Using Quality Improvement Tools to Reduce Chronic Lung Disease

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KEYWORDS

• Chronic lung disease • Respiratory care • Potentially better practices
• Key driver diagram • Quality improvement

KEY POINTS

- Overall chronic lung disease (CLD) rates have not decreased appreciably in the past 20 years when compared to other neonatal morbidities and new approaches may need to be taken.
- Studies have demonstrated reduction in CLD by use of following strategies: avoidance of intubation by application of early CPAP/non-invasive ventilation, selective use of surfactant, initiation of caffeine, gentle ventilation and extubation strategies for intubated infants.
- Development of a local quality improvement initiative using the best available evidence, along with multidisciplinary involvement of team members can lead to success in educing CLD rates.

INTRODUCTION

Despite the increased use of exogenous surfactant administration, increased access to antenatal steroids for mothers threatening preterm delivery, and substantial advancements in respiratory care, the overall incidence of chronic lung disease (CLD) has remained stubbornly elevated in the very low birthweight (VLBW) population over the past two decades.[1] During this time period, other improvements in medical care have led to substantial decreases in the incidence of other morbidities of VLBW infants, such as hospital-acquired bloodstream infections, necrotizing enterocolitis (NEC), severe interventricular hemorrhage, and severe retinopathy of prematurity.

CLD was first described by Northway and colleagues[2] in 1967, and these early cases were usually seen in premature infants with severe respiratory distress syndrome (RDS) who received positive pressure ventilation and oxygen administration. This chronic

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Clin Perinatol 44 (2017) 701–712
http://dx.doi.org/10.1016/j.clp.2017.05.010 perinatology.theclinics.com

pulmonary disease was descriptively named bronchopulmonary dysplasia (BPD) because of the pathologic changes of injury and cellular repair of the parenchyma of the lung tissue, coupled with alterations in growth of the developing lung. Before the advent of mechanical ventilation, infants with RDS had high mortality rates because it was the leading cause of death in live-born premature infants; after the introduction of mechanical ventilation in neonatal care, BPD was seen primarily as a disease of mechanically ventilated late preterm infants. In modern times, because of advancements in neonatal care, infants at this gestation now rarely have severe pulmonary-related morbidity, and CLD is primarily seen in smaller preterm infants.

CLD is currently defined as need for supplemental oxygen for infants at 36 weeks corrected postmenstrual age,[3] although there remains a spectrum of severity of illness for infants with this diagnosis. Newer definitions have been proposed to reflect this reality with the following classification: mild CLD is need for supplemental oxygen at 28 days, but not at 36 weeks post-menstrual age (PMA); moderate BPD is need for supplemental oxygen at 28 days and less than 30% oxygen at 36 weeks PMA; and severe BPD is need for supplemental oxygen at 28 days and greater than 30% oxygen at 36 weeks PMA and/or positive pressure ventilation at 36 weeks PMA.[4]

Quality improvement (QI) projects have become a mainstay of neonatal care over the past decade, with an increasing number of publications devoted to this topic. Neonatal intensive care units (NICUs) are well positioned for QI projects because of a long-standing history of participation in data collection, data benchmarking, and collaborative learning opportunities that exist throughout neonatology.[5]

Borrowing liberally from manufacturing and other industries, medicine has started to embrace the theory and methodology of QI science and how to apply that science to their daily work in improving the care of infants and families in their respective NICUs.

There have been several single-center and multicenter publications that have demonstrated QI projects leading to a reduction in CLD,[6–8] but there has been no sustained overall decrease in CLD rates in VLBW infants in large national data sets.[1,9,10] Many interventions that are described at the unit-level have either not been translatable or have not been successful in a broad application across a multitude of NICUs. This disparity between successful local initiatives and lack of widespread improvement likely highlights the importance of local context. Although any QI effort needs to structure its measures and interventions to the local environment, this may be particularly true for neonatal respiratory care, where the complex nature of CLD requires specific interventions and culture change that may not be easily translated from one NICU to another.[11]

This article examines several strategies to reduce CLD in premature infants. It is hoped that the information provided is useful to neonatal providers seeking to evaluate or improve respiratory care practices in their NICU with a goal of reducing the burden of CLD in their patients and their families.

QUALITY IMPROVEMENT FOR CHRONIC LUNG DISEASE: GENERAL CONSIDERATIONS

A broad and expansive description of QI science and methods has been discussed extensively in other articles and is not included here. However, several common principles are important to apply when focusing on QI for CLD reduction. A specific QI project for CLD, similar to other projects, must be based on best available evidence in the medical literature, expert recommendations, or based on work by previous QI initiatives. Clinical practices that have the potential to improve the outcomes of neonatal care are known as potentially better practices (PBPs).[12]

These PBPs are existing recommendations or protocols that have the potential to improve the care and change the outcome of the specific clinical project. They are tested, modified, and changed to fit each individual NICU microsystem in which they are introduced; not all PBPs work for each and every unit. Examples of specific PBPs vary for reducing the incidence of CLD or lung injury, but most include the use of early continuous positive airway pressure (CPAP), caffeine use in specific populations, selective surfactant use, minimization of the duration of mechanical ventilation, and gentle ventilation strategies.

Once a unit-based multidisciplinary team (including parent or family members) has been established and executive leadership buy-in obtained by the team, progression to the QI project involves the choosing of a specific aim or aims from a list of accepted PBPs or toolkits, many of which are available in previously published QI initiatives or retrieved online. Construction of tools, such as key driver diagrams, can help structure the team and allow for all members to contribute and understand the rationale for new changes to practice that are being introduced.

QUALITY IMPROVEMENT FOR CHRONIC LUNG DISEASE: SPECIFIC STRATEGIES

Several specific strategies have evidence supporting their use in improvement initiatives to reduce CLD. Some of these are summarized next, and **Table 1** provides an overview of how these strategies can be used in the context of a local QI effort.

Early Continuous Positive Airway Pressure

Multiple trials have proven the benefit of early nasal CPAP in the delivery room for initial respiratory stabilization of the preterm and even the extremely preterm infant,[13–15] with a combined reduction in death or CLD. Even the most preterm infant at 24 to 25 weeks gestation has shown benefit from this approach with a lower mortality rate in the COIN (Continuous Positive Airway Pressure or Intubation at Birth) trial when compared with initial planned intubation/mechanical ventilation group. CPAP started soon after birth is a strategy that seems to reduce CLD/death and is an accepted alternative to prophylactic surfactant approach.

After the aim statement has been created by the team, measurement for this specific intervention needs to be chosen, with common measurement point consisting of percent of infants who receive nasal CPAP before positive pressure ventilation via an endotracheal tube. A potential complication of earlier CPAP use is higher risk of pneumothorax. In the COIN trial, a higher pneumothorax rate was seen in the CPAP group compared with the immediate intubation group, but this was not seen in other trials, and was not significantly different between the two groups in meta-analysis. Nevertheless, tracking pneumothorax rates as a balancing measure should be considered.

Certain barriers exist for starting CPAP soon after birth. The most common barrier identified is the belief that VLBW infants, especially extremely low birth weight infants, require immediate intubation and surfactant therapy. However, there have been several trials that do not lend support to this approach as being superior to a nasal CPAP-first approach.[13,16–18]

One strategy that can help address staff concerns includes the development of a consensus guideline with specific criteria for delivery room management of premature infants with noninvasive ventilation. Participation of all team members including physicians, neonatal nurse practitioners, neonatal nurses, respiratory therapists, family members, and other allied health professionals would allow for locally constructed guidelines based on a shared approach and would be extremely effective in

Table 1
Specific strategies for a quality improvement initiative to reduce chronic lung disease

	Intervention	Process Measure	Balancing Measure	PDSA/Test of Change	Barriers to Change
Early CPAP	Early CPAP in delivery room for infants that meet criteria	Number of infants CPAP attempted in the delivery room	Pneumothorax	Apply early CPAP to spontaneously breathing infant in delivery room	Preconceived notion that infants <28 wk need to be ventilated at birth
Selective surfactant	Develop criteria for INSURE method	Number of infants who meet criteria but were not extubated	Pneumothorax	Develop criteria for intubation and surfactant administration	Practice patterns to leave infants intubated for a period of time following surfactant
Caffeine	Start caffeine on infants when weaning from ventilator	Number of infants who were started on caffeine	Number of intubated infants still on caffeine >7 d	Develop protocol with standard caffeine dosing for initiation and maintenance	Fear of increased rates of NEC
Gentle ventilation	Reduction of tidal volume to specified daily target	Daily audits on ventilator setting with recorded tidal volumes	Number of ventilator changes	Develop a specific tidal volume target	Inability to accurately measure tidal volumes
Extubation guidelines	Develop criteria for extubation of ventilated infants	Attempt SBT on all infants before extubation	Number of reintubations	Develop passing criteria for SBT for infants ready for extubation	Previous practice of allowing infant to remain ventilated "vent to grow"

Abbreviations: INSURE, intubate, surfactant, extubate; PDSA, Plan, Do, Study, Act; SBT, spontaneous breathing test.

overcoming staff resistance or staff perceptions regarding the need for immediate intubation.[19] Based on best available evidence and this local consensus-driven process, each NICU team should detail specific criteria for infants that may be appropriate candidates for early CPAP in their NICU, based on gestational age, presence of antenatal steroid administration, and other factors, and should then prospectively collect process and outcomes data closely, along with prompt feedback to team members.

Selective Surfactant Use

Surfactant-replacement therapy has been an effective mainstay therapy for RDS in neonates and has been shown to decrease mortality, combined outcome of death/CLD, and pneumothoraces.[20,21] Given the evidence described supporting early CPAP as an improvement strategy for very preterm infants, the role of surfactant must be considered differently. Earlier studies advocated for prophylactic surfactant, but more recent data demonstrated that early CPAP in the delivery room versus prophylactic surfactant has improved outcomes (lower death/CLD combined outcome) when compared with CPAP alone.[18] In the SUPPORT (Surfactant, Positive Pressure and Oxygenation Randomized Trial) trial,[13] infants 24 to 25 weeks who were randomized to CPAP had a lower mortality rate than infants who were intubated and received prophylactic surfactant.

Based on these data, current guidelines advise noninvasive ventilation as a PBP in the delivery room, but if the neonate requires intubation and mechanical ventilation, then administration of surfactant within the first 3 hours of life reduces mortality and morbidity associated with RDS.[20]

In addition, techniques to avoid prolonged positive ventilation and the concomitant damage to lung tissue, such as intubate-surfactant-extubate and less invasive surfactant administration, may reduce CLD and the need for ventilation[22–24]

Development of guidelines and workflow to introduce early CPAP/noninvasive ventilation in the delivery room with previously agreed on indication for administration of rescue surfactant is an important component to selective surfactant use in a NICU. Measurement of how many infants at a specified gestational age have an attempt at noninvasive ventilation allows for the unit-based QI team to further refine their protocols to stratify which infants are successful with this approach. Having a unit-based approach[19] to the use of intubation and surfactant-replacement therapy based on agreed on parameters (eg, pH <7.2; F_{IO_2} $>40\%$; increased work of breathing) and prospectively collecting data on compliance with the parameters to give feedback to providers is valuable. An example of such an approach is given in **Fig. 1**. Also, it is important to collect data on balancing measures, such as pneumothoraces, to confirm that the local change in practice is not leading to worse outcomes.

Caffeine

Apnea is a common occurrence in NICUs, especially prevalent in VLBW infants less than 32 weeks gestation.[12] The CAP (Caffeine for Apnea of Prematurity) trial demonstrated that infants less than 1250 g who did not receive caffeine treatment had increased CLD and additional short-term and long-term morbidities.[25] In addition, infants who received caffeine in this trial had decreased time on ventilator support, decreased postnatal corticosteroid use, and decreased oxygen use when compared with the placebo group. Long-term developmental outcomes did not differ between in the two groups,[26] but the short-term pulmonary benefits of caffeine treatment were important.

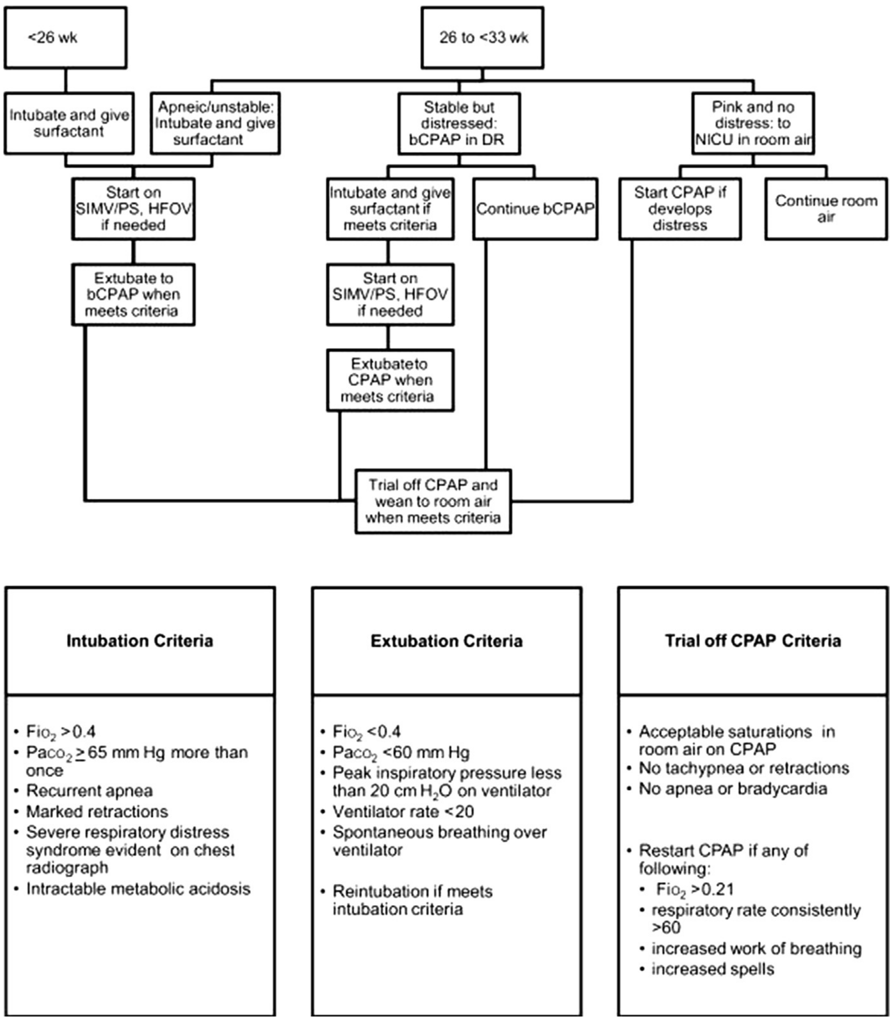

Fig. 1. Respiratory management of infants. F_{IO_2}, fraction of inspired oxygen; HFOV, high frequency oscillatory ventilation; SIMV/PS, synchronized intermittent mandatory ventilation/pressure support. (*From* Levesque BM, Kalish LA, LaPierre J, et al. Impact of implementing 5 potentially better respiratory practices on neonatal outcomes and costs. Pediatrics 2011;128(1):e221; with permission.)

NICUs should consider establishment of a local guideline for caffeine administration, in consultation with hospital pharmacists. Specific components of this guideline should include initiation of caffeine when weaning from the ventilator, dosing caffeine with a standard loading dose and maintenance dose, and conversion of intravenous caffeine to enteral when a certain volume of feeds are reached. Such measurements as number of eligible infants who received caffeine or the time from birth when caffeine was first received by the infant are metrics that can be tracked by teams that use this as a process measure. Barriers, such as the fear of increased rates of NEC with administration of methylxanthines, have not been noted in larger studies.[25]

Gentle Ventilation (Low Tidal Volume/Permissive Hypercapnea)

During mechanical ventilation of an infant, a balance must be achieved where the infant is provided with the lowest possible inspiratory pressure to minimize volutrauma, but enough pressure to ensure adequate gas exchange. Expiratory tidal volume may be measured by the ventilator and a goal of no more than 4 to 6 mL/kg. The respiratory system of premature infants with RDS has low lung compliance, coupled with low resistance, which leads to a short time constant. To take advantage of these characteristics in a recently delivered infant, optimal ventilation with short inspiratory times and fast rates results in less air leak syndromes and nonsignificant mortality when compared with infants ventilated with slow rates and long inspiratory times.[27]

Permissive hypercapnia is a ventilatory strategy that may reduce injury to the developing lung through a variety of mechanisms. Data based on the current literature, pertinent physiologic rationale, and experimental research demonstrate that permissive hypercapnia may be beneficial. Several trials suggest that a strategy of permissive hypercapnia (usually limited by a pH of at least 7.2) started early, before initiation of mechanical ventilation, combined with prolonged permissive hypercapnia during mechanical ventilation optimizes pulmonary/survival benefits and seems to be safe in neonates.[13,28] These data support the use of permissive hypercapnia as an alternative to traditional ventilator support strategies that aim to maintain normocapnia. Further research is necessary to elucidate better strategies of permissive hypercapnia, such as target CO_2 levels, duration of the intervention, and minimal tidal volume ventilation.

QI projects centered on gentle ventilation and permissive hypercapnia can have an aim to reduce tidal volume of the infant to a specific target (eg, <4–6 mL/kg) and mildly elevated P_{CO_2} ($\leq$65 mm Hg) to mechanically ventilated infants. Daily audits of ventilated infants (tidal volumes with accompanying ventilator settings and P_{CO_2} levels) with feedback given to provider and team allows for needed adjustments to be made in the PDSA (Plan, Do, Study, Act) cycles of this specific initiative. Barriers to this test of change include a tradition of long-standing ventilator settings with resistance of low inspiratory pressures and high ventilator rates, along with providing normocapnia to ventilated infants; education to all team members (physicians, nursing, respiratory therapists, and families) on this approach may ease its adoption and acceptance.

Extubation Strategies and Protocols

One of the most difficult decisions in a NICU involved the timing of weaning and extubation for a mechanically ventilated infant. The potential success of rapid weaning and extubation needs to be weighed against the potential negative outcome of an infant who may develop clinical deterioration and then require subsequent reintubation shortly after being extubated.

High level of evidence and standard criteria for extubation guidelines in neonatal medicine do not exist. The decision to extubate an infant is usually left to the clinical team who may not have defined criteria for extubation readiness. In the absence of defined extubation criteria, infants may remain ventilated longer than needed, along with a potential for ventilator-induced volutrauma. Some researchers have evaluated the utility of a spontaneous breathing test (SBT) to select and predict VLBW infants who may have greater success with extubation. The SBT is a 3-minute period of endotracheal intubation and infants who are successful are then extubated. Most infants who were successful with the SBT remained extubated, with 22% of this cohort needing reintubation,[29] but further studies are needed to evaluate the diagnostic accuracy of this test.

Another bedside test that has been evaluated for extubation readiness is the minute ventilation test (MVT), where the minute ventilation on endotracheal CPAP alone must be greater than 50% of the minute volume of mechanical ventilation. In one small study,[30] infants who were extubated according to success of an MVT were extubated several hours earlier (8 vs 36 hours) when compared with those infants who were evaluated clinically; the extubation rates in both groups were similar.

Creation a local protocol for extubation readiness can incorporate existing bedside tests, such as SBT or MVT, with defined criteria (eg, pH >7.2; P_{CO_2} <60 mm Hg; F_{IO_2} <40%; MAP (mean airway pressure) <7; caffeine administration to infant) to successfully extubate a mechanically ventilated infant (see **Fig. 1**). Success or failures of each eligible infant, along with an assessment of process measures and potential refinement of protocol based on rapid PDSA cycles, allows for the team to accept the protocol or amend it as needed to fit the clinical microsystem of the NICU. Barriers to extubation success include prior practice of prolonged intubation to let a VLBW infant rest and "vent to grow," along with fear of potential reintubation.

Other Strategies

Multiple other care practices may impact the development of BPD, and may be amenable to improvement initiatives. These include systemic corticosteroids, fluid restriction, diuretics, use of vitamin A, noninvasive positive pressure ventilation, and oxygen saturation targeting. Although these are not reviewed in detail here, in general, a lack of compelling data on efficacy, a lack of long-term data on outcomes, or other concerns limit the potential widespread use of these interventions as improvement strategies. For example, although controversial, systemic corticosteroids have shown a reduction in CLD, but with an unacceptable increased risk in cerebral palsy. Although there may be data that delayed use of systemic corticosteroids (>7 days of age) has less short-term morbidities than early (<7 days of age) systemic corticosteroids, the limited follow-up data give pause to routine administration of steroids, and in cases where it is given the dose and duration should be minimized during the treatment course.[31] Inhaled corticosteroids have shown reduced CLD in a recent meta-analysis, but long-term follow-up data are not yet available.[32]

DEVELOPING A QUALITY IMPROVEMENT INITIATIVE FOR CHRONIC LUNG DISEASE

There have been many collaborative efforts to reduce CLD over the past decade leading to site-specific reductions in CLD. With any type of QI project, there is always concern that improvement is related to the Hawthorne effect, but the powerful effect of culture change and increased teamwork with all involved disciplines to implement process change cannot be understated. Local development of a collaborative QI project should include interventions, process measures, balancing measures, tests of change, and barriers to change (see **Table 1**). This process should be multidisciplinary and also include the parent voice to make sure that the changes proposed by the group for the initiative not only is evidence-based, but is patient focused.

Development of a key driver diagram allows for the project to have a visual representation of a structured improvement roadmap. The construction of these diagrams details the project planning with keeping a focus on factors that allow the team to realize the project aim. This diagram organizes the improvement aim, the key drivers (the "what" needed to accomplish that aim), and the interventions (the "how" [change concepts], also known as secondary drivers) into a learning and communication framework. An example of a key driver diagram for surfactant administration is shown in **Fig. 2**.

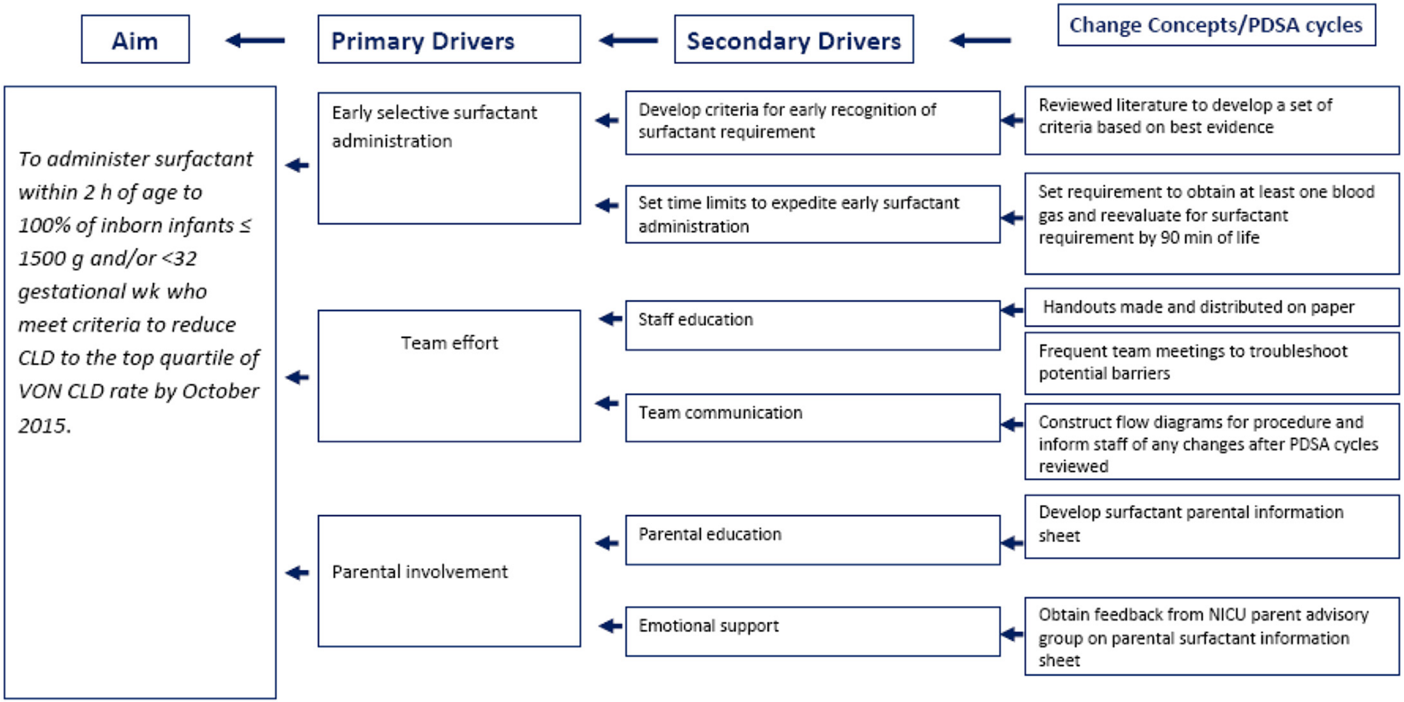

Fig. 2. Example of a key driver diagram for surfactant administration. PDSA, Plan, Do, Study, Act; VON, Vermont-Oxford Network.

Examples of Quality Improvement Initiatives

A large cluster-randomized trial performed by the National Institute of Child Health and Human Development Neonatal Research Network for prevention of CLD in infants less than 1250 g saw no improvement in survival free of CLD in a cohort of greater than 4000 patients. The centers that were randomized to the intervention group included adoption of PBPs from the benchmark centers that were recognized for having high rates of CLD-free survival in this population. The authors believed that although the intervention centers adopted care practice from benchmark institutions, the possibility of no significant decrease in the outcome may have been because there was only weak evidence supporting some of the new practices that were introduced.[6]

Conversely, in the Vermont-Oxford Breathsavers group, 19 hospitals participated in the adoption of PBPs during a 2-year collaborative QI project, consisting of close to 3600 VLBW infants during the collaborative time periods. Most (15 of 19) hospitals saw a decrease in the CLD rates during this project, and the pooled data across the collaborative demonstrated a statistically significant reduction in CLD rates and a statistically significant increase in VLBW infants who survived free of CLD.[8]

In addition, there have been publications of single-center experiences that have demonstrated reduction in CLD rates by implementation of pre-existing PBPs in addition to site-specific improvement bundles. One center instituted a bundle of practices to reduce CLD, including a site visit to a nearby NICU with a low CLD rate. By the addition of a series of new practices around respiratory care, this NICU was able to achieve a 50% reduction (46.5% to 20.5%) in rates of CLD over a 2-year time period that was sustained.[7] Another center implemented five PBPs centered around noninvasive ventilation (bubble CPAP) and strict intubation and extubation criteria and demonstrated a reduction in CLD rates from 17% preintervention to 8% postintervention.[19]

SUMMARY

Rates of CLD in VLBW infants have not decreased at the same pace as other neonatal morbidities during the past 20 years. Multifactorial causes of CLD make this common morbidity difficult to reduce, although there have been several individual QI projects in individual NICUs that have had success, but the lessons learned in these single centers have not been adopted by most NICUs. Building on the PBPs incorporated by these NICUs that were successful in lowering their rates of CLD, a road map for lower rates of CLD exists for NICUs that are struggling with rates of CLD that are higher than they would expect.

A comprehensive QI project incorporating all or a portion of PBPs, such as the use of early CPAP, caffeine use in specific populations, selective surfactant use, minimization of the duration of mechanical ventilation, and gentle ventilation strategies, can lead to a successful reduction in CLD rates. As more and more NICUs incorporate these new strategies into their daily work, establishing protocols to ensure safe and effective ventilatory care, we believe that CLD can join the reductions seen in nosocomial infections, interventricular hemorrhage, and NEC that have been realized in VLBW infants over the past 20 years.

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