 4 to 6 mL/kg.

### Multidisciplinary Team

During the preintervention phase, a multidisciplinary team was formed, consisting of 3 neonatologists, 1 neonatal fellow, 1 neonatal nurse practitioner, a bedside NICU nurse, a research nurse, and 2 respiratory therapists. The multidisciplinary team was formed to evaluate potential causes of the increased incidence of pneumothorax.

### Period 1

During this phase, the incidence of pneumothorax was tracked for all VLBW infants concurrent with the development of an intervention. The multidisciplinary team met regularly to intensively review cases of pneumothorax and perform a root cause analysis. Based on these reviews, most pneumothoraces were noted to occur during the first week of life, especially after the administration of surfactant. Ventilator parameters were reviewed, which indicated delivery of high \( V_T \), beyond a 4- to 6-mL/kg physiologic range, around the time of occurrence of pneumothorax. Based on the findings of the multidisciplinary team, an intervention was developed.

### Intervention

Based on the analysis, NICU nurses, respiratory therapists, pediatric residents, pediatric hospitalists, neonatal nurse practitioners, and neonatal fellows were educated on the elevated incidence of pneumothorax and the recommendations to improve the outcomes. NICU nurses were educated of the recommendations through posters and interactive sessions during Critical Skills Sessions that are conducted yearly. The ventilation section of the nursing flow sheets was revised to include a column for documentation of exhaled \( V_T \) if on S-TCPL ventilation. Nurses were also educated on the importance of close monitoring of \( V_T \) or PIP and the need for rapid feedback to the clinicians if these parameters were outside the set range. Respiratory therapists received similar education through the Department of Respiratory Care. Pediatric residents, pediatric hospitalists, neonatal nurse practitioners, and neonatal fellows were educated at the start of their rotation and on bedside rounds by the neonatologists.

The recommended guidelines were as follows:

1. Close monitoring of \( V_T \) and PIP depending on the chosen mode of ventilation.
2. \( V_T \) goal set as 4 to 6 mL/kg.
3. Rapid nursing feedback of high \( V_T \) or high PIP to the medical team.
4. Hourly documentation of exhaled \( V_T \) during routine ventilation documentation on the nursing flow sheets if on S-TCPL mode of ventilation.

A flowchart for the intervention was developed, along with a reference guide for the \( V_T \) based on weight, and was posted on all ventilators (Fig 1 and Table 1). The mode of ventilation, weaning, or escalation of care was left to the decision of the clinician.

### Period 2

The previously described interventions were set into effect once it was felt that all the groups of individuals involved in the care of the infant had been well educated on the intervention. During period 2, infants were enrolled and the incidence of pneumothorax continued to be monitored.

### Statistical Analysis

Demographic data were analyzed by using 1-way analysis of variance or \( \chi^2 \). Statistical run charts were used to measure the impact of interventions over time on the incidence of pneumothorax. These charts are particularly useful for displaying and analyzing variation in time-series data. They differentiate common cause variation (inherent in the process over time) from special cause variation (not part of the process but arise because of the specific circumstance, eg, intervention) and evaluate the effectiveness of the intervention. All statistical analysis was done by using Statistica (version 10, Tulsa, OK).

### RESULTS

There were 115 VLBW infants admitted to the NICU in period 1 and 76 infants in period 2. Patient demographics and clinical characteristics of infants in both periods are listed in Table 2. There were no differences in the gestational age, birth weight, use of antenatal steroids, surfactant, or mechanical ventilation between the 2 groups.

Based on the “root-cause” analysis performed by the multidisciplinary team, interventions were developed that included educating the caregivers on the high incidence of pneumothorax, the potential causes, and methods to monitor and improve outcomes. The interventions were well accepted by the nursing staff and the clinicians. A process control chart showing the occurrence of pneumothorax over time.

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**Note:**

1. Close monitoring of \( V_T \) and PIP depending on the chosen mode of ventilation.
2. \( V_T \) goal set as 4 to 6 mL/kg.
3. Rapid nursing feedback of high \( V_T \) or high PIP to the medical team.
4. Hourly documentation of exhaled \( V_T \) during routine ventilation documentation on the nursing flow sheets if on S-TCPL mode of ventilation.
in period 1 and period 2 is shown in Fig 2. The process was found to be in control for our NICU in period 1, with the incidence closer to the upper control limit. In period 2, there was a sustained shift in the process toward a lower mean rate of pneumothorax. Reduction in pneumothorax reached statistical significance in period 2, during tracking of the 140th patient. The overall rate of pneumothorax during the 1-year QI project was 7.8%. The rate of pneumothorax decreased from 10% (n = 12) in period 1 to 2% (n = 2) in period 2 (P = .04).

As part of the QI project, balancing measures were tracked, including the number of PaO2 measurements in the high, normal, and low range, and incidence of CLD and bronchopulmonary dysplasia (BPD). Table 3 illustrates these results. The number of blood gases that had a PaO2 <35 torr was less in period 2 when compared with period 1 but was not statistically significant. There were no differences in the number of blood gases with PaO2 >45 torr or in the incidence of CLD or BPD between the 2 periods.

We faced a few minor barriers to ensure the project was well implemented, which included getting all the clinicians to agree with the interventions, educating a large number of diverse caregivers (nursing, respiratory therapy, residents, fellows, attending physicians), assessing if the team was well versed with the changes/interventions, and ensuring that the process is ongoing. Some clinicians felt that the intervention endorsed VT mode of ventilation rather than S-TCPL ventilation. We did have to reassure the medical team that the mode of ventilation remained the choice of the clinician. The nursing staff routinely accepted the new expectation of charting hourly VT values, with no missing charting values noted by using periodic random chart review, and reported high VT values to the medical team.

DISCUSSION
Pneumothorax remains an important cause of mortality and morbidity among hospitalized VLBW infants. In our NICU, we were able to reduce the rate of pneumothorax from 10.4% to 2.6% by using a bundle of interventions. Our intervention included education, increased monitoring of VT and PIP, and rapid feedback from nursing to clinicians regarding elevated VT and PIP. Our data highlight the importance of tracking NICU outcomes, including pneumothorax, to allow for QI. To date, there has been a paucity of studies on reducing pneumothorax in VLBW infants. Our QI project provides a potential template for improvement for NICUs with elevated rates of pneumothorax.

The bundle of interventions in our project focused on careful monitoring of VT and PIP. The relationship between elevated VT and pneumothorax is well established. Volume targeted ventilation has been associated with reduction in air leak.10 The volume of gas delivered to the lungs is a likely determinant of lung injury during mechanical ventilation.11 This finding gave rise to the

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**TABLE 1** Reference Guide at Bedside for VT Based on Weight

<table>
<thead>
<tr>
<th>Grams</th>
<th>4 mL/kg</th>
<th>5 mL/kg</th>
<th>6 mL/kg</th>
<th>7 mL/kg</th>
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</thead>
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<tr>
<td>400</td>
<td>1.6</td>
<td>2.0</td>
<td>2.4</td>
<td>2.8</td>
</tr>
<tr>
<td>450</td>
<td>1.8</td>
<td>2.3</td>
<td>2.7</td>
<td>3.2</td>
</tr>
<tr>
<td>500</td>
<td>2.0</td>
<td>2.5</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>550</td>
<td>2.2</td>
<td>2.8</td>
<td>3.3</td>
<td>3.9</td>
</tr>
<tr>
<td>600</td>
<td>2.4</td>
<td>3.0</td>
<td>3.6</td>
<td>4.2</td>
</tr>
<tr>
<td>650</td>
<td>2.6</td>
<td>3.3</td>
<td>3.9</td>
<td>4.6</td>
</tr>
<tr>
<td>700</td>
<td>2.8</td>
<td>3.5</td>
<td>4.2</td>
<td>4.9</td>
</tr>
<tr>
<td>750</td>
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<td>3.8</td>
<td>4.5</td>
<td>5.3</td>
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<tr>
<td>800</td>
<td>3.2</td>
<td>4.0</td>
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</tr>
<tr>
<td>850</td>
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<td>900</td>
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<td>4.5</td>
<td>5.4</td>
<td>6.3</td>
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<tr>
<td>950</td>
<td>3.8</td>
<td>4.8</td>
<td>5.7</td>
<td>6.7</td>
</tr>
<tr>
<td>1000</td>
<td>4.0</td>
<td>5.0</td>
<td>6.0</td>
<td>7.0</td>
</tr>
<tr>
<td>1050</td>
<td>4.2</td>
<td>5.3</td>
<td>6.3</td>
<td>7.4</td>
</tr>
<tr>
<td>1100</td>
<td>4.4</td>
<td>5.5</td>
<td>6.6</td>
<td>7.7</td>
</tr>
<tr>
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<td>5.8</td>
<td>6.9</td>
<td>8.1</td>
</tr>
<tr>
<td>1200</td>
<td>4.8</td>
<td>6.0</td>
<td>7.2</td>
<td>8.4</td>
</tr>
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<td>1250</td>
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<td>6.3</td>
<td>7.5</td>
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<tr>
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<td>7.8</td>
<td>9.1</td>
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<td>7.5</td>
<td>9.0</td>
<td>10.5</td>
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</tbody>
</table>
concept of volutrauma as a mechanism for ventilator-induced lung injury. Evidence for the importance of volutrauma as a cause of lung injury also comes from the Adult Acute Respiratory Distress Syndrome Network trial. This trial found that using a lower VT decreased mortality and the number of ventilator days. Keszler et al showed that an excessive VT in neonates can lead to hypocarbia and neurologic damage.

Conversely, ventilation with low lung volumes may also cause lung injury, especially in surfactant-deficient lungs. This injury is believed to be related to the repeated opening and closing of lung units (atelectotrauma) with each mechanical breath. This explains the observation that recruitment of lung to increase the functional residual capacity protects against ventilator-induced lung injury.

One previously published study on reducing pneumothorax in preterm infants focused on timing of surfactant administration. Our study achieved similar results by focusing on ventilator management, specifically high VT and PIP. The VT guidelines in our QI project were established on the basis of observations that VT of 4 to 6 mL/kg is physiologic in the first few weeks of life and is associated with normocapnia and decreased ventilator-induced lung injury. The intervention of the project was developed to maintain more stable VT, avoiding inadvertently high PIP and atelectasis and thereby decreasing the incidence of air leak in VLBW infants. We did consider other causes that could have led to the high incidence of pneumothorax, especially the practice of surfactant administration. We have been administering surfactant as per the manufacturer’s instructions in 4 positions. In developing the QI project, we planned to implement a bundle of changes based on the multidisciplinary team’s initial review. If the first bundle of interventions did not produce significant changes, then additive interventions, including potentially changing the practice of surfactant administration would have been considered.

While performing a QI project, and implementing a bundle of changes, as in our project, caution should be taken to monitor other outcomes that could be negatively influenced by the change. It is also essential to continue monitoring the primary outcome to ensure that the process is in control, the guidelines continue to be implemented, and effort is made for further improvement when possible. Our study showed no increase in the occurrence of BPD, CLD, or hypoventilation after the implementation of the guidelines.

One of the strengths of our study includes a bundle of intervention developed by a multidisciplinary team. Multidisciplinary teams are an important component of QI initiatives, and facilitated “buy-in” from multiple caregivers in the NICU. In addition, other strengths include a relatively large sample size, prospective monitoring of outcomes, and use of process

### TABLE 2: Patient Demographics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Period 1 (n = 115)</th>
<th>Period 2 (n = 76)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gestational age, wk</td>
<td>27.7 ± 2.7</td>
<td>27.3 ± 2.6</td>
<td>.37</td>
</tr>
<tr>
<td>Weight, g</td>
<td>1038 ± 297</td>
<td>980 ± 289</td>
<td>.18</td>
</tr>
<tr>
<td>Antenatal steroids, %</td>
<td>75</td>
<td>80</td>
<td>.25</td>
</tr>
<tr>
<td>Surfactant, %</td>
<td>85</td>
<td>77</td>
<td>.18</td>
</tr>
<tr>
<td>Mechanical ventilation in first wk of life, %</td>
<td>86</td>
<td>77</td>
<td>.09</td>
</tr>
</tbody>
</table>

### TABLE 3: Balancing Measures

<table>
<thead>
<tr>
<th>Variable</th>
<th>Period 1</th>
<th>Period 2</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{O_2}$ &lt; 35 torr (4.7 kPA) (No. of measurements/patient in first 72 h of life)</td>
<td>1.9 ± 2.4</td>
<td>1.1 ± 1.4</td>
<td>.07</td>
</tr>
<tr>
<td>$P_{O_2}$ &gt; 45 torr (6 kPA) (No. of measurements/patient in first 72 h of life)</td>
<td>6.0 ± 6.6</td>
<td>6.3 ± 6.6</td>
<td>.69</td>
</tr>
<tr>
<td>Total $P_{O_2}$ (Measurements in the first 72 h of life)</td>
<td>12.8 ± 10</td>
<td>11.4 ± 9.2</td>
<td>.51</td>
</tr>
<tr>
<td>Any $P_{O_2}$ &lt; 35 torr (Measurements in the first 72 h of life)</td>
<td>62</td>
<td>51</td>
<td>.13</td>
</tr>
<tr>
<td>CHD, %</td>
<td>22</td>
<td>22</td>
<td>.91</td>
</tr>
<tr>
<td>BPD, %</td>
<td>43</td>
<td>49</td>
<td>.48</td>
</tr>
</tbody>
</table>

**FIGURE 2**
Run chart depicting the incidence of pneumothorax during the 2 periods of the project. The 5 points marked with a triangle, and the arrow in period 2, depict a sustained shift in the process toward a lower mean. UCL, upper confidence interval.
control. We designed the intervention with some sustainable components. We ensured that the changes were sustainable by (1) including the interventions to the nursing critical skill evaluations conducted every year; (2) adding a column on the nursing flow sheet to document VT; and (3) hanging flowcharts and quick reference guides to every ventilator in the unit.

Our study has a number of important limitations. Although we focused on careful monitoring of VT and PIP, clinicians may have also made other important ventilator changes, such as alterations of positive end-expiratory pressure, rate, and pressure support that were not measured. Quantifying all aspects of ventilator support over a prolonged period was not feasible in this QI initiative, as every mechanically delivered or supported breath was not recorded. Similarly, other important components of pulmonary function, such as lung compliance, were not routinely measured. Our QI project was designed to have a discrete start date to period 2 after a 6-month period 1. Because the intervention was designed by a multidisciplinary group, it is likely that components of the intervention “bled in” during the final months of period 1. Because our ultimate goal was to reduce the rate of pneumothorax, this limitation did not affect our study objective. Another limitation of our study was that we did not make an assessment of whether all groups of individuals were well educated on the intervention. The nurses and respiratory therapists had to complete the critical skills poster session as part of their annual training session, which educated them on the high incidence of pneumothorax in our unit, the interventions that were being implemented, and their role in the project. Other members of the multidisciplinary team, including the pediatric residents, the neonatal nurse practitioners, and fellows, were taught during bedside rounds but no assessment of learning or competency was in place. Changes in the rate of surfactant administration over time and the methods of administration of surfactant may have had some influence on the outcome; however, the decreased rate of surfactant in period 2 did not reach significance. Our findings may not be generalizable to other NICUs that use different modes of mechanical ventilation or that have different rates of pneumothorax.

CONCLUSIONS

Increased vigilance, real-time monitoring of VT and PIP, and timely communication between the bedside nurses or respiratory therapists and the clinicians of sustained elevations of these parameters decreased the incidence of pneumothorax in our population of VLBW infants. Our data illustrate the benefits of comparative NICU benchmarking and organized QI effort in advancing patient care outcomes.

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