Evaluation and Development of Potentially Better Practices to Reduce Bronchopulmonary Dysplasia in Very Low Birth Weight Infants

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ABSTRACT

OBJECTIVE. The objective of this study was to describe development and implementation of potentially better practices to reduce bronchopulmonary dysplasia in very low birth weight infants (birth weight: 501–1500 g).

METHODS. Results of Breathsavers Group meetings, conference calls and critically appraised topic summaries were used to construct potentially better practices. Implementation plans and experiences were reported by participants and collated.

RESULTS. The Breathsavers Group developed 13 potentially better practices, based on published evidence and expert opinion. Participants determined which potentially better practices to implement and implementation methods. Participating NICUs implemented an average of 5 potentially better practices (range: 3–9). The Breathsavers Group also developed a resource kit, identified common obstacles to implementation, and initiated research to define bronchopulmonary dysplasia better.

CONCLUSIONS. Multinstitutional collaboration facilitated development and implementation of potentially better practices to reduce bronchopulmonary dysplasia.
The Vermont Oxford Network (VON) sponsored the Neonatal Intensive Care Quality Improvement Collaborative 2002 (NIC/Q 2002) to help participating NICUs make measurable improvements in care for very low birth weight (VLBW) infants. This collaborative was patterned after 2 previous collaboratives (NIC/Q and NIC/Q 2000).1-3 The essential components of NIC/Q 2002 were (1) evidence-based potentially better practices (PBPs), (2) current methods of quality improvement and adult education, (3) multicenter collaboration, and (4) outcomes measurement. Central to the collaborative were 4 key habits: change, evidence-based practice, systems thinking, and collaborative learning.3

Of centers that initially participated in NIC/Q 2002, 17 chose reducing bronchopulmonary dysplasia (BPD) as a primary objective and joined the Breathsavers Group. One institution dropped out of the collaborative, leaving 16 centers (19 hospitals) that completed the project. One center consisted of 4 separate hospitals that collaborated as a single center. Rates of BPD vary widely among centers, even after adjustment for differences in patient populations.4,5 A previous report from the original NIC/Q collaborative showed a significant decrease in BPD among participants who focused on reducing BPD rates.2 The Breathsavers Group believed that they could lower BPD rates by implementing PBPs. The goal was to reduce BPD by 10% in 2003 compared with the baseline year, 2001.

METHODS
The Breathsavers Group consisted of 16 centers (19 hospitals) with Jay P. Goldsmith, MD, Medical Expert; Meena LaCorte, MD, Group Leader; and Debra Miller and Diane Miller, Facilitators. Participating hospitals are listed in the Acknowledgments. One center, Columbus Children’s Hospital (Columbus, OH), was closely associated with 3 referral hospitals (Doctor’s Hospital West, Riverside Methodist Hospital, and Grant Medical Center). These 4 hospitals worked very closely with each other and participated in the NIC/Q 2002 collaborative as a single center. For the purposes of this report, these 4 hospitals were considered as 1 center.

The primary goal of the Breathsavers Group was to decrease BPD in VLBW infants by 10% of the pre-NIC/Q 2002 rate using the VON definition of BPD: need for supplemental oxygen at 36 weeks’ postmenstrual age (PMA). Data from 2001 served as a baseline, and data from 2003 served as the outcome year. Secondary goals were to decrease oxygen days, ventilator days, and postnatal steroid use without increasing mortality. To accomplish these goals, the group met during the semianual sessions of the NIC/Q 2002, held conference calls, and shared implementation experiences via e-mail and a list-serve. Members also shared surveys of respiratory care processes and outcomes data. Participants developed a high level of trust in one another and were willing to share both successes and failures in implementing PBPs.

PBPs
PBPs were derived from critically appraised topic summaries (CATS), which are reviews of clinical topics that summarize the available information on a particular practice or problem. For some topics, there were insufficient data, and expert opinion was used. The group agreed on 6 PBPs that were considered “first tier” (Table 1), because they were most likely to be accepted, implemented, or effective. The group also identified 7 PBPs as “second tier” because they were less likely to be accepted by NICU staff, more difficult to implement, or less likely to reduce BPD rates. Categorization of PBPs as first tier or second tier was subjective and did not predict which PBPs ultimately were adopted by participants (Table 2). Participants adopted as many PBPs as they thought were appropriate and implemented them according to the unique circumstances of their centers (Table 2). Implementation measures (Table 3) for PBPs were recommended to the group but were not mandatory.

Patient Data
Outcomes data were deidentified and submitted by each participating institution, collated, and analyzed. Outcomes data used the same data set and definitions as the VON.6-8 Each participating hospital’s institutional review board approved the use of these data for the study.

<table>
<thead>
<tr>
<th>TABLE 1 PBPs to Reduce BPD</th>
<th>Level of Evidencea</th>
<th>References</th>
</tr>
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<tbody>
<tr>
<td>First-tier recommendations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decrease sentinel events such as unplanned extubations and air leak syndromes</td>
<td>3</td>
<td>25–28</td>
</tr>
<tr>
<td>Extubate infants from assisted ventilation as soon as possible</td>
<td>5</td>
<td>5, 37, and 38</td>
</tr>
<tr>
<td>Increase use of permissive hypercapnia</td>
<td>2</td>
<td>4, 5, 16, 17, and 20</td>
</tr>
<tr>
<td>Monitor Vi of mechanically ventilated patients</td>
<td>4</td>
<td>16, 17, and 37–41</td>
</tr>
<tr>
<td>Improve team work in the DR</td>
<td>5</td>
<td>42 and 43</td>
</tr>
<tr>
<td>Improve use of surfactant in the DR</td>
<td>1</td>
<td>10 and 11</td>
</tr>
<tr>
<td>Second-tier recommendations</td>
<td></td>
<td></td>
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<tr>
<td>Use NeoPuff instead of hand ventilation</td>
<td>5</td>
<td>42 and 43</td>
</tr>
<tr>
<td>Use vitamin A</td>
<td>1</td>
<td>12 and 13</td>
</tr>
<tr>
<td>Target Spo2 lower than traditional normal, adult Spo2 values</td>
<td>2</td>
<td>14, 15, and 29–36</td>
</tr>
<tr>
<td>Minimize use of supplemental O2 in the DR by titrating FiO2 and monitoring Spo2</td>
<td>3</td>
<td>29–36</td>
</tr>
<tr>
<td>Close a PDA early in the neonatal course (medical or surgical)</td>
<td>3</td>
<td>22–24</td>
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<tr>
<td>Provide consistent respiratory management</td>
<td>5</td>
<td>46 and 47</td>
</tr>
<tr>
<td>Provide blended O2 in the DR and during transport to the NICU</td>
<td>5</td>
<td>29–36</td>
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</table>

Vi indicates tidal volume; DR, delivery room; Spo2, pulse oxygen saturation; FiO2, fraction of inspired oxygen.
aMuir Gray classification system.6
TABLE 3  Suggested Implementation Measurements for Sites That Implemented Specific PBPs

First-tier PBP implementation measures

Reduce sentinel events: count sentinel events, such as unplanned extubations, before and after implementing the PBP-associated plan-do-study-act cycles

Early extubation: develop and implement a weaning protocol

Count endotracheal tube days before and after implementation of PBP

Daily audit to track compliance with the weaning protocol

Reintubation rate before and after implementation of PBP

Permissive hypercapnia: suggested PCO₂ target range, \( \frac{1}{2} \times 10^2 \) mmHg

- No. of ventilated days with PCO₂ outside the target range
- Percentage of infants with birth weight \( \leq 1500 \) g and PCO₂ outside the target range
- Percentage of infants with blood gas done 0.5–1 h after a change in ventilator setting
- Percentage of infants with PIP change, if PCO₂ \( \leq 10^2 \) mmHg and length of time between gases

VT monitoring and ventilator management: record average VT (measured at least every 8 h) during the first 4 postnatal days; centers also must submit their guidelines for VT

Increase team work in DR: number of minutes from delivery to leaving DR

Surfactant in the DR: minutes to surfactant (already collected as part of VON data); minutes from delivery to leaving the DR

Second-tier PBP implementation measures

NeoPuff

- No. of resuscitations in which NeoPuff was used, divided by total resuscitations
- No. of times PIP raised above the set PIP divided by the total resuscitations (set pressure limit at 20/5)
- Initial PICO₂ on admission to NICU before and after implementation of NeoPuff use

Vitamin A: patients with (a) no vitamin A, (b) incomplete vitamin A, or (c) complete vitamin A courses

Targeting O₂ saturations: set saturation alarms between 80 and 97 and target saturations between 88 and 95; write orders for the target oxygen range and alarm limits; discuss this daily on rounds

Conduct random unannounced checks once or twice a day and note the percentage of infants who are \( \leq 1500 \) g and on oxygen and outside the target range

Develop a policy for targeting oxygen saturation, circulate it, and note what percentage of the staff read the policy

Blended O₂ in the deliver room and on transport from the DR to NICU

One center dropped out of the collaborative before the matrix was completed and is not included above. X indicates PBP implemented during collaborative; O, PBP implemented before collaborative; P, plan to start it soon; N, not planning to implement.

TABLE 2  Breathsavers Group Implementation Matrix

<table>
<thead>
<tr>
<th>PBPs</th>
<th>Center</th>
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First-tier recommendations

- Decrease unplanned extubations and air leak syndromes
- Early extubation from assisted ventilation
- Increased use of permissive hypercapnia
- Ventilation by VT monitoring
- Improve team work in the DR
- Improve use of surfactant in the DR

Second-tier recommendations

- NeoPuff use
- Administer vitamin A
- Target O₂ saturations
- Reduce use of O₂ in the deliver room: titration of FiO₂ by SpO₂
- Early PDA closure
- Increased consistency in respiratory management
- Blended O₂ in the deliver room and on transport from the DR to NICU

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PPI indicates peak inspiratory pressure.
Benchmarking
Participants reviewed rates of BPD among Breathsavers Group participants as well as those in published studies. A survey of respiratory care practices was developed and completed by all participating centers (Table 4). Collated results of the survey were distributed to each participant. The survey showed variations in practice but failed to identify superior respiratory practices.

RESULTS
Participating Centers
The 19 participating hospitals had 12 to 225 VLBW admissions and BPD rates of 13.4% to 66.7% for 2001. Twelve hospitals had BPD rates higher than the mean BPD rate for all centers that submitted data to the VON in 2001. Seven hospitals joined the collaborative, although their BPD rate was not higher than the mean. In 3 of these 7 hospitals, the BPD rate was perceived by the participating institution to be too high.

Development of PBPs
PBPs were developed on the basis of evidence review, expert opinion, and group discussion. Some PBPs were supported by meta-analyses of multiple randomized, controlled trials and others only by expert opinion. Supporting evidence was ranked according to the criteria of Muir-Gray: level 1, strong evidence from at least 1 systematic review of multiple well-designed, randomized, controlled trials; level 2, strong evidence from at least 1 properly randomized, controlled trial of appropriate size; level 3, evidence from well-designed trials without randomization, including single group, pre-post, cohort, time-series, or matched-case controls; level 4, evidence from well-designed, nonexperimental studies, preferably from >1 center or research group; and level 5, opinion of respected authorities, based on clinical evidence, descriptive studies, or reports of expert committees. The NIC/Q has consistently emphasized that PBPs are potentially, not necessarily proven, better practices (Table 1).

PBPs Supported by Level 1 Evidence
Only 2 PBPs were ranked as resting on level 1 evidence: prophylactic surfactant and vitamin A supplementation.

PBPs Supported by Level 2 Evidence
Two PBPs were based on level 2 evidence: targeting oxygen saturations that are lower than traditional adult normal values and permissive hypercapnia. At least 2 studies have suggested that maintaining lower pulse oxygen saturation values could improve respiratory outcomes. Targeting oxygen saturations received more emphasis than other PBPs, possibly because of the reported benefit of reducing retinopathy of prematurity. By mid-2004, most participating centers were implementing changes in target oxygen saturations for VLBW infants.

Permissive hypercapnia, combined with reduced tidal volumes, seems to reduce lung injury in adults and may do so in infants as well. However, permissive hypercapnia has not been shown to reduce BPD rates when examined in the absence of a ventilation strategy that is centered on avoidance of mechanical ventilation. The opposite of permissive hypercapnia, hypocarbia, has been reported to increase BPD. On the basis of adult studies and several neonatal reports, this PBP was assessed to rest on level 2 evidence and to be an important part of an overall strategy to reduce mechanical ventilation, tidal volumes, and BPD.

PBPs Supported by Level 3 Evidence
Early closure of a patent ductus arteriosus (PDA), reducing sentinel complications such as air leak syndrome, and minimizing use of supplemental oxygen in the delivery room all were judged to be supported by level 3 evidence. Two well-designed, nonrandomized studies reported an association between PDA and BPD. Furthermore, a recent meta-analysis reported that in certain birth weight groups, prophylactic indomethacin reduced the duration of supplemental oxygen but not necessarily BPD. Reducing sentinel events also may reduce BPD. Past neonatal studies and a recent study on adults suggested that reducing sentinel events can reduce complications of mechanical ventilation. In addition to published evidence, reducing sentinel events was strongly advocated by expert opinion from the Breathsavers Group.

Recent studies have emphasized the potential toxicity of supplemental oxygen. Animal studies, Resuscitation of Asphyxiated Newborn Infants With Room Air or Oxygen (the Second Multicenter Study) (Resair 2), and the Supplemental Therapeutic Oxygen for Prethreshold Retinopathy of Prematurity (STOP-ROP) studies all suggest that minimizing exposure to high concentrations of oxygen benefits neonates. Tin and Silverman emphasized that too little information exists to know with certainty which level of supplemental oxygen is safe for newborn infants. However, the evidence so far indicates that oxygen is potentially toxic. The Breathsavers Group concluded that published evidence supported minimizing the amount of supplemental oxygen that is

<table>
<thead>
<tr>
<th>TABLE 4</th>
<th>Breathsavers Group Resource Kit to Reduce BPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory Care Survey—Questionnaire</td>
<td></td>
</tr>
<tr>
<td>PBP grid to track the implementation of PBPs at the participating centers</td>
<td></td>
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<tr>
<td>36-Week Gestation Data Form: provides a “respiratory snapshot” of infants 500–1500 g birth weight to define respiratory status at 36 wk PMA better</td>
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<tr>
<td>Accidental Exubation and Umbilical Artery Catheter Dislodgement Tracking Tool</td>
<td></td>
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<tr>
<td>Tracheal Aspirate Data Form to evaluate nosocomial pneumonia</td>
<td></td>
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<tr>
<td>Neonatal Resuscitation Critique Form for evaluating the “golden” first hour after birth</td>
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<tr>
<td>FIO2 conversion tables used to determine the “effective FIO2” for infants on supplemental O2 via nasal cannula</td>
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S68 PAYNE et al

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provided to VLBW infants in the delivery room and in the NICU.

**PBPs Supported by Level 4 Evidence**

Minimizing the tidal volume of ventilated patients was based on randomized studies in adults, nonexperimental studies, and reviews of neonatal ventilation. Lower tidal volumes, which require permissive hypercapnia for implementation, reduced pulmonary morbidity in adults. Neonatal studies that examined the influence of peak inspiratory pressure, hypocapnia, or other markers of barotrauma have reported mixed results. Therefore, this PBP was ranked as resting on level 4 evidence.

**PBPs Supported by Level 5 Evidence**

The remaining PBPs, blended oxygen to reduce oxygen exposure in the delivery room, consistent respiratory management, use of the NeoPuff device (Fisher and Paykel Healthcare Corporation Ltd, Laguna Hills, CA) for manual ventilation in the delivery room, early extubation, and increased teamwork in the delivery room were largely supported by expert opinion. Consistent respiratory management often has meant the implementation of ventilator weaning protocols or avoidance of mechanical ventilation altogether. Although ventilator weaning remains more art than science, providing consistent respiratory management should improve respiratory care. The center with the lowest BPD rate in the Breathsavers Group had consistent weaning protocols with monitored implementation. Weaning protocols can reduce variation in respiratory treatment. In 1 study of pediatric patients, protocols reduced variation in respiratory care, decreased the duration of ventilatory support, but did not reduce length of hospital stay. Although ventilator weaning protocols may be effective in reducing ventilator days, there is no evidence that they can reduce BPD rates.

The NeoPuff device may minimize overventilation of the lungs during bag/mask or bag/etotracheal tube ventilation. It was shown recently to be more consistent and less likely to result in excessive ventilatory pressures when compared with manual ventilation. This device seems to be a better alternative to unmeasured, inconsistent manual ventilation in the delivery room or during tracheal suctioning in the NICU. However, no studies have demonstrated a reduction in BPD associated with using the NeoPuff.

**Implementation of PBPs**

Centers chose PBPs to implement, implementation methods, and the measures for tracking implementation (Table 3). Some centers believed that certain PBPs had already been implemented or were not appropriate. Other centers chose not to implement some PBPs during the collaborative but indicated that implementation would occur at a later time (Table 2).

Participating centers chose an average of 5 PBPs for implementation, with a range of 3 to 9 (Table 2). Breathsavers Group centers had already implemented an average of 5 PBPs before the collaborative (range: 1–11). Participating centers that had participated in a previous NIC/Q collaborative implemented an average of 5 PBPs compared with an average of 6 PBPs for new centers that had not previously participated in the NIC/Q collaboratives. There was little difference in the number of first-tier and second-tier PBPs that were adopted by participating centers. The average for first-tier PBPs was 12 centers per PBP and for second-tier PBP was 11 centers (Table 2).


The group developed implementation measurements for the PBPs (Table 3). These implementation measurements were not mandatory but helped centers to evaluate their own implementation.

**Resource Kit**

After deciding on PBPs, the group created a resource kit (Table 4) that was modeled after 1 that was prepared by the previous NIC/Q collaborative. The kit was made available to all NIC/Q 2002 participants.

**Research Studies Spawned by Collaborative Participation**

The Breathsavers Group quickly became frustrated with the current definition of BPD. Members of the Breathsavers Group (Dr Joseph Kaempf, primary investigator) initiated a research project to define BPD better. This study had as its purpose evaluating the capillary PCO2 and room air pulse oxygen saturation at 36 weeks' PMA of infants with birth weight of 501 to 1250 g. In addition, neurodevelopmental and respiratory status were to be evaluated at 1 year of corrected age. The hypothesis was that by obtaining better quantitative information about the respiratory status of these infants, their first-year outcomes could be predicted more accurately. More than 200 infants have been enrolled in the study, with enrollment continuing.

**DISCUSSION**

What Causes BPD?

Despite volumes of basic and clinical research, the precise pathophysiology and causes of BPD remain unknown. However, BPD seems more likely when the following risk factors are present: male gender, lower gestational age, lower birth weight, high fluid intake, PDA, sepsis, higher ventilator pressures, excessive tidal volume, severity of acute lung disease, and possibly white race. Therefore, it is hard to compare raw BPD rates among centers and to know whether centers differ in their BPD rates as a result of demographic or treatment differences.

However, several studies have reported that treatment practices influence BPD rates. The most compel-
ling evidence for an effective prevention strategy seems to be avoidance of mechanical ventilation.\textsuperscript{5,38,44,55,56} When mechanical ventilation is used, it probably should be restricted to the lowest possible tidal volumes, oxygen concentration, and duration.

**Will Any of the PBPs Significantly Reduce BPD?**

Proven strategies for reducing BPD, such as vitamin A administration and prophylactic surfactant administration, result in relatively small decreases in BPD rates: 5% to 20%.\textsuperscript{12,13} Many of the PBPs that were chosen in this study may have an even smaller effect on BPD rates. Major reductions in BPD may well require a shift from traditional mechanical ventilation to methods of respiratory support that do not require intubation and positive pressure ventilation, such as nasal continuous positive airway pressure with or without early surfactant.\textsuperscript{4,5,37,38,44,55,56}

Almost any reduction in BPD among the Breathsavers Group centers would represent success. During the 3 years of NIC/Q 2002, the BPD rate (supplemental oxygen at 36 weeks’ PMA) remained unchanged in the VON overall.\textsuperscript{57–59} Results from a previous NIC/Q collaborative showed that the BPD rates dropped after implementation of a set of PBPs that were somewhat different from those in this project.\textsuperscript{2,60} The centers in that first NIC/Q project had baseline BPD rates that were higher than those of a comparison group of NICUs that did not participate in the NIC/Q project. After the project, NIC/Q participating centers had BPD rates that were lower than the comparison group, but only \(-6\) percentage points lower.\textsuperscript{2} Therefore, participation in this sort of collaborative may confer greater benefit on centers with higher than average BPD rates than on centers with average or below average BPD rates.

**Applying This Work to Other Centers**

Participating centers implemented PBPs in an institution-specific manner. Although lack of standardized implementation might be a criticism, it reflects clinical reality. Practices rarely are implemented at the bedside in exactly the same way as in the clinical study that demonstrated their effectiveness. Furthermore, isolated practices may be much less likely to reduce BPD rates than a “package” of practices that are implemented consistently. For example, permissive hypercapnia is an integral part of the approach that combines deferral of endotracheal intubation until a trial of nasal continuous positive airway pressure.\textsuperscript{4,5} However, permissive hypercapnia, as an isolated PBP, may be ineffective when used with a more isolated strategy of mechanical ventilation.\textsuperscript{18}

The NICUs in this collaborative selected themselves for participation on the basis of willingness to make fundamental changes in respiratory practices. Each center invested considerable effort in implementing change and participating in conference calls, semiannual meetings, site-specific team meetings, and other endeavors. By far the most important commitment was that of center-specific, regular coordination of various NICU disciplines to plan and report progress in implementing PBPs. Centers that are not willing to make this investment in time and energy are less likely to derive benefit from quality collaboratives. Although quality improvement can save more money than it costs,\textsuperscript{61} participation in a collaborative such as the Breathsavers Group requires institutional commitment and funding.

**Implementing PBPs**

Collaboration and communication are essential to quality improvement projects. Failure to involve all constituencies when planning and implementing practice change creates resistance. The use of outcome data from one’s own center and comparative data from other centers often neutralizes this resistance. Although some PBPs were based primarily on expert opinion, seeing the rationale for that opinion increased cooperation.

All participants reported difficulties with recruiting support for implementing many of the PBPs. Barriers to successful implementation included failure to obtain staff buy-in, inadequate communication before instituting practice changes, and confusion over which practice changes were required. Modifying old habits and traditional care practices was uniformly described as difficult. Groups found that multiple methods of communication were more effective than a single strategy. One-on-one discussions, group meetings, wide dissemination of supporting data, and revising standing orders and redesigning routines and roles were required to implement the PBPs successfully.

The Breathsavers Group experience and published reports suggest that there is no single best way to implement better care practices.\textsuperscript{62} Consistent with published reviews, extensive educational campaigns did not ensure implementation.\textsuperscript{62–64} Consensus processes, use of opinion leaders, performance feedback, etc also resulted in only modest, if any, improvements when used by themselves.\textsuperscript{61} Multiple interventions and multifaceted implementation efforts are most likely to result in a change in care practices.\textsuperscript{60–62} The Breathsavers Group also found that contests, prizes, and celebration of even minor successes succeeded when memos, protocols, rules, and negative feedback did not.

**Value of Sustained Commitment**

Successful initial implementation of PBPs did not guarantee continued implementation. Over time, staff compliance waned, requiring continued educational efforts. In addition, personnel changes of both staff and leadership undermined past progress. When leadership in the NICU changes, the focus of quality improvement efforts often also changes. Sustained implementation of PBPs
requires sustained educational efforts and stable NICU leadership. In summary, reducing BPD requires PBPs that are based on solid evidence, as a systems approach to implementation, extensive educational efforts, and sustained effort by NICU leadership.

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