Comprehensive Oxygen Management for the Prevention of Retinopathy of Prematurity: The Pediatrix Experience

Dan L. Ellsbury, MD*, Robert Ursprung, MD, MMSc

In 2003, Chow and coworkers described a striking reduction in retinopathy of prematurity (ROP) after implementation of a structured oxygen management protocol, focused on avoiding hyperoxia and repeated episodes of hypoxia-hyperoxia in very low birth weight infants. This publication generated much interest and discussion in the neonatology community including practices within Pediatrix Medical Group. Some Pediatrix Physician Groups adopted the general approach proposed by Chow and coworkers with similar results, as did a number of centers outside of Pediatrix. Within Pediatrix Medical Group, discussions continued by intranet discussion forums and presentations at Pediatrix quality improvement conferences. In 2006, the basic principles of avoiding hyperoxia and repeated episodes of hypoxia-hyperoxia were expanded into a Pediatrix quality improvement initiative called “Comprehensive Oxygen Management for the Prevention of Retinopathy of Prematurity” (COMP-ROP).

COMP-ROP was enthusiastically received. Eighty neonatal intensive care units (NICU) formally participated in the initiative, with many more informally participating. The COMP-ROP Collaborative was loosely structured. NICUs were provided with a toolkit containing a basic description of the oxygen management process and multiple tools to facilitate rapid adaptation and implementation of the program within their centers.

Because of the uncertainties and controversies surrounding the definition of “optimal oxygen saturation” in extremely premature infants, rigid oxygen saturation...
limits were not mandated.\textsuperscript{8,9} Emphasis was placed on NICU staff education, system-based approaches to decreasing hyperoxia, avoidance of large fluctuations in oxygen saturation, ensuring compliance with oximeter alarm use, and using oxygen saturation trending to assist and guide oxygen management efforts.

Between 2003 and 2008, a striking decrease in severe ROP (stage 3, 4, 5, or surgical) was seen in the Pediatric Network. In infants with birth weights of 400 to 1500 g, severe ROP dropped from 11% in 2003 to 5.8% in 2008 (Fig. 1). During this time period, mortality rates remained stable. Necrotizing enterocolitis decreased, then increased during this time period, with 2008 rates very similar to 2003. This pattern was also seen in infants with birth weights greater than 1500 g, who were not included in COMP-ROP. Patent ductus arteriosus and patent ductus arteriosus ligation rates also fluctuated, with 2008 rates remaining similar to 2003. Oxygen use at 28 days of life and at 36 weeks postmenstrual age decreased from 2003 to 2008.

**WHY WAS COMP-ROP SUCCESSFUL?**

Why did this initiative succeed? Early adopters started the process after Chow and coworkers\textsuperscript{11} publication. The quality improvement infrastructure within Pediatrix Medical Group fostered the spread of this information, eventually formalizing the process as the COMP-ROP program. Berwick\textsuperscript{10} describes seven guiding rules for diffusion of innovations, all of which were used in the events leading up to the COMP-ROP initiative and continued in the implementation of the program:

1. Find sound innovations: The structure of the Pediatrix system encourages, by intranet and conferences, continuous discussion and debate of new innovations found in the medical literature.
2. Find and support innovators: The ongoing communication and debate of new innovations includes discussion of the initial successes and difficulties with implementation of new ideas. Successful innovators could be identified despite the size of the network (almost 1000 physicians in 33 states, providing care for approximately 20% of infants receiving neonatal intensive care in the United States).

![Severe ROP Run Chart](image-url)

**Fig. 1.** COMP-ROP severe ROP annotated run chart.

Annotations:
1. Chow publication in 02/03.
2. Initial discussion and adaption by some practices.
3. Further discussion and refinement, increasing network wide interest.
4. Presentations in QI conferences, informal sharing of materials.
5. COMP-ROP toolkit distributed and initiative formally started in 02/06.
3. Invest in early adopters: The early adopters were identified in these ongoing intranet discussions and quality conferences. Corporate support including mentorship, education materials, conference calls, and so forth was provided to assist these early adopters in effectively implementing the COMP-ROP program.

4. Make early adopter activity observable: The COMP-ROP program was encouraged and promoted by corporate staff in a variety of settings. Although participation was encouraged, it was not mandated.

5. Trust and enable reinvention: As the program was implemented, objections to some components of the program were raised. Elements that were completely acceptable in one center were not accepted in others. All participating centers were encouraged to adapt the program to fit the culture and workflow of their centers.

6. Create slack for change: Center participation was valued at the corporate level and viewed as an important contribution to the practice and the patients. Quality improvement activity was considered a vital part of the practice, not an extracurricular activity.

7. Lead by example: Leaders of the COMP-ROP program were practicing neonatologists who shared their ongoing successes and difficulties with implementation in their own centers.

THE COMP-ROP PROGRAM

This article describes the components of the COMP-ROP toolkit and lessons learned from its dissemination within the Pediatrix network. The toolkit was provided to all Pediatrix practices in electronic format. Educational presentations, sample order sets, bedside signs, surveys to assess knowledge gaps, and other materials were provided. Local adaptation and modification of the materials was encouraged to facilitate acceptance and use in a variety of NICU settings.

Basic Principles

The guiding principles of the COMP-ROP program included the following: (1) the avoidance of hyperoxia and repeated episodes of hypoxia-hyperoxia is associated with reduced incidence of ROP; (2) systems should be redesigned to minimize or eliminate practices that result in periods of hyperoxia; (3) NICU staff should be educated regarding the risks and benefits of supplemental oxygen administration in premature infants, including the limitations of pulse oximetry in detecting hyperoxia; and (4) auditing compliance with oximeter alarm settings, and the percentage of time patients spend below, within, and above the targeted oxygen saturation parameters, should be used to provide short-term feedback on the success of oxygen management practices.

Program Structure

The program was structured to assess baseline ROP outcomes, oxygen management practices, and staff beliefs concerning ROP pathophysiology. Further, the program provided basic instruction in team building, multidisciplinary NICU staff education, and facilitated system-based changes designed to optimize oxygen management. After implementation, periodic review of process, outcome, and balancing measures was followed to assess the impact of COMP-ROP (Fig. 2).

The Multidisciplinary COMP-ROP Team

The COMP-ROP toolkit advocated for each unit to create a multidisciplinary ROP team. Ideally, this group would include physicians, nurses, nurse practitioners, and respiratory therapists; inclusion of leadership with the authority to make system-based
changes was encouraged. Emphasis was placed on including individuals from different work shifts (days, nights, weekend shifts). Additionally, it was emphasized that COMP-ROP was not a clinical trial or research project, and that the program was meant as a starting point, with adaptation to each center’s culture and work flow provided by each project team. Review by an institutional review committee or hospital quality improvement committee was governed by each center’s guidelines and regulations for quality improvement activities.

**Baseline Data Collection**

Certain baseline data were obtained, including ROP outcomes, and several measures of oxygen and oximetry use. These measures were followed throughout the project.

**ROP outcomes**

ROP data were available through the Pediatrix Clinical Data Warehouse (discussed elsewhere in this issue). The reports provided data on clinical outcomes and certain process measures related to ROP and could be stratified by birth weight, gestational age, NICU patient volume, and inborn-outborn status.

**Baseline oximeter alarm audits**

A sample oximeter alarm audit tool (Fig. 3) was provided to facilitate collection of oximeter alarm settings by bedside audits. The experience was that many centers had poor compliance in setting oximeter alarms in a fashion to minimize exposure to hyperoxic environments. Many centers had no process to consistently order oximeter alarm settings in the population at risk for ROP. Further, many oximeters have a factory
default high-saturation alarm setting of 100%. If this default setting is not noticed and altered, infants receiving supplemental oxygen are at risk for excess time in a hyperoxic environment.

Baseline oxygen saturation trend audits
This audit was designed to provide an estimate of the amount of time an infant spent at various oxygen saturations, with emphasis on the proportion of time the oxygen saturation is greater than 95% and the general distribution of saturation values, both high and low. Ongoing measurement of saturation trends was suggested as an important ongoing process measure. Four methods were suggested, discussed next.

Flow-sheet review Nursing or respiratory therapy flow-sheets typically capture oxygen saturations levels. Although flow sheets may provide a general sense of oxygen saturation trends, they are of limited use because of the small number of data points and the potential bias of the documenter; the provider may choose to document the “best” number over the last hour, not the “most representative.”

Monitor trend review Many bedside monitors have features that allow trending of vital sign data. Capabilities among monitors vary; however, many machines allow the data of the time spent at various oxygen saturations to be presented graphically, downloaded to a computer, or printed. Rapid feedback of oximetry trends to front-line providers is a powerful behavior change agent.

Peak PO2 in the first 24 hours As a supplement to the previously mentioned techniques, the PO2 trend, as determined by arterial blood gases, can be reviewed from the medical record. This observation is limited to babies with arterial catheters, but may be useful for some babies in the first days of life.

Saturation level and oximeter alarm random spot checks This supplementary technique involves simply walking to the bedsides of infants at risk for ROP at a random

---

**Pulse Oximetry Alarm Audit Tool**

Please review the oximeter alarm settings and mark “correct” if they are set appropriately, and “incorrect” if not, according to:

- the standard oximeter alarm setting orders, OR
- a specific order in the chart

Determine reasons for non-compliance when they occur, and address these as indicated, especially system issues

- use episodes of non-compliance as educational opportunities

The overall percent correct should be recorded on a spreadsheet (use the oximeter alarm audit run chart, in excel)

<table>
<thead>
<tr>
<th>Patient</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incorrect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. Sample oximeter alarm compliance audit tool.
time and auditing the oxygen saturation, the fraction of inspired oxygen (FIO2), and the oximeter alarm settings to determine if they are appropriate at that point in time. This “spot check,” although not precise, is an additional method to determine general compliance with the desired oxygen management strategies. This technique can be informally used during clinical rounds as part of a random safety audit program.11

**Hyperoxia Assessment**

A hyperoxia assessment survey was provided to enable teams to review the manner in which oxygen is used in their unit. This survey facilitated identification of common sources of hyperoxia, including equipment and practice style issues. Once identified, system reengineering and focused education efforts could address sources of hyperoxic exposure.

Common problem areas include use of unblended (100%) oxygen; use of high oxygen concentrations during routine procedures and handling; overtitration of oxygen in response to alarms; and therapeutic use of hyperoxia, the intentional use of high FiO2 as a treatment.

**Delivery room**

Determine if blended oxygen is available for infants less than 32 weeks’ gestational age, per the 2006 Neonatal Resuscitation Program recommendations.12 If blended oxygen was not available in the delivery room, a simple mobile cart was suggested that included an air and oxygen tank connected to an oxygen blender.

**Transport**

Some NICUs historically have used 100% oxygen during both “in-house” and “out-of-house” transports. Neonatal transport incubators are commonly designed to provide blended oxygen. If not, most systems can be adapted to include an air tank and an oxygen blender. Oximetry should be used during transports to enable titration of inspired oxygen.

**Nebulizers**

100% oxygen is often used as the gas source for nebulizer treatments, creating a significant exposure to hyperoxia for some patients. This issue can be addressed by providing blended oxygen as the nebulizer gas source, or changing to administration by a metered dose inhaler.

**Preoxygenation for procedures and cares**

Because some infants desaturate when exposed to noxious stimulation (eg, suctioning, heelsticks, diaper changes, and so forth), providers may prophylactically increase the FiO2 to “preoxygenate” the infant. This practice may result in hyperoxia, especially if large increases in oxygen concentration are given. This problem can be addressed by education and modification of nursing protocols focused on minimizing this practice, and using only small incremental increases FiO2 when indicated.

**Treatment of apnea**

Infants at risk for ROP often desaturate when apneic. Although stimulation of effective breathing typically corrects the transient hypoxia, the initial response of many providers is to increase the patient’s FiO2. Not only is increasing the FiO2 typically ineffective as an initial intervention, it places the infant at risk for an “overdose” of oxygen once respirations are reestablished. This problem can be addressed by education and modification of nursing protocols focused on minimizing this practice, and using only small incremental increases in FiO2 when indicated.
Therapeutic use of hyperoxia

Excess oxygen is given, at times, to intentionally cause hyperoxia for a specific therapeutic purpose. Many of these practices are of little benefit, and may risk significant hyperoxic injury.

Initial transition after delivery Some believe that it is better to give extra oxygen during the first hours after delivery to “enhance transition” or “help the baby recover” from a stressful delivery. There is no evidence that supports this practice. There is evidence that this is detrimental, especially in the preterm infant. This practice should be abandoned.

Pneumothorax A 100% oxygen is sometimes used as a treatment for a nontension pneumothorax (“nitrogen washout”). This practice places a preterm infant at very high risk of significant and severe hyperoxia. Conservative management is often very effective. This practice should be abandoned.

Pulmonary hypertension (early) Oxygen is a pulmonary vasodilator and can be beneficial in the management of persistent pulmonary hypertension of the newborn. Maintaining high oxygen saturation levels (>95%) in these infants incurs a significant risk of hyperoxic injury, however, including ROP. This practice should be restricted, and alternative treatment strategies should be used as indicated. Additionally, early pulmonary hypertension should be clearly distinguished from pulmonary hypertension that develops later in the hospital stay in infants with severe bronchopulmonary dysplasia. The infant’s retina may be mature in this latter circumstance, or at least past the stage of retinal development where higher oxygen saturations might be detrimental.

Staff ROP Education

A major component of COMP-ROP is the educational program. Most health care providers want to provide high-quality clinical care. It was observed that many providers including physicians, nurses, and respiratory therapists had knowledge gaps concerning the pathophysiology of ROP, the physiologic impact of oxygen management practices, and the principles of oximetry. Further, NICU nursing staff and respiratory therapy staff commonly had the foundation of their training in adult medicine, providing a basic knowledge set about the risks and benefits of oxygen that is not fully applicable to premature infants. Oxygen was commonly perceived as a “safe drug” and high oxygen levels were thought to be physiologically beneficial.

The educational program consisted of a premade slide set that discussed the pathophysiology of ROP, risks and benefits of oxygen use in premature infants, and the limitations of pulse oximetry. The educational program also included a discussion of the targeted oxygen management practices described by Chow and coworkers (avoiding hyperoxia and repeated episodes of hypoxia-hyperoxia).

A brief pretest and posttest was provided to determine if adequate knowledge transfer occurred with the educational program, with remedial action if gaps remained. It was suggested to centers that the educational program should be considered mandatory or at least heavily recommended for all NICU staff that manage oxygen, including physicians, nurse practitioners, nurses, and respiratory therapists. The compliance rate with completing the educational program was considered one of the process measures of the project.

System Redesign

As discussed elsewhere in this issue, system reengineering is more likely to achieve sustainable improvement than telling people to “be careful” or to “try harder.” The
hyperoxia assessment and educational testing typically highlighted systems or processes for reengineering. To effect change in ROP outcomes, development of a structured approach to the use of oxygen and oximetry was emphasized. This process included developing standardized orders for oximeter settings and alarm limits, creating or modifying specific oxygen management nursing protocols, bedside signs, and the use of “oxygen management contracts.”

**Standardized oximeter alarm orders**

Centers were encouraged to develop center-specific oximeter alarm limits to use for all infants at risk for ROP. Two general approaches to use of alarm limits emerged. The alarm limit approach consisted of the alarm limits being placed at the precise borders of the acceptable saturation range (eg, lower alarm at 85%, upper alarm at 93%).

Alternatively, other centers preferred to use a targeting approach, which used wide alarm limits, with the staff titrating the inspired oxygen to keep the saturation level within a narrower limit (eg, alarm limits at 80% and 95%, with saturations targeted at 88%–92%). It was believed by some centers that the targeting approach resulted in fewer alarm events and hence fewer opportunities to overadjust the oxygen concentration.

The specific alarm limits and the specific approach (alarm or targeting) was determined by each center. The guiding principles were to use a strategy to minimize hyperoxia by avoidance of saturation levels above 95% when receiving supplemental oxygen and avoiding large fluctuations of the oxygen saturation levels into hyperoxic and hypoxic ranges. Development of standardized orders to reflect the center’s chosen approach was recommended.

Further, emphasis was given to ongoing saturation trending as an important process measure to assess the effectiveness of the system redesign and educational interventions. Oxygen management is a complex task. The target saturations and alarm limits are the proverbial tip of the iceberg in oxygen management. Greenspan and Goldsmith very importantly and astutely observed, “Providers need to understand that cumulative oxygen saturations over time represent a bell-shaped curve, and the role of the health care team is to minimize the tails in both directions.”

**Default oximeter alarm limits**

Many oximeters have a default high saturation alarm setting of 100%. These oximeters typically revert to this 100% default setting each time they are turned off and back on, adversely affecting compliance with the center’s agreed on alarm settings. Fortunately, many oximeter default settings can be altered by hospital biomedical engineering personnel to comply with the center’s desired alarm settings. This system-based intervention can dramatically increase compliance with desired alarm limits in many centers.

**Nursing protocols**

Commonly, nursing and respiratory therapy protocols required modifications to be consistent with the desired changes in oxygen management. These modifications commonly included specific details of responding to an oximeter alarm (eg, determine if it is real or motion artifact, observe for spontaneous recovery, assess for a loose probe, and so forth before adjusting the oxygen concentration). Guidelines were often provided on the magnitude of oxygen titration (eg, increase by 2%–5% and observe).

**Bedside signs**

Bedside signs were frequently used to reinforce desired oximeter alarm limits and the approach to titrating oxygen. Sample signs were provided for customization and
personalization at each center. These simple signs were often quite effective, especially in the initial stages of the program, when the oxygen management strategies were still new to the staff (Fig. 5).

Oxygen management contract
Chow and coworkers described use of a written oxygen management agreement, or contract, that summarized the approach to oxygen and oximetry use, and was designed to be signed by all NICU staff members. The contract clarifies and reinforces personalization at each center. These simple signs were often quite effective, especially in the initial stages of the program, when the oxygen management strategies were still new to the staff (Fig. 5).

Oxygen Saturation as Bell-Shaped Curve
The objective of COMP-ROP was to change oxygen saturation distributions:
- Minimize time with saturations >95%
- Narrow the distribution

Fig. 4. Oxygen saturation trending curves. While the average oxygen saturation for each curve is similar, the wide distribution seen in the suboptimal curve should be avoided.

Fig. 5. Sample bedside oximeter alarm sign. These were typically modified to reflect the center’s preferred oximeter alarm limits. Additional personalization (animals, logos, catch-phrases) was often added to draw attention to the sign and reinforce oxygen management principles.
the goals of the program and provides an additional opportunity to discuss any disagreements with the practice changes. It can be used as a motivational tool, to clearly demonstrate the institution’s and an individual’s commitment to improve oxygen management. Use of the contract was well received in many NICUs, but some centers had staff that reacted negatively to this concept, and elected not to use the contract.

**Ongoing Implementation**

After the initial assessment and implementation, maintenance efforts were focused on compliance with the oxygen management guideline. Random safety auditing of saturation trends and oximeter alarm settings were suggested process measures to evaluate the short-term efficacy of COMP-ROP implementation. The primary clinical outcome measure was severe ROP. If concerning trends in process or outcome measures were noted, serial plan-do-study-act cycles were to be initiated until the system provided the desired results.

**QUESTIONS AND BARRIERS ENCOUNTERED DURING THE IMPLEMENTATION OF COMP-ROP**

*What About the Infants that have Oxygen Saturation Levels Greater than 95% in Room Air or in Very Low Concentrations of Supplemental Oxygen?*

Significant hyperoxia in room air is unlikely. The difficulty in this scenario is that these infants continuously trigger the upper oximeter limit alarm; the alarm limit is then adjusted upward to prevent continuous triggering of the alarm. Unfortunately, many of these infants will require supplemental oxygen again, but the upper alarm limit (now functionally turned off) may not always be reset, creating an opportunity for hyperoxia. There is not a clear system solution to this problem.

*What About Infants Whose Oxygen Saturation Level Rapidly Fluctuates and Triggers Alarms Continuously?*

**Respiratory issues**

After ruling out common causes of artifact (eg, soiled or loose probes, motion), one should assess for airway obstruction. Malposition of the endotracheal tube, secretions, and loose taping of the endotracheal tube are common problems. Infants on continuous positive airway pressure may have nasal obstruction or malposition of the prongs or the head. Any infant with marginal lung inflation may show substantial lability in oxygenation because of decreased functional residual capacity. Attention to these issues can minimize the variability of the oxygen saturation levels.

**Oximeter issues**

Each brand of oximeter has slightly different methods of acquiring and sampling SpO2 levels. These subtle differences can affect the lability of oxygen saturation levels. Increasing averaging time and use of alarm delays may both be useful in filtering out “nuisance alarms,” but may result in a less sensitive alarm system. The optimal use of these techniques is not known.

**SUMMARY**

Comprehensive oxygen management, focused on avoiding hyperoxia and repeated episodes of hypoxia-hyperoxia in very low birth weight infants, has been successfully used for the reduction of ROP. Building on this experience, the COMP-ROP quality improvement initiative was developed to facilitate the spread and refinement of these techniques. The initiative focused on staff education, evaluation and redesign of the processes, and practices involving oxygen use. Monitoring of the effectiveness of
the system changes was supported through audits of clinical practice changes, use of oxygen saturation trending data, and the incidence of ROP.

ACKNOWLEDGMENTS

The authors thank the many neonatal nurses, respiratory therapists, and Pediatrix Medical Group clinicians that have participated in COMP-ROP. Their efforts, observations, and refinements have significantly enriched the program and are greatly appreciated.

REFERENCES

2. Ellsbury DL. Quality improvement program for the reduction of retinopathy of prematurity [abstract]. E-PAS 2006;3602.469.


FURTHER READINGS


