Implementation of Postoperative Respiratory Care for Pediatric Orthopedic Patients

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BACKGROUND AND OBJECTIVES: At our institution, one-fifth of pediatric patients undergoing hip and spine surgery require prolonged oxygen supplementation, most likely due to postoperative atelectasis. Using quality improvement methodology, we aimed to implement an innovative postoperative respiratory care algorithm for hip and spine surgery patients, with a global aim of improving respiratory outcomes.

METHODS: A multidisciplinary team developed a care algorithm that relied on an activated respiratory therapist (RT) and engagement of patients and families. The algorithm was implemented via multiple rapid tests of change. Process measures representing the beginning and end of the care algorithm were plotted on standard run charts. We evaluated the association of algorithm implementation with a primary outcome of prolonged (>10 hours) oxygen supplementation via a quasi-experimental design using Fisher’s exact and t tests.

RESULTS: The team successfully implemented the algorithm, with a reliability to process of 80%. Key interventions included education of RTs, a daily huddle, and implementation of automated orders. Among all hip and spine patients, algorithm implementation was associated with a small, non-statistically significant decrease in prolonged oxygen use (21% to 16%). Among patients with underlying chronic conditions, there was a significant decrease in prolonged oxygen use from 22% to 6% after algorithm implementation (P = .04).

CONCLUSIONS: We implemented an innovative respiratory care algorithm in hip and spine surgery patients by empowering RTs and engaging families to participate in care. We found that this approach was associated with decreased prolonged oxygen use in patients with chronic underlying conditions.

Respiratory complications are the second most common postoperative complication for all pediatric surgeries, after infection.1 Although a standardized approach to postoperative respiratory care has improved outcomes of adults,2 such approaches in children have not been well described. Postoperatively, the combined effects of pain, residual sedation from anesthesia, and additional use of opiate analgesics lead to reductions in tidal volumes and respiratory rates, impaired cough, and impaired respiratory control and mentation with predisposition to atelectasis and hypostatic pneumonia.3,4 At our institution, a large proportion of pediatric patients undergoing hip and

abstract

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Dr Shaughnessy substantially contributed to the conception and design of the study and drafted and revised the manuscript; Ms White and Drs Shah and Sawnani substantially contributed to the conception of the study and revised the manuscript critically for important intellectual content; Dr Hubbell substantially contributed to the acquisition of data and revised the manuscript critically for important intellectual content; Dr Sucharew substantially contributed to the analysis and interpretation of data and revised the manuscript critically for important intellectual content; and all authors approved the final manuscript as submitted.


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spine surgery (21%) experienced prolonged hypoxia postoperatively. Chronic comorbidities were common in this population, with almost one-third having chronic lung disease (eg, restrictive lung disease, excluding well-controlled asthma) and more than half having neurologic or muscular impairment (eg, cerebral palsy, spina bifida). These comorbidities only serve to amplify the predisposition for this population to develop respiratory complications.

A multidisciplinary team composed of representatives from orthopedics, pediatric hospital medicine, pulmonology, and respiratory therapy developed and implemented a best-practice algorithm to improve the respiratory outcomes of pediatric patients after hip and spine surgery. We hypothesized that successful implementation of the algorithm would lead to a decrease in the proportion of patients requiring prolonged oxygen therapy.

**METHODS**

The setting for this project was a pediatric surgical inpatient unit at the Cincinnati Children’s Hospital Medical Center (CCHMC), a 539-bed tertiary children’s hospital affiliated with the University of Cincinnati. This 24-bed unit admits surgical patients primarily, is staffed with pediatric nurses, and shares continuous respiratory therapist (RT) coverage with 5 other units. Spine procedures include posterior spinal fusions, vertical expandable prosthetic titanium rib placement, and growing rod placement or adjustments. Hip procedures include hip osteotomy (with or without varus derotation or epiphysiodesis), hip reduction, hip shelf procedure, and hip surgical dislocation (with or without chondroplasty or hip capsulotomy). Patients admitted directly to the PICU after surgery were not included in this study. The CCHMC Institutional Review Board reviewed and approved this study with a waiver of informed consent.

**Planning the Care Algorithm Implementation**

The multidisciplinary team examined algorithms described for adult patients that prioritize early ambulation and lung recruitment techniques. At our institution, early ambulation, particularly for spine patients, has been instituted as a best practice, with most patients receiving physical therapy evaluation on the first postoperative day. However, the team recognized that early, frequent lung recruitment therapy was not standard practice.

The team prioritized a therapeutic approach that involved early RT assessment and initiation, but that could easily be transitioned to the patient or family. This approach was important because of the limited availability of the RT for frequent encounters.

Because atelectasis is the most common cause of postoperative hypoxia, the team examined therapies designed to maintain lung recruitment. Incentive spirometry is an attractive lung recruitment therapy because of its widespread availability and familiarity. However, incentive spirometry requires both coordination and effort, precluding its use for many pediatric postoperative patients, particularly young, neurologically impaired, or sedated patients.

To serve these patients, the team selected breath-stacking, a simple, inexpensive technique that uses a 1-way valve to promote lung inflation. This device provides resistance to exhalation during spontaneous breathing, resulting in “stacking” of spontaneous inhalations to recruit additional lung volume; however, it does not require coordination or effort. Although less well studied, breath-stacking was safe and effective in adult studies, and 2 small studies have demonstrated efficacy in children.

We developed a portable breath-stacking device by attaching an anesthesia mask to a 1-way valve, with a disposable in-line manometer. The manometer served 2 functions: to assist the user in obtaining an appropriate seal of the facemask and to ensure safety by limiting pressures to 25 cm H₂O of water (Supplemental Fig 5). The device was authorized by the CCHMC Respiratory Therapy Practice Council, and RTs were subsequently trained to use it. Our protocol called for 3 cycles of up to 5 breaths, with a goal pressure of 15 to 20 cm H₂O.

The team determined that the RT was best equipped to assess each individual patient and choose a “lung recruitment therapy,” typically either incentive spirometry or breath-stacking, that would best fit the needs of the patient. The RT would initiate therapy and return every 4 hours to continue the therapy. During the encounters, the RT would teach the patient/family how to perform the therapy and hand over the therapy to the patient or caregiver if and when they demonstrated competence (Fig 1) with instructions to continue the therapy at least every 4 hours.

**Assessment of Algorithm Implementations**

To measure the reliable adoption of this respiratory algorithm, the team used 2 process measures representing the beginning and end of the care algorithm.

1. Increase the percentage of pediatric hip and spine surgery patients who received initial RT assessment and therapy within 4 hours of arrival from the postanesthesia care unit from 0% to 80% within 6 months.
2. Increase the percentage of patients or families receiving a standardized handoff of respiratory care from the RT from 0% to 80% within 6 months.
A goal of 80% was chosen for the first process measure because the team was implementing a new process and achievement of the 80% benchmark would indicate that a new stable system had been achieved. For the second process measure, the team felt that, for some patients, a handoff of respiratory care may not be appropriate or ideal because of lack of a caregiver presence or discomfort of the caregiver in taking over the therapy. Eighty percent seemed to be a reasonable target for achieving a stable system while allowing room for appropriate exceptions.

To begin implementation, the team predicted failure modes to inform an initial key driver diagram. Interventions targeting key drivers were tested in Plan-Do-Study-Act (PDSA) cycles. Most interventions were tested on 1 or 2 patients and adjusted as appropriate. The team refined the key driver diagram after a Pareto analysis of early failures. Successful interventions were spread to all patients. As the implementation reached the goal percentage, the team sought higher reliability interventions to replace successful low-reliability interventions. Success or failure was plotted on a run chart by using standard rules to identify special cause and to determine when the specific aim had been achieved.

Assessment of Clinical Outcomes
To determine impact on clinical outcomes, we reviewed medical records of similar surgical patients in the year before the implementation \((n = 81)\) and 6 months after the implementation \((n = 69)\). Baseline characteristics collected included age, gender, type of surgical procedure, and underlying medical conditions. Medical conditions were classified as chronic or not chronic. Chronic conditions were further classified as neurologic impairment, lung disease, both, or neither. Isolated orthopedic diagnoses such as idiopathic scoliosis or congenital hip dysplasia were not considered underlying medical conditions.

The primary outcome measure was prolonged oxygen supplementation, whereas the secondary outcome measure was hospital length of stay. In addition to these measures, transfers to the ICU and rates of pneumothorax were recorded as balancing measures to ensure the care algorithm was as safe as predicted.

The primary outcome measure was prolonged oxygen supplementation defined as ≥10 hours after arrival to the inpatient unit. We chose to dichotomize time on oxygen supplementation rather than treat it as a continuous variable, in part to circumvent the impact of a concurrent initiative of postoperative supplemental oxygen among the postintervention patient group. This separate initiative aimed at reducing surgical site infection risk by requiring spinal fusion patients to receive supplemental oxygen for 4 hours postoperatively. Most spinal fusion patients under this initiative had their supplemental oxygen withdrawn by 5 hours. We evaluated the distribution of time on oxygen in the combined pre- and postintervention patient groups to select a cutoff at the extreme of the distribution (top quintile) with clinical relevance, while alleviating misclassification of the outcome for spinal fusion patients receiving supplemental oxygen as part of the surgical site infection prevention initiative.

In the surgical inpatient unit, nursing staff routinely weaned oxygen to maintain saturations >92%. During this improvement initiative, nurses were blinded to the clinical outcome measures including time on supplemental oxygen.

**Analyses**

Demographic and clinical characteristics were compared between preintervention and postintervention groups by using \(\chi^2\) test or Fisher’s exact test for categorical variables and 2-sample \(t\) test for age. Wilcoxon rank sum test was used to compare groups for length of stay. The proportion of patients requiring prolonged oxygen supplementation was compared between groups by using Fisher’s exact test. Subgroup analyses based on underlying chronic conditions were conducted to compare pre- and postintervention among subsets of patients. All analyses were unadjusted.

**RESULTS**

**Algorithm Implementation**

Early PDSA cycles were designed to educate providers about the respiratory algorithm and to ensure ease of use of the algorithm. The team examined each implementation failure and categorized the reason for the failure. A Pareto diagram identified inappropriate patient
exclusion (n = 5) and incorrect order entry (n = 3) as the most common reasons for failure (Supplemental Fig 6). This analysis assisted the team to further refine the key driver diagram and to design new interventions (Fig 2). More than 40 PDSA cycles were run during the intervention period, including 4 ramps. Both process measures achieved special cause, with 8 consecutive points above the median. The final median for both processes reached the goal of 80% within the 6 months (Fig 3, Supplemental Fig 7).

Widespread education of RTs was an early intervention essential to successful implementation. Although RT education was labor-intensive, it ensured that the personnel who played a central role in the care algorithm were capable of completing that role.

The next key intervention was a physician-driven huddle. This daily huddle, led by an attending physician, increased communication and awareness of team members regarding patients’ status in the care algorithm. It also empowered the RT to take an active role in therapeutic decision-making.

The next key bundle of interventions was designed to increase family engagement. The RT taught the patients and/or families the importance of the lung recruitment therapy and how to administer the therapy and handed over the therapy when the patient or family demonstrated comfort and competence. Initially, RTs were returning for many visits, with a large amount of variation in the number of visits. After following the PDSA cycles designed to standardize a 3-step teaching and handoff process (RT demonstrates therapy, RT teaches patient/family, RT observes independent performance), the number of visits before handover decreased to a median of 1.3 visits (Fig 4).

As the project approached the target implementation percentage, the improvement team used higher-reliability interventions designed to sustain success. These interventions used electronic health record (EHR) elements to insert the care algorithm into the standard workflow. These interventions replaced labor-intensive processes such as handwritten forms, huddles, and phone calls. For example, standardized order sets were updated with a “Lung Recruitment Assessment” order that electronically generated an immediate page to the on-call RT. A standardized electronic form allowed therapists to easily document therapies, teaching, and handoff of therapy to families; the form also linked to billing functions. Laborious daily data collection ceased when the team successfully moved the median to its goal and the process was integrated into EHRs; monthly audits monitoring the process continued.

Clinical Outcomes

Of the patients classified as having a chronic medical condition, 70% had neurologic impairment, 40% had lung disease, 25% had both neurologic impairment and lung disease, and 15% had neither. The proportion of patients with neurologic impairment was significantly greater in the preintervention group than in the postintervention group (Table 1).

Time on supplemental oxygen ranged from 0 to 104 hours, with a median (25th–75th percentile) time of 2.5 (0–5.8) hours in the preintervention group and 2.4 (0–5.1) hours in the postintervention group. Overall, the proportion of patients who required prolonged supplemental oxygen (>10 hours) decreased from 21% preintervention to 16%.
postintervention, although this difference was not significant ($P = .52$) (Table 2). However, among the subset of patients with underlying chronic conditions, the proportion of patients requiring prolonged supplemental oxygen was significantly higher preintervention (22%) than postintervention (6%) ($P = .04$). There was no difference in the healthy patients in terms of rate of prolonged oxygen supplementation associated with the algorithm implementation (Table 2).

The secondary clinical outcome, median length of stay, was 4.3 days in the preintervention group compared with 3.7 days in the postintervention group; the difference was not significant ($P = .45$). Among patients with an underlying chronic condition, the median length of stay was 4.2 days in the preintervention group and 3.3 days in the postintervention group ($P = .19$). No adverse events (ie, ICU transfer, pneumothorax) occurred during the intervention period.

### DISCUSSION

Using quality improvement methodology, we reliably implemented an innovative postoperative respiratory care algorithm that uniquely met the needs of our pediatric hip and spine surgery patient population. For patients with underlying chronic conditions, this algorithm was associated with a decreased rate of prolonged oxygen supplementation.

Several factors enabled the successful implementation of the standardized early postoperative care process. At our institution, assuming a decision-making role was a significant shift for the RTs, who were more accustomed to carrying out physician orders rather than recommending a plan of care. We found that once therapists became familiar with the concept, they quickly embraced the new, proactive role. This culture change led to an increase in therapist engagement with the project as a whole. As the therapists assumed this role with greater consistency, the laborious physician-led huddle was successfully phased out without detriment. At this point, higher reliability interventions, primarily EHR elements, were introduced to support the new workflow. Examination of the run chart (Fig 3) reveals that the early interventions aimed at culture change enabled initial success; introduction of the higher reliability EHR interventions at a later time point enhanced the reliability of the new process.

A unique aspect of this initiative was the focus on family engagement as an essential part of the standardized care algorithm; RTs handed over lung recruitment therapies to patients and caregivers after teaching. We believe engagement of families may lead to increased therapy adherence and...
better outcomes; it may also directly reduce costs related to the postoperative care algorithm by reducing the number of RT encounters required. Recent studies have supported the idea of increasing patient and family engagement, leading to improved quality of care and improved patient safety. Anecdotally, families commented that they appreciated the opportunity to participate in the patient’s care. However, it is possible that we may unintentionally have caused stress to some families by requesting their participation. We did not measure family satisfaction with the algorithm.

Standardized respiratory care algorithms in postoperative adults are associated with significantly better outcomes such as decreased rates of postoperative pneumonia. The successful adult algorithms have several common elements, including ambulation and lung recruitment techniques with incentive spirometer use. Our pediatric algorithm similarly focuses on early lung recruitment via methods tailored to meet the needs of our young and neurologically impaired patients.

In our study, the clinical benefit of the algorithm occurred in patients with underlying comorbidities such as neurologic impairment and lung disease. Patients with neurologic impairment are less likely to ambulate postoperatively and are less likely to effectively use traditional incentive spirometry, which requires coordination and effort. For this group, the addition of early breath-stacking therapy and teaching was most likely the critical element that improved their respiratory outcomes.

Although patients with underlying comorbidities were at higher risk and thus more likely to achieve benefit, it is unclear why the proportion of healthy patients with prolonged oxygen supplementation did not decrease. One possible explanation is that the healthy patients, because they tended to be developmentally normal, were typically assigned incentive spirometry rather than

### TABLE 1  Demographic and Baseline Characteristics by Group

<table>
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<th>Baseline Characteristics</th>
<th>Preintervention Group</th>
<th>Intervention Group</th>
<th>P</th>
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<tr>
<td>Age, mean ± SD, y</td>
<td>9.7 ± 5.2</td>
<td>11.7 ± 5.1</td>
<td>.01</td>
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<tr>
<td>Female, n (%)</td>
<td>46 (57)</td>
<td>35 (51)</td>
<td>.38</td>
</tr>
<tr>
<td>Without underlying chronic condition, n (%)</td>
<td>22 (27)</td>
<td>35 (51)</td>
<td>.003</td>
</tr>
<tr>
<td>Lung disease, n (%)</td>
<td>25 (31)</td>
<td>22 (32)</td>
<td>.89</td>
</tr>
<tr>
<td>Neurologic impairment, n (%)</td>
<td>47 (58)</td>
<td>18 (26)</td>
<td>&lt;.001</td>
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<tr>
<td>Procedure type, n (%)</td>
<td>0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior spinal fusion</td>
<td>13 (16)</td>
<td>28 (41)</td>
<td></td>
</tr>
<tr>
<td>Other spine</td>
<td>13 (16)</td>
<td>6 (9)</td>
<td></td>
</tr>
<tr>
<td>Hip</td>
<td>55 (68)</td>
<td>35 (51)</td>
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breath-stacking as a lung recruitment therapy. Three studies have suggested that breath-stacking may achieve better lung expansion than conventional incentive spirometry.8–10 An alternative explanation is that healthier patients were less compliant with therapy after handover from the RT.

Reductions in length of stay were not statistically significant. It is possible that we were underpowered to detect significant differences in length of stay. It is also likely that prolonged oxygen supplementation is not the primary determinant of length of stay and other factors influence the duration of hospitalization.

The cost of this respiratory care algorithm is essentially the cost of RT encounters (median of 1.3 encounters per patient) plus the cost of the lung recruitment device. Although a complete analysis of costs was outside the scope of this project, we believe the cost of the intervention is outweighed by savings driven by improved respiratory outcomes, including decreased supplemental oxygen use, decreased continuous pulse oximetry monitoring, decreased need for ongoing RT encounters, and potentially decreased length of stay.

This study has several limitations. The findings of this single-center study in a highly specialized surgical population may not be generalizable to other sites and patient populations. However, we believe several of the interventions, such as RT education, daily huddle, and teaching and handover of care to families, may easily translate to another pediatric hospital. Although we designed our study to minimize the impact of another initiative aimed at reducing surgical site infection in this patient population, there may be other secular trends that may have influenced the results. We believe that we minimized risk that nurses may have weaned a patient’s oxygen more aggressively during algorithm implementation because of nurse blinding to the clinical outcomes studied. Finally, although families were instructed to continue therapy every 4 hours at the time of handover, we did not measure frequency of therapy continuation.

Using rapid tests of change, we implemented an innovative respiratory care algorithm in pediatric patients after hip and spine surgery. Key factors included empowering RTs to take an active role in care and engaging families to participate in providing respiratory therapy. This approach was associated with improved outcomes in patients with chronic underlying conditions, specifically a decrease in the proportion of patients requiring prolonged oxygen supplementation.

**TABLE 2** Comparison of Pre- and Postintervention Patient Groups in Primary Outcome Measure: Percentage of Patients Requiring Prolonged Supplemental Oxygen

<table>
<thead>
<tr>
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<th>Preintervention</th>
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<tr>
<td></td>
<td>%</td>
<td>n/N</td>
<td>%</td>
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<tr>
<td>All hip and spine patients</td>
<td>21 17/81</td>
<td>16 11/89</td>
<td>.52</td>
</tr>
<tr>
<td>Healthy (no underlying conditions)</td>
<td>18 4/22</td>
<td>25 9/35</td>
<td>.75</td>
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<tr>
<td>Any underlying medical conditions</td>
<td>22 15/59</td>
<td>6 2/34</td>
<td>.04</td>
</tr>
<tr>
<td>Underlying neurologic impairment</td>
<td>21 10/47</td>
<td>5 1/18</td>
<td>.26</td>
</tr>
<tr>
<td>Underlying lung disease</td>
<td>32 8/25</td>
<td>14 3/22</td>
<td>.17</td>
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n, number of patients requiring prolonged supplemental oxygen; N, total number of patients within the category.

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**ABBREVIATIONS**

CHCMC: Cincinnati Children’s Hospital Medical Center

EHR: electronic health record

PDSA: plan-do-study-act

RT: respiratory therapist


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