Background  In 2010, the incidence of prolonged mechanical ventilation (>24 hours) after isolated coronary artery bypass graft (CABG) surgery was 26.9% at the study site, The Ohio State University Wexner Medical Center, compared with the national like-hospital rate of 10.9%.

Objectives  To use the principles of lean management to reduce the incidence of prolonged mechanical ventilation and to assess the sustainability of that reduction over time.

Methods  A multidisciplinary prolonged ventilation task force conducted a gap analysis leading to 3 interventions: (1) a standardized extubation protocol, (2) dry erase boards in patients’ rooms to facilitate team communication, and (3) edits of the postoperative order set within the electronic health record. Outcomes of mechanical ventilation in CABG patients before and after the interventions are compared.

Results  All target outcomes changed significantly after the interventions, including a reduction in the median hours of initial mechanical ventilation (from 11.4 hours to 6.9 hours, P<.001). The percentage of patients reintubated did not increase (a decrease from 11.8% to 3.5% was not significant, P=.08). The rate of prolonged ventilation decreased from 29.4% to 8.8% (P=.004), and this reduction was sustained for 4 years after the interventions.

Conclusions  Success factors included the multidisciplinary task force and continual protocol reeducation among front-line staff. (American Journal of Critical Care. 2016;25:423-430)
A n increase in the number of coronary artery bypass graft (CABG) surgeries performed in the United States and the increasing cost of health care have led to questions about the risk and costs of the perioperative support required after CABG surgery. Specifically, cardiac anesthesia has historically involved use of high-dose opioid anesthetics, committing the patient to a postoperative period of mechanical ventilation that increased both risk and cost. With the goal of facilitating early extubation (within 6 hours of surgery), Cheng and colleagues tested the use of 15 μg/kg of fentanyl versus 50 μg/kg of fentanyl. This new protocol reduced length of stay in both the intensive care unit (ICU) and the hospital and saved health care resources, lowering total costs per CABG surgery.

Follow-up studies demonstrated that early extubation—known as “fast track” cardiac anesthesia—does not pose additional risks, positioning early extubation as the standard of care in cardiac surgery. A 2011 American College of Cardiology guideline gave a class I recommendation for an anesthetic directed toward early postoperative extubation among low- to medium-risk CABG patients. In a meta-analysis of fast-track cardiac practices, researchers reported that although anesthetic management affects the ability to allow early extubation, an extubation protocol was pivotal, thus highlighting the importance of the work processes within a cardiac surgery unit.

Given this finding, quality improvement (QI) processes play an important role as hospitals and health systems aspire to comply with current “fast-tracking” guidelines. “Lean management,” a key QI process, was first used to describe the Toyota business model. The Toyota Production System was a model developed to eliminate waste and variability. A key component of lean management is holding every individual responsible and accountable to use tools that will reduce variability in the work process. Lean management has been used in many areas of medicine, including critical care.

In this study, we applied the principles of lean management to a cardiac surgery unit within a large academic medical center in order to decrease both the incidence of prolonged mechanical ventilation and the median time to extubation following CABG. This QI process was implemented as a response to the findings of an audit conducted by the prolonged ventilation task force (details of the task force provided later). Within our health system between 2008 and 2010, the incidence of prolonged mechanical ventilation (intubation for >24 hours) for isolated CABG was 26.9%, compared with the like-hospital rate of 10.9% for the same time period. The objectives of this study were to reduce this rate to or below the mean national rate for like hospitals and to assess the sustainability of that reduction over time.

Methods

This study employed A3 thinking, which is a consensus building process that uses a succinct visual communication tool to guide project participants. Within the A3 model, we conducted a gap analysis with the goal of comparing best practices with the processes in place at the organization and identifying the gaps between current performance and best practices. The QI program was implemented in 2010, and primary outcome measures were compared in 2 groups of CABG patients, 6 months before and 6 months after the intervention. Sustainability of the main outcome measure, prolonged mechanical ventilation, was tracked for 4 years after the intervention.

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Setting

This study was implemented in the Division of Cardiac Surgery at The Ohio State University Wexner Medical Center. The Division of Cardiac Surgery provides care for patients within a dedicated heart hospital where 6 surgeons performed 2596 cardiac procedures in fiscal year 2014, qualifying the division as the busiest cardiac surgery program in the region.

Prolonged Ventilation Task Force

Formed in 2010, the task force included multidisciplinary professionals: cardiac surgeons, intensivists, anesthesiologists, nurse administrators, advanced practice nurses, respiratory therapists, pharmacists, and perfusionists. It was championed by the chief quality and patient safety officer and led by members of the Office of Quality and Patient Safety. The task force charter included 2 goals for patients undergoing isolated CABG: (1) within 1 year, achieve prolonged ventilation rates that are at or below the national Society of Thoracic Surgeons (STS) like-hospital benchmark of 12%, (2) achieve a median initial ventilation time of 7.6 hours (the STS benchmark) within the same time frame. “Like hospitals” are those with a similar bed capacity, and the benchmark is based on the median rate among those like hospitals.

Gap Analysis

Three types of data collection informed the gap analysis: retrospective chart reviews, interviews with stakeholders, and focus groups. The task force conducted retrospective chart reviews of patients who met the criteria for prolonged mechanical ventilation. A root-cause analysis was conducted for each case. Root-cause variables included lack of communication between team members, redundant and excessive analgesic medications within postoperative order sets that led to variation in ordering practices, and unstandardized extubation practices and goals. Specifically, the decision to pursue early extubation was an unstandardized and independent decision-making process supported by minimally structured clinical management by each member of the team instead of a standardized process encouraging early extubation.

Interviews and focus groups were an additional element of the gap analysis. Members of the task force conducted 1-on-1 interviews with nurses, respiratory therapists, physicians, and anesthesiologists who work on the cardiac unit. Interviewees were asked about their work processes and their perspectives on questions such as “why are some patients on vents for so long?” Similar topics were discussed in the style of focus groups during staff meetings. Information collected from the interviews and focus groups supported the prevalence of these root causes and provided contextual detail related to the situations in which these root causes occur.

Interventions

Upon completion of the gap analysis, the multidisciplinary task force developed 3 interventions aimed at addressing the identified root causes. These included (1) the development of an extubation protocol to standardize extubation practices, (2) the introduction of dry erase boards in patients’ rooms to facilitate team communication, and (3) edits of the postoperative order set within the electronic medical record to reduce medication variation and redundancy in order to facilitate appropriate drug utilization.

The extubation protocol was developed with the goal of setting early extubation as the standard and the decision to delay extubation as the exception. Figure 1 is the cardiothoracic surgery ventilator weaning and extubation protocol, which consists of a decision tree from arrival in the ICU until extubation that requires reassessment of patients every 30 minutes and a specific weaning process once weaning is initiated. The nurse and the respiratory therapist could follow this protocol without the need for additional physician orders.

The second intervention was the installation of dry erase boards in each patient’s room on the cardiac unit to facilitate communication, both among the care team and during handoffs across teams. During handoffs, the operating room team could use the board to write extubation goals, concerns, and notes to the receiving team. Team communication breakdowns were identified as a root cause of prolonged extubation because respiratory therapists and other team members did not have a method to easily identify and contact the patient’s nurse. The dry erase board addressed this problem with space for the nurse’s name and phone number to facilitate contact between the nurse and other team members.

A third intervention was developed in response to the gap analysis finding that postoperative order sets in the electronic health record allowed redundant and excessive use of analgesics and sedatives, leading to unnecessary variability in ordering and administration. Specifically, with respect to options for analgesia, the order set included multiple parenteral (fentanyl, morphine, hydromorphone) and oral agents (oxycodone/acetaminophen, hydrocodone/acetaminophen, acetaminophen). The order set was edited to reduce redundancy by limiting

The extubation protocol was developed with the goal of setting early extubation as the standard.
Upon patient arrival to patient care unit:

- Obtain initial ventilator settings from ICU intensivist or place patient on 8 mL/kg IBW
- Mode: SIMV pressure-regulated volume control (VC+) or SIMV Volume Control

Determine goal extubation time from surgeon or intensivist

After 20 minutes on settings obtain ABG

- Is pH ≥ 7.347 or PaO₂ ≥ 120 mm Hg?
- Correct for respiratory acidosis by increasing respiratory rate and obtain order to increase PEEP if indicated.
- Reassess ABG in 30 min

Begin weaning O₂:

- Wean O₂ from 100% down to 40% as tolerated keeping SpO₂ ≥ 93%.
- If PEEP is > 8 cm H₂O, obtain MD order to wean PEEP.

Wean rate as tolerated:

- Wean SIMV rate by 4 or more BPM Q 30min to Spontaneous Mode (PEEP = 5 and PS = 10).
- If patient is awake, cooperative (RASS +1 to -1) and breathing < 25 BPM, vent rate may be reduced to Spontaneous Mode more rapidly.

If patient is hemodynamically stable 5 hours post-op, place patient on Spontaneous Mode.

- Document in Adult Vent flow sheet
- Assess for tolerance

After 30 min on Spontaneous Mode, obtain ABG and weaning parameters

- Do all of the following exist?
  - pH ≥ 7.34, PaO₂ ≥ SpO₂ ≥ 93%;
  - Vt ≥ 5 mL/kg, VC ≥ 10 mL/kg,
  - NIF ≥ 25, f/Vt ≥ 100

- Extubate and place on 6 L NC
- Obtain ABG 30-60 min post extubation

If patient does not tolerate

- Resume SIMV to 8 BPM with previous Vt setting
- May repeat as often as Q 30 min

Figure 1 Cardiothoracic surgery ventilator weaning and extubation protocol.

Abbreviations: ABG, arterial blood gases; BPM, breaths per minute; f, frequency; IBW, intake body weight; ICU, intensive care unit; MD, physician; NC, nasal cannula; NIF, negative inspiratory force; O₂, oxygen; PEEP, positive end-expiratory pressure; post-op, post-operatively; PS, pressure support; Q, every; RASS, Richmond Agitation-Sedation Scale; SIMV, synchronized intermittent mandatory ventilation; SpO₂, oxygen saturation shown by pulse oximetry; vent, ventilator; Vt, tidal volume; VC, volume control.

 Courtesy The Ohio State University Wexner Medical Center, Columbus, Ohio.
standard orders to include 1 parenteral agent (hydromorphone) and 1 oral agent (oxycodeone/acetaminophen) to facilitate availability of relatively short-acting agents that are minimally affected by variable end-organ function across the population.

Education and Feedback

The 3 interventions were implemented with rigorous, and multimodal, staff education. Initial education was conducted informally through 1-on-1 discussions between members of the task force and staff from their respective disciplines, across multiple shifts both on the unit floor and during break room discussions. Additionally, members of the task force attended staff meetings to provide detailed instructions for the incorporation of the extubation protocol and the new whiteboard communication process into the current unit workflow. During these conversations, the task force was careful to frame the interventions as the work product of the extensive staff engagement that occurred during the gap analysis, in addition to highlighting the multidisciplinary nature of the task force itself.

Additional educational outreach specific to the extubation protocol included e-mailing staff to provide the protocol and a “go-live” date, and updating the nurses’ bedside references so that the new protocol would be easily accessible at the patients’ bedside. During the initial 6-month implementation period and continuing during the maintenance period, staff members were provided feedback on the outcomes of interest. At monthly meetings of nurses and respiratory therapists, a task force representative shared updates on the number of cases of prolonged ventilation and the current mean time to initial extubation. An opportunity also was provided to discuss the implementation of the interventions and troubleshoot barriers as they arose.

Data Collection

The Division of Cardiac Surgery participates in and reports to the STS national database—established in 1989 as a tool for national-level quality improvement and patient safety among cardiothoracic surgeons. In order to report to the national database, the division maintains an institution-level STS adult cardiac surgery database, comanaged with the Office of Quality and Patient Safety. This database includes patients’ demographic data, procedural data, and perioperative outcomes that are abstracted and entered into the STS database from the medical center’s electronic medical records. Access to data for this article was approved via an institutional quality data release, and the Health Insurance Portability and Accountability Act of 1996 (HIPPA) regulations were followed at all times in order to maintain the confidentiality of patients’ personal information.

Outcomes and Analysis

Patients who had CABG surgery performed during the 6 months before the quality improvement process (January through June 2010) were categorized as group 1. Patients who had surgery performed in the 6 months after implementation of the quality improvement process (January through June 2011) were categorized as group 2. Significant differences in demographic and health status variables between these groups were calculated by using $\chi^2$ tests to detect significant differences in the distribution of the variables across study groups.

Outcomes included the median number of hours of mechanical ventilation after CABG surgery, termed initial mechanical ventilation. The percentage of patients undergoing early extubation was also calculated, with early extubation defined as occurring within 6 hours of ICU arrival. Prolonged mechanical ventilation, defined as initial mechanical ventilation for more than 24 hours, was calculated as a percentage of patients in each group. The proportion of patients reintubated was collected. The outcome variables were compared between groups by using t tests of a significant difference in means for the continuous variables and $\chi^2$ tests for the categorical variables. Multivariate modeling was not conducted because the 2 groups did not differ significantly on any measured variables. Analyses were conducted by using SPSS version 20-22 (SPSS Inc).

Results

The Division of Cardiac Surgery performed 68 CABG operations in the 6 months before the interventions (group 1) and 58 in the 6 months after the interventions (group 2). Table 1 presents demographic and health status variables that may be associated with differences in intubation rates, including hypertension, dyslipidemia, chronic lung disease, the urgency of the surgery, and the presence of an intra-aortic balloon pump. These variables did not differ significantly ($P<.05$) between the groups. Other nonsignificant variables that occurred in less than 5% of our sample included previous cardiac surgery, emergent salvage, and cardiogenic shock.

All target outcomes changed significantly from before to after the interventions (Table 2), including a significant reduction in the median number of initial mechanical ventilation ($P<.001$). The median number
of hours of initial mechanical ventilation was 6.9 after the intervention, below the STS benchmark of 7.6 hours. The percentage of patients extubated early increased from 19% before the interventions to 41% after the interventions ($P = .01$) and the percentage reintubated did not increase (there was a nonsignificant decrease from 12% to 4%, $P = .08$). The rate of prolonged mechanical ventilation also decreased, from 29% to 9% ($P = .004$).

Figure 2 presents the rate of prolonged mechanical ventilation 6 months before the interventions (first quarter of 2010) until the third quarter of 2014, which is 4 years after the interventions. Within 3 months of the implementation of the interventions, the rate of prolonged mechanical ventilation was below the STS’s mean rate for like hospitals and stayed around the STS mean for the following 2 years. In 2013, the rate started to increase and the task force members turned their attention to this issue, which corresponded to a sharp decrease back to less than the STS mean.

**Discussion**

This QI project was successful at reaching the goals set by the prolonged ventilation task force. Implementation of a 3-part intervention—an extubation protocol, dry erase communication boards in patients’ rooms, and a standardized postoperative medication order set—led to a decrease in the rate of prolonged ventilation after CABG similar to the STS’s mean for like hospitals and sustained success across subsequent years. Although it was not an original goal of the task force, another finding of note is the significant increase in the rate of early extubation (extubation < 6 hours after ICU arrival). The percentage of patients reintubated did not increase after the interventions, providing evidence that the extubation protocol did not lead to premature extubation of patients.

This success is similar to that seen in other applications of lean thinking to health care, most commonly in surgery and emergency departments.\(^1^7^-^1^9\) However, in a 2015 systematic review of use of lean techniques in health care, researchers reported positive but not conclusive evidence of improved quality and safety outcomes. These inconclusive results may be due in part to a need to delineate what implementation strategies led to the success of QI initiatives.\(^2^0\) One element critical to success was the application of a thorough gap analysis. This analysis identified root causes of the high rate of prolonged mechanical ventilation, enabling the creation of interventions that were tailored to the specific causes of the problem.

Another element of success was the engagement of the key disciplines involved in the process on the
The front line of patient care. The task force was multidisciplinary, including all professional groups that care for CABG patients in the cardiac unit. This multidisciplinary approach is a key element of lean management implementation and allowed the team involved in patient care to engage in quality improvement and find solutions to provide the highest standard of care. The principles of lean management hold each member of the team accountable for creating and using tools, in this case the interventions, to reduce variability in the work process. The integration of staff at all levels in the implementation process through education and feedback facilitated buy-in and fidelity to the interventions. Specifically, the real-time assessment and feedback of patients who were extubated in a timely manner allowed rapid assessment of failure modes and modifications to facilitate protocol fidelity.

A unique element of this study is the exploration of sustainability years after initial implementation. Figure 2 also shows a slowly increasing rate of prolonged mechanical ventilation in 2013, almost to preintervention levels. When stakeholders from the task force were made aware of this increase, a flurry of discussion ensued and attention was paid to the elements of the initial QI intervention. The increasing rate required reengagement of team members, many of whom were new to the organization and unaware of the protocol. This situation revealed an opportunity to develop a process by which front-line staff members, both new and old, are continuously reeducated on patient care strategies so that current and new protocols are used. Subsequent to the implementation of this reeducation process, the rate returned to less than the STS’s mean for like hospitals.

Therefore, the important addition of this study to the literature is the identification of sustainability success factors. Our findings support many of the framework elements for supportive QI conditions recently proposed by Matthaeus-Kraemer and colleagues, including the importance of multidisciplinary members of a dedicated QI team, the engagement of front-line staff in the dissemination process, external benchmarks, and administrative support. The present study adds to this framework by considering the process of planning before implementation of interventions and long-term sustainability.

Conclusions

A lean management intervention to standardize workflow protocols and facilitate team communication achieved significant and sustained success. This sustainability across 4 years can be attributed to the multidisciplinary task force charged with addressing this issue and the continued focus on the engagement and education of front-line staff. The details provided in this article can help to guide other critical care medicine departments in their quality improvement processes.

FINANCIAL DISCLOSURES

None reported.

eLetters

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