Efficacy of Oscillation and Lung Expansion in Reducing Postoperative Pulmonary Complication

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BACKGROUND: Postoperative pulmonary complications (PPCs) cause high morbidity and mortality. Targeted treatment for patients at risk for PPCs can improve outcomes. This multicenter prospective trial examined the impact of oscillation and lung expansion (OLE) therapy, using continuous high-frequency oscillation and continuous positive expiratory pressure on PPCs in high-risk patients.

METHODS: In stage I, CPT and ICD codes were queried for patients (n = 210) undergoing thoracic, upper abdominal, or aortic open procedures at 3 institutions from December 2014 to April 2016. Patients were selected randomly. Age, comorbidities, American Society of Anesthesiologists physical status classification scores, and PPC rates were determined. In stage II, 209 subjects were enrolled prospectively from October 2016 to July 2017 using the same criteria. Stage II subjects received OLE treatment and standard respiratory care. The PPCs rate (prolonged ventilation, high-level respiratory support, pneumonia, ICU readmission) were compared. We also compared ICU length of stay (LOS), hospital LOS, and mortality using *t*-tests and analysis of covariance. Data are mean ± SD.

RESULTS: There were 419 subjects. Stage II patients were older (61.1 ± 13.7 years vs 57.4 ± 15.5 years; $p < 0.05$) and had higher American Society of Anesthesiologists scores. Treatment with OLE decreased PPCs from 22.9% (stage I) to 15.8% (stage II) ($p < 0.01$ adjusted for age, American Society of Anesthesiologists score, and operation time). Similarly, OLE treatment reduced ventilator time (23.7 ± 107.5 hours to 8.5 ± 27.5 hours; $p < 0.05$) and hospital LOS (8.4 ± 7.9 days to 6.8 ± 5.0 days; $p < 0.05$). No differences in ICU LOS, pneumonia, or mortality were observed.

CONCLUSIONS: Aggressive treatment with OLE reduces PPCs and resource use in high-risk surgical patients. (J Am Coll Surg 2019;229:458−466. © 2019 by the American College of Surgeons. Published by Elsevier Inc. on behalf of the American College of Surgeons. This is an open access article under the CC BY-NC-ND license [http://creativecommons.org/licenses/by-nc-nd/4.0/].)

Postoperative pulmonary complications (PPCs) result in significant morbidity, mortality, and healthcare costs. The incidence of "important" PPCs is 2% to 5% in the general surgical population. These consist of respiratory infection, respiratory failure, atelectasis, prolonged invasive mechanical ventilation, prolonged high-level

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Abbreviations and Acronyms

ASA = American Society of Anesthesiologists
CHFO = continuous high-frequency oscillation
CPAP = continuous positive airway pressure
CPEP = continuous positive expiratory pressure
LOS = length of stay
OLE = oscillation and lung expansion
PPC = postoperative pulmonary complication
PSHA = post-surgical hospital admission

respiratory support, and readmission to the ICU for pulmonary complications. However, additional patient factors and types of surgical procedures can increase the risks for PPCs. Pulmonary complications are especially common after thoracic and upper abdominal operations. Other risk factors include advanced age, higher American Society of Anesthesiologists (ASA) physical status classification scores, functional dependency, congestive heart failure, COPD, smoking history, and BMI $\geq$30 kg/m^2. Of these, ASA score $\geq$2 and functional dependency have consistently been associated with a higher rate of significant PPCs, such as postoperative respiratory failure. Occurrence of postoperative respiratory failure requiring prolonged mechanical ventilation or re-intubation accounts for poor outcomes and high economic costs.[1-5]

Although PPCs are an incompletely understood multifactorial occurrence, atelectasis is recognized as a critical component.[6] Evidence suggests that atelectasis is a common precursor of PPCs. Nearly all patients undergoing major operations experience some degree of transitory, clinically unimportant atelectasis. Most do not require aggressive therapy. However, in subgroups of high-risk individuals, treatment of atelectasis and mobilization of secretions can help prevent deterioration to postoperative respiratory failure.[7]

A variety of strategies have demonstrated therapeutic benefits reducing the risks for postoperative atelectasis. These include optimal analgesia, judicious use of respiratory-depressing medications, and selective use of nasogastric decompression. In patients at higher risk for complications, secretion mobilization techniques and lung expansion therapies might be indicated.[6-9] Lung expansion devices that provide either oscillating airflow or positive expiratory pressure therapy have been used for more than 25 years.[10-32] Those using continuous positive airway pressure (CPAP) have shown therapeutic benefits in high-risk hypoxemic patients.[33,34] In a meta-analysis, Qaseem and colleagues[34] found that lung expansion therapies reduced PPCs by >50% compared with no treatment. Delivering oscillating airflow with positive expiratory pressure can facilitate mucous clearance, promote lung expansion, and enhance aerosol delivery. This combination of oscillation and lung expansion (OLE) could represent an important adjunct to help reduce PPCs.

Preliminary evidence suggests use of OLE can be effective in postoperative patients prone to atelectasis and PPCs.[35] The primary objective of this study was to determine if treatment with OLE reduces rate of pulmonary complications in high-risk postoperative patients compared with standard treatment alone.

METHODS

Study design

IRBs at each site approved the protocol. Informed consent was waived for stage I/retrospective cohort and obtained for stage II/prospective patients. This was a nonrandomized pre-post intervention study (Fig. 1). Three academic facilities that had not previously used OLE conducted the study in patients undergoing open thoracic, aortic, or upper abdominal operations.

For the stage I retrospective cohort, CPT, ICD-9, and ICD-10 codes for thoracic, upper abdominal, and aortic procedures were queried to screen for 761 appropriate patients. From this group, patients were then randomly selected based on predefined entry criteria. Data were collected for patients who met inclusion criteria, for open thoracic, upper abdominal and aortic procedures. These patients received incentive spirometry but no OLE therapy. Data from 210 randomly selected patients were collected (70 patients from each site). At all sites, additional respiratory treatment was provided based on patient's clinical indication and attending physicians' preference. Stage I included patients randomly selected from a year before stage II. This allowed inclusion of patients from a seasonally consistent and contemporaneous period. The purpose was to determine the incidence of PPCs in patients receiving standard care. This group provided the control group for comparison with the stage II practice change cohort.

Stage II began after implementation of a practice change. Eligible patients received therapy with OLE in addition to standard care. Demographic, clinical, and outcomes data for 209 patients were collected. Outcomes were tracked for each day from post-surgical hospital admission (PSHA) through postoperative day 7. Total ICU length of stay (LOS), hospital LOS, and length of

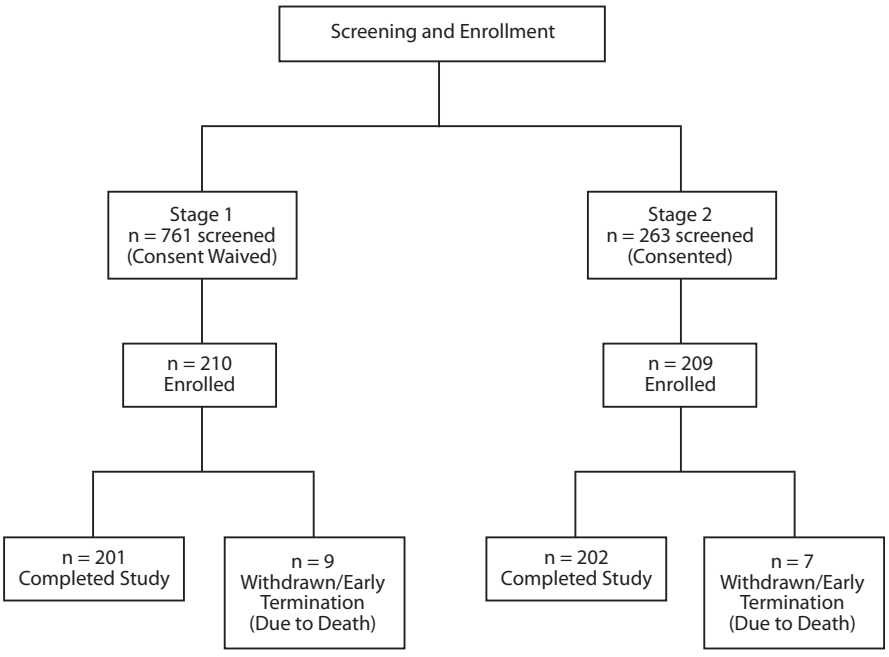

Figure 1. Study design.

time on mechanical ventilation were determined. Readmission after 30 days was captured, a timeline showing data procedures and collection points is available in the eTable 1.

Study participants

Post-thoracic, post-upper abdominal, and post-aortic surgical patients at least 18 years old and deemed high-risk (as defined by ASA class $\geq$3 or ASA class 2 and 1 or more of the following: current smoker or smoking history within past 6 months; history of COPD; documented obesity and/or BMI $\geq$30 kg/m^2; aged 75 years or older) were eligible. Surgical procedures were opened with incisions at or above the umbilicus. Patients were excluded for contraindication to OLE therapy (eg untreated tension pneumothorax), organ transplantation, spinal operation involving a posterior approach, minimally invasive or a "scopic" procedure, and if they were on positive pressure ventilation at baseline.

Study device

The device used in the study was The MetaNeb System (Hill-Rom). It consists of a pneumatic compressor that delivers OLE therapy using both continuous high-frequency oscillation (CHFO) and continuous positive expiratory pressure (CPEP). It is recommended for mobilization of secretions, lung expansion, and treatment and prevention of pulmonary atelectasis. The device also provides supplemental oxygen when used with compressed oxygen and can deliver aerosol therapy during CPEP and/or CHFO.

Treatment regimen

Only patients in stage II received treatment with OLE in addition to standard care. For intubated patients, treatment regimen consisted of in-line therapy with OLE with the ventilator 6 times per day (q4h) in CHFO mode only. Non-intubated patients received therapy with OLE 4 times per day via a mouthpiece or mask, alternating between CHFO and CPEP mode. The target duration of each treatment was 10 minutes, for a minimum of 48 hours. The CHFO and CPEP treatment settings and duration were adjusted based on patient tolerance, at the discretion of healthcare providers.

Outcomes measures

The primary end point for the study was rate of significant PPCs. A significant PPC was defined as occurrence of 1 or more of the following within 7 days of the PSHA: prolonged invasive mechanical ventilation (>24 hours from PSHA); prolonged high-level respiratory support oxygen requirement of >40% or >5 L/min via nasal cannula (and above patient's baseline), and/or requirement for non-invasive ventilation or CPAP above patient's baseline requirement for more than 24 hours of PSHA; diagnosis of pneumonia (pneumonia was defined based on CDC criteria consisting of new lung infiltrate plus new onset of fever, purulent sputum, leukocytosis,

and decline in oxygenation; the diagnosis of pneumonia was performed by directional sputum specimen or bronchoalveolar lavage, depending on institutional standard of practice); and readmission to the ICU (or transfer to an elevated level of care) for pulmonary complications.

Secondary end points included patient requirement for invasive mechanical ventilation for more than 48 hours, requirement for prolonged high-level respiratory support for more than 48 hours, total time on mechanical ventilation, time to extubation, ICU LOS, hospital LOS, and readmissions to the hospital, for any cause, within 30 days of discharge.

Statistical analyses

The primary analysis was performed using intent-to-treat methodology. Descriptive statistics were calculated for demographics, medical history, and primary and secondary end points. Time to event data (eg time to readmission) was calculated using unadjusted Cochran-Mantel Haenszel for survival data. The 95% CI was computed for the primary end point, incidence of significant PPCs. Incidence rates for various demographic subsets and operation types were also computed. Stage I and stage II incidence rates were compared to identify any statistical associations that can be attributed to use of OLE. Data are reported as mean ± SD and adjusted analyses used analysis of covariance (adjustment for age, operation duration, and ASA score).

RESULTS

Patients in stage I and II were similar with respect to baseline demographics and medical history (Table 1). The distribution of the primary operations performed, based on CPT coding, was similar between the groups (Table 2). However, stage II patients tended to be older by a mean of 3.7 years ($p < 0.05$). The proportion of patients with an ASA score of 4 or 5 was higher in stage II (24.9%) compared with stage I (17.6%; $p < 0.05$). Preoperative respiratory status was similar between the 2 stages, although more stage II patients were on CPAP before the operation compared with stage I patients (Table 3). There were more thoracic and aortic surgical procedures in stage II compared with stage I ($p < 0.0001$), and mean operation duration was higher in stage II period ($p = 0.07$) (Table 3).

In stage I, 22.9% of patients experienced ≥1 PPC compared with 15.8% in stage II, a 7.1% absolute reduction in PPCs ($p = 0.06$). After adjusting for age, ASA score, and operation duration, reduction in PPCs was statistically significant (Table 4).

Table 1. Patient Demographics and Illness Characteristics by Stage

Demographic or characteristic	Stage I (n = 210)	Stage II (n = 209)
Age, y		
Mean ± SD	57.4 ± 15.48	61.1 ± 13.72
Median (min, max)	58.5 (18, 95)	63.0 (23, 85)
Sex, n (%)		
Male	115 (54.8)	131 (62.7)
Female	95 (45.2)	78 (37.3)
Race, n (%)		
White	168 (80.0)	177 (84.7)
Black or African American	32 (15.2)	29 (13.9)
Asian	1 (0.5)	2 (1.0)
Other	8 (3.8)	1 (0.5)
Missing	1 (0.5)	0
Ethnicity, n (%)		
Hispanic or Latino	5 (2.4)	7 (3.3)
Not Hispanic or Latino	203 (96.7)	201 (96.2)
Missing	2 (1.0)	1 (0.5)
Asthma, n (%)		
Yes/no	26/183 (12.4)	22/187 (10.5)
Missing	1	0
COPD, n (%)		
Yes/no	28/181 (13.3)	33/176 (15.8)
Missing	1	0
Obstructive sleep apnea, n (%)		
Yes/no	31/178 (14.8)	42/167 (20.1)
Missing	1	0
Smoking, n (%)		
Yes/no	46/159 (21.9)	47/162 (22.5)
Missing	5	0
Documented obesity, n (%)		
Yes/no	83/126 (39.5)	101/108 (48.3)
Missing	1	0
Baseline ASA score, n (%)		
ASA 2 + comorbidity	26 (12.4)	24 (11.5)
ASA 3	147 (70.0)	133 (63.6)
ASA 4/ASA 5	37 (17.6)	52 (24.9)

ASA, American Society of Anesthesiologists.

The main contributor to PPC rate was prolonged mechanical ventilation after PSHA, but within 7 days of PSHA (Table 4). The portion of patients requiring prolonged (>24 hours) mechanical ventilation after PSHA was 12.9% in stage I and 8.1% in stage II. Patients requiring prolonged (>24 hours) high-level respiratory support decreased from 13.8% in stage I to 11.5% in stage II. In addition, there were 17 patients who had ≥2 PPCs in stage I and 14 patients in stage II. There was no difference in pneumonia or the number

Table 2. Number of Surgical Procedures by System

Surgical procedure (CPT code range)	Stage I (n = 210)	Stage II (n = 209)
Cardiovascular system (33010–37799)	20	43
Digestive system (40490–49999)	144	109
Endocrine system (60000–60699)	1	3
Hemic and lymphatic systems (38100–38999)	5	8
Integumentary system (10030–19499)	2	0
Musculoskeletal system (20100–29999)	7	3
Respiratory system (30000–32999)	7	22
Urinary system (50010–53899)	24	21

readmitted to the ICU or transferred to higher level of care between the 2 stages (Table 4). Of importance, patients with higher ASA scores had the largest reduction in PPCs (Fig. 2).

As a secondary end point, the number of patients requiring prolonged (>48 hours) mechanical ventilation in stage I vs stage II were 19 (9.0%) and 14 (6.7%), respectively. Similarly, the number of patients requiring prolonged (>48 hours) respiratory support was 21 in stage I and 19 in stage II. Differences were not statistically significant.

Mean reduction in hospital LOS was 1.62 days ($p < 0.02$) (Table 5). The decrease in hospital LOS was greater among patients who were intubated (stage I n = 53, stage II n = 60), with an observed mean reduction of 4.85 days ($p < 0.05$). A greater difference was observed after adjustments for age, ASA score, and operation duration by analysis of covariance.

Table 3. Patient Preoperative Respiratory Status and Operation Information

Respiratory status and operation information	Stage I (n = 210)	Stage II (n = 209)
Mechanical non-invasive ventilation administered before operation, n (%)	1 (0.5)	1 (0.5)
CPAP (continuous) administered before operation, n (%)	8 (3.8)	20 (9.6)
Supplemental oxygen administered before operation, n (%)	3 (1.4)	1 (0.5)
Operation type, n (%)		
Thoracic	18 (8.6)	30 (14.4)
Aortic	14 (6.7)	42 (20.1)
Upper abdominal	178 (84.8)	137 (65.6)*
Operation duration, h		
Mean ± SD	3.84 ± 2.30	4.23 ± 2.05*
Median	3.32	4.07
Min, max	0.4, 13.2	0.8, 11.9

*$p < 0.05$ compared with stage I cohort.
CPAP, continuous positive airway pressure.

The ICU LOS decreased by 2.04 days in stage II (Table 5). The reduction in ICU LOS was greater among patients who were intubated (stage I n = 53, stage II n = 60), with an observed mean reduction of 3.86 days. Differences were not statistically significant.

Mean reduction for time to initial extubation, from stage I to stage II, was 46.9 hours ($p < 0.02$) (Table 5). Similarly, mean reduction for total time on mechanical ventilation was 64.4 hours ($p < 0.02$). In addition, for intubated patients, there was an absolute PPC rate reduction of 33.1% in stage II patients.

Mortality rates were similar in the 2 stages. There was a total of 16 deaths in the study (9 in stage I and 7 in stage II). All stage II deaths were deemed unlikely/not related to the study device per the site principal investigators. Cause of subject deaths is available in eTable 2.

Number of patients readmitted to hospital, for any cause, within 30 days of discharge was 36 (17.1%) in stage I vs 28 (13.4%) in stage II.

Compliance to treatment regimen (stage II)

The study protocol called for each patient to receive OLE treatment approximately 4 hours from PSHA. More than 85% of enrolled patients received therapy within 6 hours. Study regimen called for patients to receive 4 or more OLE treatments within the first 40 hours of PSHA. Mean ± SD number of treatments was 5.0 ± 2.1, and 76.6% (160 of 209) of enrolled patients met the goal.

Adverse events

Two events were deemed possibly related to the device. The first was intolerance of OLE postoperative day 0. This event was deemed not serious. Therapy resumed 8 hours thereafter. The second event was pneumonia on postoperative day 3, deemed serious, but resolved by discharge.

DISCUSSION

This multicenter prospective trial evaluated integration of OLE into standard postoperative respiratory therapy in high-risk patients undergoing open thoracic, aortic, or upper abdominal operations.

The precise definition of PPC remains controversial. Reported incidence varies from 2% to 40%.[6] In 2015, a European Perioperative Clinical Outcome task force recommended a definition of PPC including respiratory infection, respiratory failure, pleural effusion, atelectasis, pneumothorax, bronchospasm, aspiration pneumonitis,

Table 4. Postoperative Pulmonary Complications

Variable	Stage I	Stage II	p Value*	p Value†
Total number of patients, n	210	209	—	—
Patients with ≥1 PPC, n (%)	48 (22.9)	33 (15.8)	0.06	0.007
Prolonged mechanical ventilation >24 h, n (%)	27 (12.9)	17 (8.1)	—	—
Prolonged high-level respiratory support >24 h, n (%)	29 (13.8)	24 (11.5)	—	—
Pneumonia	3 (1.4)	3 (1.4)	—	—
Readmission ICU, higher-level care, n (%)	5 (2.4)	5 (2.4)	—	—

*Unadjusted Cochran-Mantel-Haenszel.
†Analysis of covariance, adjusting for age, American Society of Anesthesiologists, and operation duration.
PPC, postoperative pulmonary complication.

acute respiratory distress syndrome, pulmonary edema, and pulmonary embolism.[36] In the current study, PPCs consisted of the following clinically relevant parameters: prolonged invasive mechanical ventilation, prolonged high-level respiratory support, requirement for noninvasive ventilation or CPAP above patient's baseline, diagnosis of pneumonia, and readmission to the ICU (or transfer to higher level of care) for pulmonary complications. Our stage I cohort had a 22.9% incidence of PPCs, comparable with previous studies. In addition, our definition of high-risk patients—incorporating types of surgical procedure, age, comorbidities, and ASA scores—is consistent with risk stratification models reported in the literature.[5,37] Although the pathophysiology of PPCs is unclear and likely multifactorial, atelectasis and diminished mucous clearance constitute critical components.[38]

Aggressive pulmonary care in high-risk patients has potential to improve outcomes. However, although postoperative mobilization, chest physiotherapy, and oral hygiene bundles have been associated with reduced PPCs, evidence remains limited.[38] In addition, practices, including multimodal analgesic regimen, judicious prescription of narcotics, selective use of nasogastric decompression, and secretion mobilization techniques, can provide clinical benefits; yet these modalities have not been evaluated systematically. Lung expansion therapy shows the most promising results in reducing PPCs.[34]

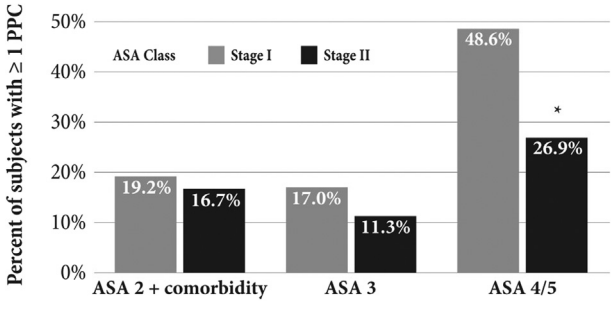

Figure 2. Postoperative pulmonary complication (PPC) rate by American Society of Anesthesiologists (ASA) class. *p = 0.02.

In the current healthcare climate, patients demand better outcomes, payers require value-based performance (eg decreased ICU LOS, hospital LOS, and reduced costs), and health agencies and advocacy groups mandate transparency and public reporting of quality and safety measures. Clinical providers and healthcare systems face escalating pressure to deliver high-quality care at greater value. The provision of value-based healthcare requires the best outcomes with fewest complications. The Center for Medicare and Medicaid, the Institute of Medicine, the Joint Commission, federal agencies, and industries require healthcare systems to measure and report surgical outcomes. Postoperative ventilation longer than 48 hours and hospital LOS after major operations represent important quality measures mandated by the American College of Surgeons NSQIP. As such, reducing PPCs, ventilator days, and hospital LOS constitute vital quality targets for healthcare systems to achieve best practices and to remain competitive.

In this study, we delivered lung expansion using OLE. In patients who remained intubated postoperatively, our data demonstrated that the number of patients who experience ≥1 PPC decreased from 69.8% to 36.7%. Importantly, the number of patients requiring prolonged mechanical ventilation decreased from 50.9% to 28.3%. Incidence of pneumonia (1.4% in each cohort), readmission to higher level care (2.4% in each cohort), and 30-day mortality (3.9% overall) did not differ between groups. Incidence of these outcomes was low and our study was not adequately powered to examine these end points. We did not observe a reduction in ICU LOS. Although the median reduction was 2 days, 2 patients in the stage I cohort had long ICU stays (more than 40 days). This rendered the ICU outcomes nonstatistically significant. In addition, the inclusion of these 2 patients in the stage I cohort might have affected the hospital LOS analysis by disproportionally increasing the overall hospital LOS of the stage I group. Because of the concern about the impact of outliers, we conducted additional nonparametric (Wilcoxon) analysis, and the

Table 5. Mechanical Ventilation and Length of Stay End Points

End point	Stage I	Stage II	p Value*	p Value†
Total no. of patients, n	210	209	—	—
Mechanical ventilation				
No. of patients	53	60	—	—
Time to initial extubation, h				
Mean ± SD	73.56 ± 136.05	26.61 ± 41.15	<0.02	<0.05
Median	20.4	11.3	—	—
Min, max	1.4, 806.3	1.5, 213.1	—	—
Time on mechanical ventilation, h				
Mean ± SD	94.06 ± 199.20	29.70 ± 44.81	<0.02	<0.02
Median	21.8	12.3	—	—
Min, max	1.4, 1134.6	1.5, 213.1	—	—
ICU LOS				
No. of patients	82	79	—	—
Mean ± SD, d	5.39 ± 8.66	3.35 ± 3.46	NS	NS
Median, d	2.0	2.2	—	—
Min, max, d	0.3, 50.3	0.3, 16.1	—	—
Hospital LOS				
No. of patients	210	209	—	—
Mean ± SD, d	8.40 ± 7.90	6.78 ± 4.98	<0.02	<0.02
Median, d	6.59	5.51	—	—
Min, max, d	0.3, 67.7	0.8, 42.2	—	—

*Unadjusted Cochran-Mantel-Haenszel.
†Analysis of covariance, adjusting for age, American Society of Anesthesiologists, and operation duration.
LOS, length of stay.

difference in hospital LOS remained statistically significant ($p = 0.03$). Although we did not examine financial data, reduction in PPCs might have provided cost savings. Cost of inpatient hospitalization has been reported at $2,300 per day.[39] Cost of ICU stay is estimated at $10,800 per day for mechanically ventilated patients.[40] Based on these estimates, savings from reduced hospital LOS in our study might be up to $10,800 per patient.

We acknowledge that daily sedation interruption, early mobilization, or other clinical practices might have changed during the course of the 31-month study period. However, except for adding OLE, none of the 3 institutions reported alterations in care for postoperative patients. We also acknowledge that, due to the non-randomized nature of our study, the 2 cohorts of patients might not be entirely comparable. However, the stage II cohort, who received OLE, were older, had higher ASA scores, longer operation duration, and included more thoracic and aortic procedures compared with stage I. As such, our results might underestimate the magnitude of effect for OLE. To account for seasonality differences, the stage I screening list was randomly sorted before patient selection. Operation dates for stage I ranged from December 2014 to April 2016, and stage II from October 2016 to July 2017. Overall, the distribution of operation dates was similar. Introduction of the OLE modality might have created inherent bias in stage II cohort of patients. Due to the before-after non-randomized design of the study, this confounder is perhaps unavoidable. That stated, our ICUs are staffed by multiple providers rotating on a weekly basis, the respiratory treatments were episodic, and only the principal investigators for each site had in-depth knowledge of the study; we believe these factors might have helped mitigate some of the confounding effects.

CONCLUSIONS

Our study demonstrated that patients who received treatment with OLE experienced fewer PPCs and had less time on mechanical ventilation. In addition, incorporating OLE resulted in a significant reduction in hospital LOS. Importantly, patients with higher ASA scores had the largest PPC reduction.

The results suggest the modality is feasible and can help achieve value-based quality care for surgical patients. In addition, other disease entities with a high likelihood of pulmonary complications should be considered for future OLE studies, including those admitted after blunt chest trauma, COPD exacerbation, cystic fibrosis, and pneumonia.

Author Contributions

Study conception and design: Liesching, Diette
Acquisition of data: Lei, Nahouraii, Frazer
Analysis and interpretation of data: Huynh, Liesching, Cereda, Diette
Drafting of manuscript: Huynh

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eTable 1. Data Procedures and Collection

Data collected	Preoperation	Day of operation	Postoperation days 1–7	Hospital discharge	Early term	Day 30 post-discharge
Selection criteria/enrollment	X					
Demographic data	X					
Medical history	X					
Informed consent*	X					
Baseline respiratory status	X					
Postoperative data on day of operation		X				
Patient location (admission unit, transfer unit)		X	X	X		
Respiratory status (7:00 AM and 7:00 PM)		X	X			
Respiratory treatment and milestone		X	X			
Hospital discharge summary				X		
30-d review for readmission(s) post-discharge					X	X
Study exit					X	X

*Informed consent was obtained for patients in stage II only.

eTable 2. Causes of Patient Deaths

Stage I (n = 9)	Stage II (n = 7)
Complication from pancreatic cancer	Acute respiratory distress syndrome
Intra-abdominal infection from untreated diffuse large B-cell lymphoma	Diffuse anoxic brain injury
Pneumatosis intestinalis	Cardiac arrest, cause unspecified
Cardiomyopathy; cardiac arrest	Cardiac death
Inflammatory response syndrome due to aortic aneurysm	Cause of death is unknown
Cardiorespiratory failure	Aspiration
Respiratory failure	Cardiac arrest
Hemorrhage-intracranial not otherwise specified	
Respiratory arrest, hepatic failure	