Impact of Implementing 5 Potentially Better Respiratory Practices on Neonatal Outcomes and Costs

abstract

OBJECTIVE: We implemented 5 potentially better practices to limit mechanical ventilation (MV), supplemental oxygen, and bronchopulmonary dysplasia in newborn infants born before 33 weeks' gestation.

METHODS: The methods used in this study included (1) exclusive use of bubble continuous positive airway pressure (bCPAP), (2) provision of bCPAP in the delivery room, (3) strict intubation criteria, (4) strict extubation criteria, and (5) prolonged CPAP to avoid supplemental oxygen. We excluded outborn infants and those with major anomalies and obstetric complications from analysis.

RESULTS: Demographics were similar in 61 infants born before and 60 born after implementation. For infants born at 26 to 32 6/7 weeks' gestation, intubation (first 72 hours) decreased from 52% to 11% ($P < .0001$) and surfactant use decreased from 48% to 14% ($P = .0001$). In all infants, the mean ± SD fraction of inspired oxygen requirement (first 24 hours) decreased from 0.27 ± 0.08 to 0.24 ± 0.05 ($P = .0005$), days of oxygen decreased from 23.5 ± 44.5 to 9.3 ± 22.0 ($P = .04$), and days of MV decreased from 8.8 ± 27.8 to 2.2 ± 6.2 ($P = .005$). Hypotension decreased from 33% to 15% ($P = .03$). The percentage of infants with bronchopulmonary dysplasia was 17% before and 8% after ($P = .27$). Nurse staffing ratios remained unchanged.

CONCLUSIONS: Implementation of these potentially better practices reduced the need for MV, surfactant, and supplemental oxygen as well as reduced hypotension among infants born before 33 weeks' gestation without adverse consequences. The costs for equipment and surfactant were lower. *Pediatrics* 2011;128:e218–e226

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KEY WORDS

bronchopulmonary dysplasia, mechanical ventilation, premature infants, blood pressure, cost analysis, continuous positive airway pressure

ABBREVIATIONS

RDS—respiratory distress syndrome
CPAP—continuous positive airway pressure
BPD—bronchopulmonary dysplasia
SEMC—St Elizabeth's Medical Center
bCPAP—bubble continuous positive airway pressure
FIO_2—fraction of inspired oxygen

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Respiratory distress syndrome (RDS) is caused by lung immaturity and surfactant deficiency and is common among premature infants. Survival and outcomes for infants with RDS have improved in the past 30 years as a result of the development of exogenous surfactant, continuous positive airway pressure (CPAP), and better mechanical ventilators. Exogenous surfactant reduces mortality and short-term respiratory morbidity in premature infants with RDS[1] but requires intubation and mechanical ventilation to administer. Mechanical ventilation increases the risk of subsequent bronchopulmonary dysplasia (BPD),[2] a chronic lung disease associated with adverse pulmonary and neurodevelopmental outcomes.[3,4] On the other hand, early treatment with CPAP can preserve endogenous surfactant and reduce the need for mechanical ventilation and surfactant administration[5–11] but may be insufficient support for infants born before 26 weeks' gestation.[12] Although there is a growing body of evidence to guide decision making, there is not yet consensus on the best treatment approach for RDS.

It has long been known that management of RDS and the incidence of subsequent BPD vary among institutions.[13,14] More than 20 years ago Avery et al[13] reported that Columbia University in New York had a comparatively low incidence of BPD among infants with birth weights of <1500 g and attributed this to early intervention with CPAP and avoidance of mechanical ventilation.[13] This finding was confirmed by Van Marter et al[15] in 2000.

There has been increasing interest in pursuing respiratory management strategies for RDS that minimize mechanical ventilation in an effort to reduce the incidence of BPD. These strategies include the provision of CPAP in the delivery room[5–11] and early extubation from mechanical ventilation to CPAP.[16] However, the growing body of supportive evidence has not resulted in widespread adoption of either of these strategies in US NICUs. This may be attributed to a perceived lack of evidence and/or lack of consensus at individual units.

In 2007, we undertook a major change in practice for infants born before 33 weeks' gestation at St Elizabeth's Medical Center (SEMC). Although our use of mechanical ventilation and incidence of BPD approximated the Vermont Oxford Neonatal Network averages, they were higher than the best-performing units. We implemented 5 potentially better respiratory practices with the goal of limiting mechanical ventilation and supplemental oxygen and reducing our incidence of BPD. This is a report of our rationale for these practices; how we built an effective team, achieved consensus, implemented and ensured compliance; and the impact these new practices had on clinical care, outcomes, and cost of care.

METHODS

Team Formation, Guideline Development, and Implementation

We assembled a team consisting of a neonatologist (Dr Levesque), a respiratory therapist (Ms LaPierre), a neonatal nurse practitioner (Ms Welch), and a bedside nurse (Ms Porter). All team members were well known to the clinical staff and were employed full time in their positions. The team reviewed the contemporaneous institutional nursing and respiratory care policies and physician guidelines regarding respiratory management of premature infants with RDS and conducted a limited chart review. We chose our target population of infants born before 33 weeks' gestation as most likely to benefit from this quality-improvement effort on the basis of our baseline rate of mechanical ventilation use. As part of the planning phase, the team attended the 18th Annual Respiratory Care of the Newborn: A Practical Approach Conference at Morgan Stanley Children's Hospital of New York–Presbyterian in New York, New York, on October 21–22, 2006, during which details of the "Columbia approach" were presented. A written proposal detailing 5 potentially better practices, with rationales for each, was distributed to all neonatologists and neonatal nurse practitioners, and a formal presentation was made at a faculty meeting. The final guideline was approved by the SEMC NICU Medical Director, the Chair of Pediatrics, and the Directors of Nursing and Respiratory Therapy. All staff members were in-serviced by the team member in their discipline or department regarding the details of the guideline, the rationale for each change, and the technical aspects regarding bubble CPAP (bCPAP). The guideline was instituted on January 14, 2007. Flow diagrams outlining the management of infants born before 26 weeks' gestation, those born between 26 and 32 6/7 weeks, and criteria for intubation, extubation, and trial of CPAP are provided in Fig 1.

Rationale for Each Potentially Better Practice

Exclusive Use of bCPAP

There are several modes of pressure generation for CPAP, and although there is not yet enough information to conclude that one is more effective than another,[17] bCPAP may be more effective. For example, bCPAP enhances gas exchange in premature infants compared with ventilator-derived CPAP[18] and leads to less ventilation inhomogeneity and better gas exchange in premature lambs.[19] Extubation to bCPAP is more successful than extubation to infant flow-driver CPAP in infants born between 24 and 29 weeks'

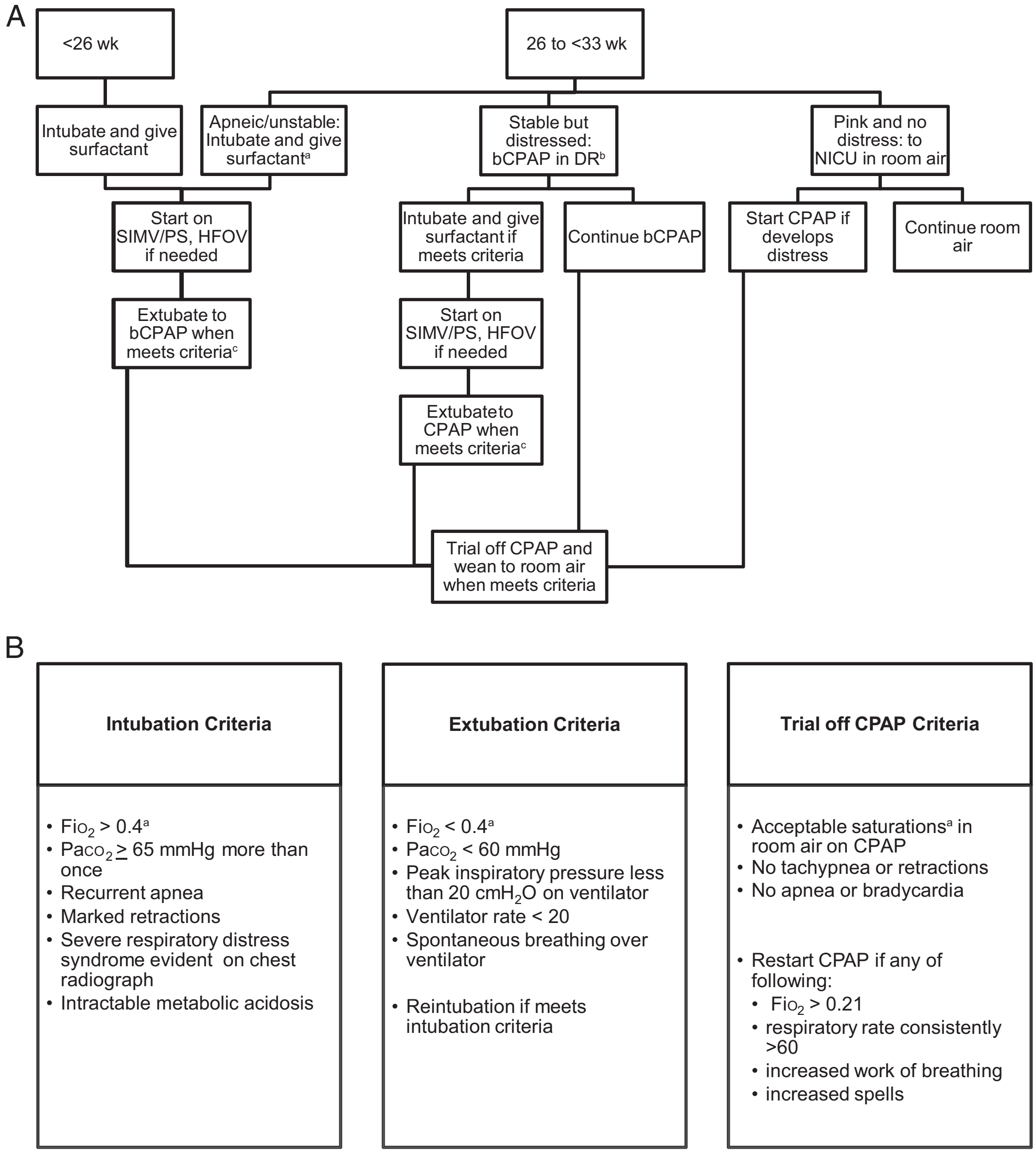

FIGURE 1

A, Respiratory management of infants based on gestational age. [a] Give surfactant in delivery room (DR) if the infant is <28 weeks' gestational age and requires intubation in the delivery room for resuscitation or apnea; [b] goal to start bCPAP by 5 minutes of age; [c] goal is extubation by 24 hours. SIMV/PS indicates synchronized intermittent mandatory ventilation with pressure support; HFOV, high-frequency oscillatory ventilation. B, Criteria for intubation, extubation, and trial off CPAP. [a] Goal pulse-oximetry saturations: 87% to 94% for infants ≤32 weeks' postmenstrual age and 87% to 97% for infants >32 weeks' postmenstrual age.

gestation after short-term ventilation.[20] The equipment required for bCPAP is cheaper than that for ventilator-derived CPAP and is easily made portable by mounting all components on a heavy-duty pole with wheels. We chose to change from ventilator-derived CPAP to bCPAP because of the potential for improved efficacy, lower cost, and excellent portability.

Provision of bCPAP in the Delivery Room

Provision of CPAP in the delivery room reduces the need for intubation and subsequent mechanical ventilation of premature infants[5–11,21] and may decrease the incidence of BPD[8,9,11] but is successful in avoiding early mechanical ventilation in only 31% of infants born before 26 weeks' gestation.[12] Because infants who require mechanical ventilation for management of RDS have improved outcomes if they receive early surfactant,[22,23] we decided to intubate and provide surfactant in the delivery room for all infants born before 26 weeks' gestation but to start CPAP in the delivery room for breathing but distressed infants born at ≥26 weeks' gestation.

Strict Intubation Criteria

Although ventilated premature infants have better outcomes with early surfactant,[22,23] there are limited data regarding the timing of surfactant for infants who are first managed with CPAP. The available data suggest that it is better to receive surfactant early in the course of RDS, when the fraction of inspired oxygen (F_{IO_2}) requirement is still low, rather than later.[16,24] In a study of infants born before 30 weeks' gestation initially managed with delivery-room CPAP, Verder et al[24] reported that infants who received early surfactant (when arterial-to-alveolar oxygen ratio = 0.35, equivalent to an F_{IO_2} of ~0.40 with arterial partial pressure of oxygen at ~50 mm Hg) required less mechanical ventilation and had a shorter hospital course than infants who received late surfactant (arterial-to-alveolar oxygen ratio < 0.22, equivalent to an F_{IO_2} of ~0.60 with arterial partial pressure of O_2 at ~50 mm Hg). Although our practice had been to give rescue surfactant to infants on CPAP when F_{IO_2} requirement reached 0.3 to 0.35 or higher to maintain saturations higher than 87%, we decided to change our practice to give rescue surfactant to infants on CPAP when their F_{IO_2} reached 0.4 or higher and/or their arterial-to-alveolar oxygen ratio was ≥0.35 on the basis of the Verder et al[24] study.

Mechanical ventilation is indicated for infants with recurrent apnea, hypoventilation, and hypercapnia. Maintaining arterial partial pressure of carbon dioxide (Pa_{CO_2}) levels of 45 to 55 mm Hg is likely safe in ventilated premature infants,[25,26] but there are few data to determine a threshold Pa_{CO_2} level that alone should prompt intubation. Our practice had been to intubate for any Pa_{CO_2} level higher than 60 mm Hg. Elevated Pa_{CO_2} levels may be transient on bCPAP and at Columbia they intubate for Pa_{CO_2} levels of higher than 70 mm Hg but only if it persists for more than 1 arterial blood gas. We modified our practice and intubated for Pa_{CO_2} higher than 65 mm Hg if it persisted for more than 1 arterial blood gas.

Strict Extubation Criteria

Our practice had been to extubate to CPAP after gradual weaning to low ventilator settings, but immediate or early extubation after surfactant administration may be beneficial. Early surfactant followed by extubation to CPAP within 1 hour compared with later surfactant and continued ventilation is associated with a lower incidence of mechanical ventilation, air leaks, and BPD.[16] We changed our practice to extubate infants as soon as possible, ideally within 2 to 6 hours of reaching our extubation criteria (Fig 1) and ideally within the first 24 hours of age.

Prolonged CPAP With Avoidance of Nasal Cannula Oxygen Before 35 Weeks' Postmenstrual Age

There are no studies regarding the best time to wean premature infants off CPAP, but prolonging the use of CPAP and avoiding nasal cannula oxygen may be preferable. Excess supplemental oxygen increases the risk of retinopathy of prematurity and BPD,[27] whereas CPAP may improve lung growth.[28,29] In the absence of clinical data but with the suggestion of the added benefit of prolonged CPAP, we decided to adopt the Columbia criteria for trial off CPAP (Fig 1).

Equipment

Three portable bCPAP units and 9 stationary bCPAP units were assembled, mostly from previously purchased components, and we changed from Inca (Cooper Surgical, Trumbull, CT) to Hudson RCI (Teleflex, Arlington Heights, IL) CPAP prongs. All nursing and respiratory therapy staff members were instructed in the set up and maintenance of bCPAP. Nine older-model conventional ventilators that were previously used for CPAP were removed from the NICU.

Compliance

The majority of the staff was supportive of these changes in respiratory management, but these were not easy changes to make. In accordance, each team member was vigilant in reminding staff members of the guideline, offering guidance and further explanation when needed. Because there was a team member from each of the key disciplines, reinforcement of the guideline could be conducted among peers. One team member (Dr Levesque) visited or called the NICU daily from January 14, 2007, until January 31, 2008, to review the daily management of all infants at <33 weeks' gestational age in the NICU, plan for anticipated preterm deliveries, remind the medical staff of relevant aspects of the guideline, and encourage compliance of all staff members. Deviations from the guideline were noted and discussed with the clinical staff, but formal assessment of compliance was done by chart review after discharge.

Data Collection

This project was done as a quality-improvement project and not as a clinical study, but our goal was to evaluate the impact of these practice changes on outcomes. With SEMC institutional review board approval, we collected data from chart reviews after patient discharge, without informed consent, and analyzed deidentified data.

Cost Analysis

Data for nonpersonnel costs were collected and analyzed according to methods described by Zupancic et al.[30] Most infants were assigned as 1 nurse to every 2 infants at SEMC, with sicker infants assigned to 1 nurse for every 1 infant. Nursing personnel costs were evaluated indirectly by analyzing the percentage of time infants were assigned 1-to-1 staffing while at SEMC. Equipment costs were tabulated separately. At the time of this project, the hospital owned 9 soon-to-be-out-of-warranty conventional ventilators that were used for both CPAP and mechanical ventilation. Equipment costs for replacement of these conventional ventilators versus bCPAP units were calculated.

Statistical Analysis

Categorical variables were summarized with percentages and compared between subgroups using Fisher's exact test. Continuous variables were summarized by using means (±SD) and/or median (interquartile range) and compared using the Mann-Whitney test. We reported both means and medians for respiratory and cost outcomes, which tended to have skewed distributions, and when medians were not reported we verified that *t* tests and Mann-Whitney tests gave similar *P* values. All *P* values were 2-sided and were considered statistically significant at ≤.05.

RESULTS

A total of 150 infants born at <33 weeks' gestation were admitted to SEMC between January 1, 2006, and January 31, 2008, 76 before and 74 after the guideline was implemented (Fig 2). Outborn infants and those with major congenital anomalies or major obstetric complications were excluded from analysis, leaving 61 infants before and 60 infants after, for a total analysis cohort of 121 infants. Most of the infants were born between 26 and 32$\frac{6}{7}$ weeks' gestation. Demographic characteristics were similar between the groups (Table 1). Compliance with the 5 elements of the initiative was 100% (bCPAP), 95% (delivery room CPAP), 97% (intubation criteria), 83% (extubation criteria), and 88% (prolonged CPAP).

All infants born at <26 weeks' gestation were intubated and given prophylactic surfactant in the delivery room, but initial respiratory management of infants born between 26 and 32$\frac{6}{7}$ weeks' gestation changed significantly after the guideline (Table 2). Among these infants, more infants had CPAP as their first mode of respiratory support, more were started on CPAP in the delivery room, fewer were intubated in the delivery room or in the first 72 hours of age, and fewer were given surfactant replacement. Infants born after the guideline were started on CPAP earlier than those born before but received their first dose of surfactant, if required, at a similar age. Facial

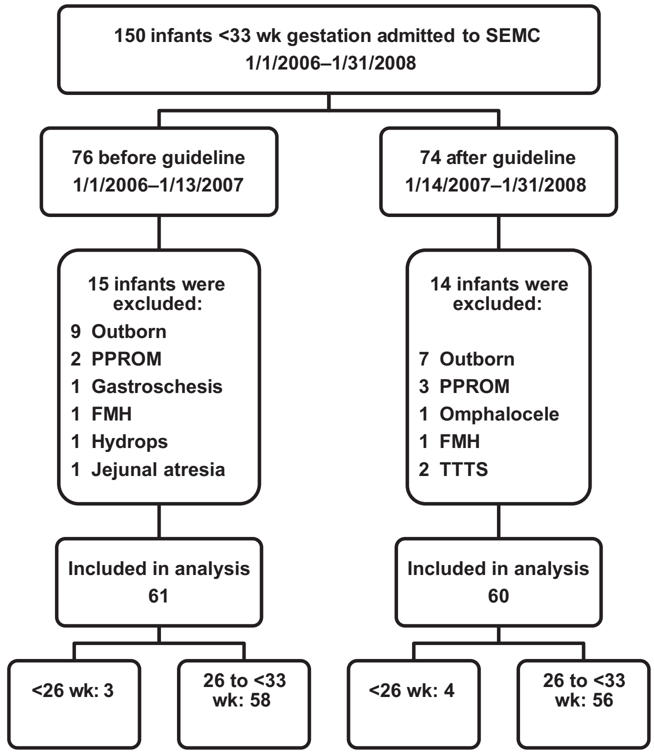

FIGURE 2
Flow diagram of infants. PPROM indicates preterm prolonged rupture of the membranes for >2 weeks' duration or at before 24 weeks' gestation at >2 weeks' or before 24 weeks' gestation; FMH, fetal-to-maternal hemorrhage; TTTS, twin-to-twin transfusion syndrome.

TABLE 1 Demographic Characteristics of All Infants

	Before	After	*P*
n	61	60	
Gestational age, mean ± SD, wk	30.2 ± 2.3	30.0 ± 1.9	.19
Gestational age <26 wk, *n* (%)	3 (5)	4 (7)	.72
Birth weight, mean ± SD, g	1393 ± 446	1394 ± 375	.98
Weight *z* score for gestational age, mean ± SD	−0.22 ± 0.76	0.01 ± 0.87	.11
Small for gestational age	8 (13)	4 (7)	.36
Chorioamnionitis	5 (8)	7 (12)	.56
Male gender	35 (57)	35 (58)	>.99
Nonwhite race	29 (48)	25 (42)	.58
No prenatal care	2 (3)	1 (2)	>.99
Betamethasone not complete	12 (20)	10 (17)	.81
Cesarean delivery	45 (74)	43 (72)	.84
5-min Apgar score, mean ±SD	8.2 ± 1.1	8.4 ± 0.9	.75

TABLE 2 Initial Respiratory Management for Infants at ≥26 Weeks' Gestational Age

	Before	After	*P*
n	58	56	
Maximum delivery-room support			<.0001
None	44 (76)	12 (21)	
CPAP	0 (0)	39 (70)	
Mechanical ventilation	14 (24)	5 (9)	
Maximum support during the first 72 h			<.0001
None	15 (26)	4 (7)	
CPAP	13 (22)	46 (82)	
Mechanical ventilation	30 (52)	6 (11)	
Surfactant			
Any administered	28 (48)	8 (14)	.0001
Age of first dose, if given[a]			
Minutes, median (25th–75th percentiles)	75.5 (10–677)	91 (21.5–775)	.91
CPAP			
First mode of support	27 (47)	48 (86)	<.0001
Age started, if first mode[b]			
Minutes, median (25th–75th percentiles)	29 (17,3)	4 (2.5,5)	<.0001

[a] Calculated for infants who received surfactant ($n = 28$ before, $n = 8$ after).
[b] Calculated for infants who were managed first with CPAP ($n = 25$ before, $n = 48$ after).

CPAP, which was commonly used in the delivery room before the guideline, was not considered as CPAP in these analyses, regardless of timing or duration.

Subsequent management and outcomes were analyzed including all infants born before 33 weeks' gestational age (Table 3). Infants born after the guideline received lower F_{IO_2}, while maintaining similar arterial Pa_{O_2} and Pa_{CO_2} in the first 24 hours, were exposed to fewer days of supplemental oxygen and fewer days of mechanical ventilation and had more ventilator-free days in the first 30 days of life compared with those born before. There were no differences in number of days on CPAP or overall length of mechanical support among infants who received these forms of support and no differences in the incidence of apnea of prematurity, pneumothorax, or need for oxygen on discharge from the hospital. The incidence of BPD, defined as supplemental oxygen requirement at 36 weeks' postmenstrual age, was reduced by ~50%, although this was not statistically significant ($P = .27$). Mortality and nonrespiratory morbidities were similar before and after the guideline, with the exception of the number of infants treated for hypotension in the first 24 hours of age, which was lower after. Time to start and to reach full feeds and length of stay were similar.

Infants born before 29 weeks' gestation and/or who were born weighing <1500 g are at high risk for adverse outcome. Mortality and complications of prematurity were similar before and after the guideline among infants born before 29 weeks' gestation. There were no statistically significant differences in mortality or complications of prematurity among infants born weighing <1500 g, although the incidence of BPD was reduced 60% after the guideline was instituted (Table 4).

The cohort of 121 infants was analyzed, regardless of admission date, to assess the impact of CPAP timing on CPAP success and the correlation of mechanical ventilation days with subsequent BPD. Infants who succeeded on CPAP ($n = 56$) were started on CPAP earlier than those who failed on CPAP ($n = 17$) (median age at starting CPAP: 4.3 minutes [interquartile range: 3–19] versus median age at starting CPAP: 29 minutes [interquartile range: 15–33], respectively; $P = .007$). Of 121 infants, 119 survived to 36 weeks' postmenstrual age and 15 developed BPD, whereas 104 did not. Infants that went on to develop BPD were ventilated for a significantly longer time (median: 11 [interquartile range: 4–48] versus median: 0 [interquartile range: 0–1] days, respectively; $P < .0001$).

Overall nonpersonnel cost of care for infants born before 33 weeks' gestation was similar during the first 12 weeks of hospitalization before and after the guideline. Specific cost for surfactant replacement therapy was significantly lower after the guideline. The percentage of SEMC days spent with a 1:1 staffing ratio was similar before and after the guideline (Table 5). Using this measure of personnel costs, there was no difference from before to after the guideline. The cost of the 9 stationary and 3 portable bCPAP units was much lower than the estimated 2007 cost of replacing the 9 out-of-warranty ventilators with new basic model conventional ventilators ($19 500 for bCPAP vs $135 000 for ventilators).

DISCUSSION

We were able to implement 5 potentially better respiratory practices in our unit with a team effort that required preparation, written and oral communication, buy-in and in-servicing of all levels of staff, and ongoing support and encouragement. The largest impact of this project was on measures of respiratory care.

Fewer infants required mechanical ventilation or surfactant administration, and more were managed exclusively with CPAP, but we did not find differences in average Pa_{CO_2} levels in the first 24 hours age or timing of the first dose of surfactant, when given. The small decrease in F_{IO_2} in the first 24 hours of age was contrary to what might have been expected, considering many infants in the before group received surfactant, whereas most in the after group did not. Days of supple-

TABLE 3 Respiratory Management and All Outcomes for Infants Born Before 33 Weeks' Gestation

	Before	After	*P*
n	61	60	
F_{IO_2} during the first 24 h, mean ± SD	0.27 ± 0.08	0.24 ± 0.05	.0005
Pa_{O_2} for the first 24 h of age, mean ± SD, mm Hg	78.5 ± 33.8	81.4 ± 38.0	.70
Pa_{CO_2} for the first 24 h of age, mean ± SD, mm Hg	46.0 ± 9.9	47.2 ± 10.1	.43
Days supplemental oxygen			.04
Means ± SD	23.5 ± 44.5	9.3 ± 22.0	
Median (25th–75th percentiles)	3 (0–33)	1 (0–3)	
Days of mechanical ventilation, all infants			.005
Mean ± SD	8.8 ± 27.8	2.2 ± 6.2	
Median (25th–75th percentiles)	1 (0–4)	0 (0–1)	
Days of mechanical ventilation, if ventilated			.63
Mean ± SD	16.2 ± 36.5	9.1 ± 11.5	
Median (25th–75th percentiles)	3 (1–11)	1.5 (1–16)	
Ventilator-free days during the first 30 d of life			.002
Mean ± SD	25.5 ± 8.5	28.0 ± 5.3	
Median (25th–75th percentiles)	29 (26–30)	30 (29–30)	
Days CPAP, if CPAP was provided			.20
Mean ± SD	9.5 ± 10.4	13.0 ± 14.8	
Median (25th–75th percentiles)	4.5 (3–14)	6 (3.5–18)	
Postmenstrual age off mechanical support, mean ± SD, wk	32.8 ± 4.6	32.1 ± 1.6	.78
Apnea of prematurity	48 (79)	45 (75)	.67
Caffeine for apnea of prematurity	37 (61)	39 (65)	.71
Pneumothorax	1 (2)	2 (3)	.62
BPD[a]	10 (17)	5 (8)	.27
Home in oxygen[a]	3 (5)	1 (2)	.62
Death in hospital	1 (2)	1 (2)	>.99
Cardiovascular outcomes			
Hypotension first 24 h of age	20 (33)	9 (15)	.03
Medically treated patent ductus arteriosus	15 (25)	11 (18)	.51
Surgically treated patent ductus arteriosus	7 (11)	3 (5)	.32
Neurologic outcomes			
Any intraventricular hemorrhage	13 (21)	10 (17)	.64
Periventricular leukomalacia	2 (3)	3 (5)	.68
Retinopathy of prematurity	12 (20)	9 (16)	.63
Necrotizing enterocolitis	4 (7)	2 (3)	.68
Culture-positive sepsis	11 (18)	7 (12)	.44
Packed red blood cell transfusion	17 (29)	15 (25)	.68
Growth and nutrition			
Day of life infant started feeds, mean ± SD	3.7 ± 4.9	2.5 ± 2.9	.21
Day of life infant reached 130 mL/kg per day feeds, mean ± SD	13.4 ± 11.5	12.1 ± 6.9	.59
Feeds (mL/kg per day) first 14 d, mean ± SD	69.7 ± 45.2	72.9 ± 34.1	.76
Postmenstrual age at full oral feed, mean ± SD, wk	35.4 ± 1.7	35.6 ± 1.5	.37
Weight at discharge or death, mean ± SD	2535 ± 635	2624 ± 532	.28
Weight *z* score at discharge or death, mean ± SD	−0.94 ± 0.77	−0.70 ± 0.81	.19
Length of stay			
Total hospital days, mean ± SD	52.6 ± 39.9	51.3 ± 23.5	.40
Postmenstrual age at death or discharge, mean ± SD	37.7 ± 4.3	37.3 ± 2.3	.99

Pa_{O_2} indicates arterial partial pressure of oxygen.

[a] Denominators are infants who survived to 36 weeks or discharge home ($n = 60$ before, $n = 59$ after).

mental oxygen were significantly reduced, but it seems that this was not a result of our proposed use of prolonged CPAP because the average postmenstrual age when infants were weaned off all mechanical support was similar. This finding supports our observation that most infants in the after group not only avoided mechanical ventilation in favor of CPAP but also weaned to room-air CPAP quickly.

We observed a 50% reduction in the incidence of BPD after the guideline was instituted, but this effect was not statistically significant, perhaps as a result of our small patient population. Although 1 randomized controlled study of delivery room CPAP reported an increased incidence of pneumothorax,[21] we did not find this result with our approach in our patient population.

The most significant nonrespiratory outcome was a reduction in the incidence of hypotension requiring treatment. Increased mean airway pressure and tidal volumes associated with mechanical ventilation are known to decrease blood pressure and/or cardiac output in animal studies,[31,32] but there are limited data on this relationship in human infants. This finding was not attributed to differences in the use of sedatives and may be clinically significant because hypotension in the newborn period is associated with adverse neurodevelopmental outcomes.[33–35]

Although compliance with each of the 5 elements of this quality-improvement initiative was high, there was a learning curve for using bCPAP. Initial challenges were in maintaining bubbling in the system and in positioning infants prone with the Hudson prongs in place. These challenges were met by our nurses and respiratory therapists mostly by persistent trial and error. It was not difficult to start CPAP in the delivery room or to achieve compliance with intubation criteria, but the occasional and erroneous application of the intubation criteria to infants born at >33 weeks' gestation had some adverse results. Because of the risk of pulmonary hypertension in infants born after 33 weeks' gestation and the low risk of BPD, we continue to have a low threshold for administering surfactant in this population. The most difficult potentially better practice to implement was early extubation, particularly for infants born at 25 weeks' gestation or earlier. Although these infants all met criteria for extubation at <24 hours of age, these extubations initially caused anxiety. The presence

TABLE 4 Morbidity and Mortality for Infants Born Before 29 Weeks' Gestational Age or Those Born Weighing Less Than 1500 g

	Before	After	P
Born before 29 wk gestational age			
n	14	16	
Death	1 (7)	1 (6)	>.99
BPD[a]	5 (38)	3 (20)	.41
Retinopathy of prematurity	7 (50)	7 (44)	>.99
Intraventricular hemorrhage	4 (29)	2 (13)	.38
Periventricular leukomalacia	1 (7)	1 (6)	>.99
Necrotizing enterocolitis	3 (21)	2 (13)	.64
Any major complication	10 (71)	10 (63)	.71
Born weighing <1500 g[b]			
n	35	36	
Death	1 (3)	1 (3)	>.99
BPD[c]	10 (29)	4 (11)	.08
Retinopathy of prematurity	11 (31)	8 (23)	.59
Intraventricular hemorrhage	12 (34)	7 (19)	.19
Periventricular leukomalacia	2 (6)	2 (6)	>.99
Necrotizing enterocolitis	4 (11)	2 (6)	.43
Any major complication	21 (60)	17 (47)	.34

[a] Denominators are infants who survived to 36 weeks' postmenstrual age ($n = 13$ before, $n = 15$ after).
[b] Gestational age in weeks (means ±SD) for infants born weighing <1500 g = 28.7 ± 2.2.
[c] Denominators are infants who survived to 36 weeks' postmenstrual age ($n = 34$ before, $n = 35$ after).

TABLE 5 Nonpersonnel and Nursing Personnel Cost Analysis

	Before	After	P
Nonpersonnel costs[a]			
n	58	60	
Week 1 cost, $[b]			.51
Mean ± SD	1302 ± 1353	855 ± 871	
Median (25th–75th percentiles)	752 (307–1560)	493 (307–918)	
Total cost for weeks 1–12, $[b]			.83
Mean ± SD	4116 ± 5218	3021 ± 2906	
Median (25th–75th percentiles)	2104 (764–5114)	1952 (1147–3578)	
Cost of surfactant, $			.0006
Mean ± SD	623 ± 794	193 ± 438	
Median (25th–75th percentiles)	0 (0–722)	0 (0–0)	
Nursing personnel costs			
n	61	60	
Percentage in the 1-to-1 nursing assignment[c]			.46
Mean ± SD	19.0 ± 22.2	21.5 ± 23.0	
Median (25th–75th percentiles)	12.5 (0.0–28.1)	11.5 (5.2–30.2)	

[a] Sample size excludes 2 patients with incomplete data in the before group.
[b] Costs included surfactant, chest radiograph, red blood cell transfusion, platelet transfusion, head ultrasound, surgery, abdominal radiograph, parenteral nutrition, and echocardiogram.
[c] Analysis excludes 62 (1.7%) of 3720 SEMC patient-days when the number of nurses was more than or equal to the number of patients in the unit and all were 1-to-1.

of at least 1 team member at each extubation was useful. Achieving compliance with early extubation of infants >26 weeks' gestation was less challenging.

This effort followed the transition of our unit from an independent NICU to a Children's Hospital Boston community NICU in 2006. This transition provided a good opportunity to introduce change, but fortitude on the part of team members was necessary. Ongoing support from the chair of pediatrics and the NICU medical director was instrumental, and publicity around the effort arranged by the Chair encouraged compliance.

CONCLUSIONS

Institution of this guideline decreased the need for intubation, surfactant, mechanical ventilation, and supplemental oxygen in infants born before 33 weeks' gestation. The biggest impact was on measures of respiratory care and a reduction in treated hypotension. Overall, nonpersonnel cost-of-care and nurse staffing ratios were unchanged, but equipment costs and the cost of surfactant were lower. The success of this effort is largely attributed to a multidisciplinary team approach, leadership support, and good timing. Additional studies comparing bCPAP with other modes of CPAP and investigating the potential benefit of prolonged CPAP would be useful.

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