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# Evaluation of Safety and Short-term Outcomes of Therapeutic Rigid Bronchoscopy Using Total Intravenous Anesthesia and Spontaneous Assisted Ventilation

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**Keywords**
Rigid bronchoscopy · Anesthesia · Spontaneous assisted ventilation · Neuromuscular blockade

**Abstract**
***Background:*** There is a paucity of published data regarding the optimal type of anesthesia and ventilation strategies during rigid bronchoscopy. ***Objective:*** The aim of our study is to report the procedural and anesthesia-related complications with rigid bronchoscopy using total intravenous anesthesia and spontaneous assisted ventilation. ***Methods:*** A retrospective review of patients undergoing therapeutic rigid bronchoscopy at the University of Chicago between October 2012 and December 2014 was performed. Data were recorded relating to patients' demographics, comorbidities, type of anesthesia, need for neuromuscular blockade (NMB), intraoperative hypoxemia, hypotension, perioperative adverse events, and mortality. ***Results:*** Fifty-five patients underwent 79 rigid bronchoscopy procedures; 90% were performed for malignant disease and 90% of patients had an American Society of Anesthesiologists (ASA) class III or IV. The majority (76%) did not require use of NMB. The most common adverse events were intraoperative hypoxemia (67%) and hypotension (77%). Major bleeding and postoperative respiratory failure occurred in 3.8 and 5.1% of procedures, respectively. There was no intraoperative mortality or cardiac dysrhythmias. The 30-day mortality was 7.6% and was associated with older age, inpatient status, congestive heart failure, home oxygen use, and procedural duration. Intraoperative hypoxemia, hypotension, and ASA class were not associated with 30-day mortality. The majority (94%) of patients were discharged home. The use of NMB did not impact outcomes. ***Conclusions:*** This study suggests that therapeutic rigid bronchoscopy can be safely performed with total intravenous anesthesia and spontaneous assisted ventilation in patients with central airway obstruction, significant comorbidities, and a high ASA class. The only significant modifiable variable predicting the 30-day mortality was the duration of the procedure.





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## Introduction

Therapeutic rigid bronchoscopy is performed to improve symptoms and quality of life in patients suffering from benign and malignant central airway obstruction (CAO) [1]. Unlike flexible bronchoscopy, rigid bronchoscopy requires deep sedation or general anesthesia, typically with the aid of neuromuscular blockade (NMB) and mechanical ventilation [2]. There is no consensus regarding the optimal anesthetic approach to therapeutic interventional rigid bronchoscopy in adults suffering from CAO.

Some anesthesiologists continue to recommend the use of general anesthesia and NMB for rigid bronchoscopy while others prefer spontaneous assisted ventilation (SAV). The rationale for the use of NMB is that it provides a "quiet field" for the operator and complete control of ventilation by the anesthesiologist. Over the last decades, however, it has become evident that in patients undergoing a wide variety of surgical procedures, residual NMB is a contributing factor to adverse events including delayed discharge from recovery, need for tracheal reintubation, impaired oxygenation and ventilation, aspiration, atelectasis, and pneumonia [3–10]. These effects are likely mediated by decreased airway tone and impaired respiratory effort persisting during recovery from anesthesia [11, 12]. Despite awareness of this problem, residual NMB after anesthesia remains a common adverse event and has been a focus of initiatives by the Anesthesia Patient Safety Foundation as recently as February 2016 [13]. With the introduction of neuromuscular blocker selective reversal agents (i.e., sugammadex), the concerns of residual NMB may no longer be justified in the near future; however, these drugs are not yet standard practice globally [14, 15] and were not used in our practice during the study period. In addition, intraoperatively, the use of NMB can convert a critical airway obstruction into a complete obstruction due to expected central airway collapse, potentially resulting in an inability to visualize the residual airway lumen and leading to airway emergencies.

On the other hand, during the use of SAV without NMB during these procedures, while the incidence of severe hypoxemia may be less frequent, the role of the anesthesiologist becomes more challenging as the depth of anesthesia must be continuously monitored and adjusted to balance patient safety and operator comfort. From a technical standpoint the procedure can be more challenging without NMB, as there could be significant movement of the target airway lesion during respiration. It is noteworthy, however, that many of the large original studies evaluating rigid bronchoscopy were performed with SAV without NMB but the actual procedural or anesthesia-related complications were not the main reported outcomes [16–18]. In fact, in the last 25 years, only scattered case reports and small case series have been published on the role of different anesthetic techniques for rigid bronchoscopy in the adult population [19, 20]. Herein, we review procedural and anesthesia-related complications in patients undergoing rigid bronchoscopy with total intravenous anesthesia (TIVA) and SAV at a single institution.

## Materials and Methods

We conducted a retrospective evaluation of patients undergoing therapeutic rigid bronchoscopy at the University of Chicago between October 2012 and December 2014. The medical records were reviewed and data regarding the clinical indication for the procedure, demographics, and comorbid conditions were collected. The operative report and anesthetic record from each procedure was reviewed and details of the procedure, anesthetic approach, intraoperative hemodynamic and respiratory parameters, and postoperative outcomes were collected.

*Surgical Technique*

All procedures were performed using Efer-Dumon rigid bronchoscopes (Bryan Corp., Woburn, MA, USA) in the operating room under general anesthesia by a single attending bronchoscopist (S.M.). This system allows for use of silicone-plastic caps, partially sealing the telescope and working channel and reducing circuit leak. After the induction of anesthesia, direct laryngoscopy was performed to facilitate the application of topical lidocaine to the larynx, vocal cords, and proximal trachea. The rigid bronchoscope was then used to directly intubate the trachea after which the side port of the bronchoscope was connected to the ventilator. The teeth were protected with a gauze pad, and the mouth and nasal passages were packed with gauze to further minimize circuit leak.

*Anesthesia Technique*

All attempts were made by the participating anesthesiologists managing these patients to maintain SAV and avoid the use of NMB. A wide variety of modes of anesthesia and ventilation were employed, including the use of volatile inhalational anesthetics (used only during induction of anesthesia) and intravenous anesthetics via continuous infusion or intermittent injection. The choice of anesthetic agent was left to the discretion of the treating anesthesiologist. NMB was used to facilitate the surgical procedure only in cases of refractory coughing and/or biting despite maximum doses of intravenous anesthetic agents. Vasoactive drugs were administered at the discretion of the anesthesiologist to treat hypotension.

*Definitions*

Major bleeding was defined as greater than 200 mL of blood loss as noted in the wall suction canister and documented in the

bronchoscopy report. Intraoperative hypoxemia was defined as any oxygen saturation less than 90% for greater than 1 min [21–23]. Intraoperative hypotension was defined as any systolic blood pressure less than 100 mm Hg [24]. Postoperative respiratory failure was defined as the need for positive pressure ventilation or an increase in oxygen requirement compared with the preoperative levels.

*Statistical Analysis*

For binary outcomes, association with the outcomes and the covariate of interest was evaluated with a $\chi^2$ test or Fisher's exact test for categorical variables as appropriate, or a Wilcoxon-Mann-Whitney two-sample test for continuous variables. All statistical analysis was performed using Stata Statistical Software: Release 12 (StataCorp LLC, College Station, TX, USA).

## Results

A total of 55 patients underwent 79 interventional therapeutic rigid bronchoscopy procedures. The mean age of the patients was 64 years. Seventy percent of these procedures were performed on outpatients. The majority of procedures (89.9%) were performed for malignant CAO, with lung cancer being the etiology in 38 cases. The mean American Society of Anesthesiologists (ASA) physical status score was 3.2, with comorbid pulmonary and cardiac conditions being common. Table 1 describes the baseline demographic and clinical characteristics of the patient population.

*Rigid Bronchoscopy*

Endoluminal thermal ablative techniques were frequently used (67 procedures, 84.8%), either in the form of neodymium-doped yttrium aluminum garnet (Nd:YAG) laser or argon plasma coagulation (APC). The mean operative duration was 86.5 min. A total of 17 airway stents were placed during 16 cases. Table 2 describes the details of the bronchoscopic procedures based on whether NMB was used or not during the intervention.

*Anesthesia*

Of the 79 procedures, 18 (23%) utilized volatile inhalational anesthetics during the induction of anesthesia. Propofol infusion was used in all cases, with additional intermittent injections given as needed. NMB was completely avoided in 60 procedures (76%). Of the 19 procedures requiring NMB, in 6 instances neuromuscular blockers were given exclusively during induction. Vasoactive medications were administered in 49 cases. Table 3 describes the details of the anesthetic technique for the procedures.

**Table 1.** Demographics and clinical characteristics ($n$ = 79)

| | |
|---|---|
| Age, years | 64.2±10.5 |
| Height, cm | 168±10.6 |
| Weight, kg | 67.9±17.2 |
| Inpatient | 24 (30.4) |
| ASA score | 3.2±0.6 |
| ASA 2 | 8 (10.1) |
| ASA 3 | 48 (60.8) |
| ASA 4 | 23 (29.1) |
| Comorbidities | |
| COPD | 33 (44.0) |
| Home oxygen | 26 (32.9) |
| Tobacco abuse | 47 (59.5) |
| OSA | 3 (3.8) |
| CAD | 23 (29.1) |
| CHF | 8 (10.1) |
| Atrial fibrillation | 6 (7.6) |
| Diabetes mellitus | 20 (25.3) |
| Hypertension | 45 (57.0) |
| Anemia | 26 (32.9) |
| Etiology of airway obstruction | |
| Malignancy | 71 (89.9) |
| Benign | 8 (10.1) |
| Malignancy type[a] | |
| Lung | 38 (53.5) |
| NSCLC | 27 (38) |
| Small cell lung cancer | 2 (2.8) |
| Other | 9 (12.7) |
| GI/GU | 14 (19.7) |
| Other | 19 (26.8) |

Data are presented as mean ± standard deviation or $n$ (%). ASA, American Society of Anesthesiologists; CAD, coronary artery disease; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; GI, gastrointestinal; GU, genitourinary; NSCLC, non-small cell lung cancer; OSA, obstructive sleep apnea. [a] Percentages are based on a total of 71 cases of malignant airway obstruction.

*Complications*

Intraoperative hypoxemia and hypotension were common, seen in 67.1 and 77.2% of procedures, respectively (Table 2). Major bleeding was seen in 3 cases. There were no episodes of cardiac dysrhythmias. Postoperative respiratory failure occurred in 4 patients (5.1%), 3 of whom required escalation of care in the form of application of positive pressure ventilation. The majority of patients (75/79 cases, 94.4%) were discharged home.

On univariate analysis, clinical factors associated with intraoperative hypoxemia included a malignant etiology for CAO and pre-existing coronary artery disease ($p$ = 0.014 and $p$ = 0.018, respectively). Procedural factors associated with intraoperative hypoxemia included the placement of an airway stent and a procedure duration

**Table 2.** Procedural details, complications, and outcomes

| | All cases ($n$ = 79) | No NMB ($n$ = 60) | NMB used ($n$ = 19) | $p$ value |
|---|---|---|---|---|
| Procedure duration, min | 86.5±42.7 | 86.1±43.3 | 87.8±41.6 | 0.88 |
| Stent placed[a] | | | | |
| Any stent | 16 (20.3) | 15 (25) | 2 (10.5) | 0.87 |
| Silicone | 2 (2.5) | 2 (3.3) | 0 (0) | |
| SEMS | 15 (19) | 14 (23.3) | 2 (10.5) | |
| Ablative technique[b] | | | | |
| Any ablative technique | 67 (84.8) | 53 (88.3) | 14 (73.7) | 0.148 |
| Nd:Yag laser | 55 (69.6) | 46 76.7) | 9 (47.4) | 0.016 |
| APC | 34 (43) | 28 (46.7) | 6 (31.6) | 0.296 |
| Balloon dilation | 6 (7.6) | 6 (7.6) | 0 (0) | 0.327 |
| Procedural complications | | | | |
| Major bleeding | 3 (3.8) | 1 (1.7) | 2 (10.5) | 0.153 |
| Requiring intervention | 1 (1.3) | 0 (0) | 1 (5.3) | 0.241 |
| Any respiratory failure | 4 (5.1) | 2 (3.3) | 2 (10.5) | 0.243 |
| Requiring PPV | 3 (3.8) | 1 (1.7) | 2 (10.5) | 0.142 |
| Cardiac arrest/arrhythmia | 0 (0) | 0 (0) | 0 (0) | |
| Death within 24 h | 0 (0) | 0 (0) | 0 (0) | |
| Intraoperative hypoxemia | 53 (67.1) | 40 (66.7) | 13 (68.4) | 0.99 |
| Intraoperative hypotension | 61 (77.2) | 46 (76.7) | 15 (78.9) | |
| 30-day mortality | 6 (7.6) | 4 (6.7) | 2 (10.5) | 0.63 |
| Disposition | | | | |
| Home | 75 (94.9) | 58 (96.7) | 17 (89.5) | 0.46 |
| SNF | 2 (2.5) | 1 (1.7) | 1 (5.3) | |
| Death in hospital | 2 (2.5) | 1 (1.7) | 1 (5.3) | |

Data are presented as mean ± standard deviation of $n$ (%). APC, argon plasma coagulation; Nd:Yag, neodymium-doped yttrium aluminum garnet; PPV, positive pressure ventilation; SEMS, self-expanding metallic stent; SNF, skilled nursing facility. [a] One case included placement of both a silicone stent and self-expanding metallic stent. [b] More than one ablative technique may have been used for an individual case.

greater than 100 min ($p$ = 0.002 and $p$ < 0.001, respectively). There were no clinical or procedural variables significantly associated with intraoperative hypotension. The intraoperative use of NMB was not significantly associated with any of the studied adverse outcomes including hypoxemia, respiratory failure, hypotension, or mortality ($p$ > 0.05). No clinical variables were associated with the development of major bleeding or respiratory failure ($p$ > 0.05).

*30-Day Mortality*

Among the 79 rigid bronchoscopies, 6 patients (7.6%) died within 30 days of the procedure. On univariate analysis the following characteristics were associated with 30-day mortality: older age ($p$ = 0.03), inpatient status ($p$ = 0.009), pre-existing congestive heart failure ($p$ = 0.012), pre-existing home oxygen use ($p$ = 0.013), and a longer duration of the procedure ($p$ = 0.04). Intraoperative hypoxemia and hypotension, though common, were not associated with 30-day mortality ($p$ = 0.658 and $p$ = 1.0, respectively). Table 4 summarizes the patients' characteristics and their association with 30-day mortality.

## Discussion

Patients requiring therapeutic rigid bronchoscopy often have multiple comorbidities that may necessitate challenging anesthesia techniques to maintain airway and hemodynamic stability [19, 25, 26]. Many anesthesiologists use general anesthesia with NMB and mechanical ventilation during these procedures because of perceived improved control of cardiorespiratory parameters [27–30]. Although the introduction of neuromuscular blocking drugs was groundbreaking in the 1940s, risks became apparent after years of clinical use. An older study found that 24.1% of patients receiving NMB developed hypox-

**Table 3.** Anesthetic agents and modes of ventilation ($n$ = 79)

| | |
|---|---|
| Inhalational agent | 18 (22.8) |
| Induction only | 17 (21.5) |
| Intravenous anesthetic[a] | |
| Propofol | 79 (100) |
| Propofol, mg | 1,508.4±862.2 |
| Remifentanil | 60 (76) |
| Remifentanil, μg | 509.5±915.6 |
| Fentanyl | 47 (59.5) |
| Fentanyl, μg | 147.9±81.9 |
| Ketamine | 16 (20.3) |
| Ketamine, mg | 12.3±7.8 |
| Dexmedetomidine | 2 (2.5) |
| Dexmedetomidine, μg | 54.9±35.6 |
| Neuromuscular blockade | |
| Any agent used | 19 (24.1) |
| Succinylcholine only | 4 (5.1) |
| Non-depolarizing NMB only | 12 (15.2) |
| Succinylcholine + other NMB | 3 (3.8) |
| No agent used | 60 (75.9) |
| NMB reversal agent | 11 (13.9) |
| Vasopressor use[a] | |
| Any vasopressor | 49 (61.25) |
| Phenylephrine | 45 (57) |
| Phenylephrine, μg | 841±669 |
| Ephedrine | 19 (24.1) |
| Ephedrine, mg | 27.1±19.8 |
| Vasopressin | 8 (10.1) |
| Vasopressin, U | 5.5±4.7 |
| IV fluids, mL | 1,076±553 |
| Modes of ventilation[a] | |
| Spontaneous | 40 (50.6) |
| Manual/assisted | 56 (70.9) |
| Volume cycled | 18 (22.8) |
| Pressure cycled | 14 (17.8) |

Data are presented as mean ± standard deviation or $n$ (%). NMB, neuromuscular blocker; IV, intravenous. [a] An individual case may have used more than one anesthetic agent, vasopressor, or mode of ventilation.

emia and resulted in postoperative respiratory failure requiring intubation in 10% of patients [10]. In fact, mortality may be increased substantially during the perioperative period when these agents are used [31]. It appears that residual NMB during the immediate postoperative period is much more common than appreciated and may contribute to substantial morbidity, including the need for tracheal reintubation, impaired oxygenation/ventilation, impaired pulmonary function, increased risk of aspiration and pneumonia, pharyngeal dysfunction, and delayed discharge from the recovery area [5, 7, 9, 12, 32–36].

**Table 4.** Association with 30-day mortality

| | Alive ($n$ = 73) | Dead ($n$ = 6) | $p$ value |
|---|---|---|---|
| Age, years | 63.3±9.9 | 74.7±13.3 | 0.03 |
| Inpatient | | | |
| Yes | 19 | 5 | |
| No | 54 | 1 | 0.009 |
| ASA | | | |
| ≤3 | 54 | 2 | |
| >3 | 19 | 4 | 0.056 |
| Malignancy | | | |
| Yes | 65 | 6 | |
| No | 8 | 0 | 1 |
| Comorbidities | | | |
| Atrial fibrillation | | | |
| Yes | 4 | 2 | |
| No | 69 | 4 | 0.063 |
| Anemia | | | |
| Yes | 23 | 3 | |
| No | 50 | 3 | 0.389 |
| CAD | | | |
| Yes | 21 | 2 | |
| No | 52 | 4 | 1 |
| CHF | | | |
| Yes | 5 | 3 | |
| No | 68 | 3 | 0.012 |
| Cirrhosis | | | |
| Yes | 1 | 1 | |
| No | 72 | 5 | 0.147 |
| COPD | | | |
| Yes | 32 | 2 | |
| No | 41 | 4 | 0.695 |
| DM | | | |
| Yes | 17 | 3 | |
| No | 56 | 3 | 0.167 |
| Hypertension | | | |
| Yes | 43 | 2 | |
| No | 30 | 4 | 0.394 |
| Tobacco abuse | | | |
| Yes | 43 | 4 | |
| No | 30 | 2 | 1 |
| Home oxygen | | | |
| Yes | 21 | 5 | |
| No | 52 | 1 | 0.013 |
| OSA | | | |
| Yes | 2 | 1 | |
| No | 71 | 5 | 0.213 |
| Procedure duration, min | 83.2±40.4 | 125.8±54.0 | 0.04 |
| Stent placed | | | |
| Yes | 14 | 3 | |
| No | 59 | 3 | 0.11 |
| Any paralytic used | | | |
| Yes | 17 | 2 | |
| No | 56 | 4 | 0.627 |
| Intraoperative hypoxemia | | | |
| Yes | 48 | 5 | |
| No | 25 | 1 | 0.658 |
| Intraoperative hypotension | | | |
| Yes | 56 | 5 | |
| No | 17 | 1 | 1 |

ASA, American Society of Anesthesiologists; CAD, coronary artery disease; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; DM, diabetes mellitus; OSA, obstructive sleep apnea.

In our study, despite our original attempt to complete the procedure without the use of any intraprocedural NMB, in 19 out of 79 procedures (16.5%) we required the use of some period of NMB due to refractory coughing or biting, which impaired our ability to proceed with or continue the intervention. In these patients, intraoperative hypoxemia and hypotension were seen in 68.4 and 78.9% of patients, respectively; this was not significantly different than in those who did not receive NMB. Furthermore, although the number of patients is small, we did not find a significant association between the use of NMB and postoperative respiratory failure or 30-day mortality. This is in agreement with the largest registry study to date on therapeutic bronchoscopy, though that study included both flexible and rigid therapeutic bronchoscopic interventions and did not differentiate between SAV and volume-cycled ventilation [37]. In previous studies on this topic, SAV was found to allow completion of a rigid bronchoscopic procedure with a low rate of postoperative respiratory failure, even in octogenarians and patients with a high ASA class [19, 20]. An older study on rigid bronchoscopy with SAV found that severe intraoperative hypoxemia occurred in 12% of patients (in that study hypoxemia was defined as an oxygen saturation of less than 90% for greater than 30 s or a saturation less than 85% for any duration) [19]. A more recent study reported intraoperative hypoxemia in 25.5% of patients undergoing rigid bronchoscopy with SAV [38]. In our study, the rate of intraoperative hypoxemia was 67.1%, markedly higher than the previous studies [19, 34]. One possible explanation for this disparity was our use of Nd:YAG and APC in 84.8% of our procedures, which requires lowering the fraction of inspired oxygen ($FiO_2$) to below 0.40 when applying these thermal ablative techniques. In the study by Perrin et al. [19], thermal ablation was utilized in 43% of the procedures and $FiO_2$ was decreased to less than 0.50. In the study by Chumpathong et al. [38], thermal ablation was utilized in less than 25% of the procedures and the majority of patients were suffering from benign disease. Our study and these prior reports suggest that the use of thermal ablation, intervention for malignant disease, the placement of an airway stent, as well as preoperative comorbidities (e.g. coronary artery disease) increase the risk of intraoperative hypoxemia. Our study found that intraoperative hypoxemia, though common, was not associated with cardiac dysrhythmias or 30-day mortality ($p = 0.658$ and $p = 0.658$, respectively). This finding is consistent with the prior reports [19, 38]. We also found that the prevalence of intraoperative systolic hypotension was not associated with 30-day mortality ($p = 1.0$). Propofol was used in all our cases. Ketamine infusion preserves respiratory drive and airway reflexes and has profound analgesic properties, and was used in 20.3% cases at the discretion of the anesthesiologist. Opioids like remifentanil were used in most cases as they suppress airway reflexes, supplement sedation, and have good analgesic properties, allowing a safer procedure.

In regard to postoperative respiratory complications, we detected escalation in oxygen requirements or a need for positive pressure ventilation in 5.1% of cases; however, this was not associated with 30-day mortality ($p = 0.276$). In our study the 30-day mortality rate was 7.6%, which compares favorably with the AQuIRE registry data which evaluated more than 1,000 patients undergoing therapeutic flexible and rigid bronchoscopy and reported a 17% 30-day mortality rate in patients who were managed with volume-cycled ventilation (which included the SAV patients) [37]. In our study, older age, inpatient status, pre-existing congestive heart failure, pre-existing home oxygen use, and the duration of the procedure were associated with 30-day mortality. The modifiable variable among these is duration of procedure, which, in our experience, correlates with the use of thermal ablation because of the intermittent need to reduce the intraoperative $FiO_2$ to avoid airway fires. We believe this is relevant information for bronchoscopists and anesthesiologists alike as keeping the procedure as short as possible should become a goal of therapeutic bronchoscopy. Our study provides the evidence to justify this practice and potentially make the duration of procedure a quality care metric. Reduction in the duration of the procedure may be possible by using effective coagulation tools and mechanical debulking and not solely vaporization through the use of laser or superficial coagulation as achieved by APC. Alternatively, nonthermal ablation techniques may require less intraoperative time, but this hypothesis has never been tested in direct comparative trials. We believe our study is meaningful for the anesthesiologists involved in managing these patients with CAO as it adds to the body of literature that suggests that intraoperative hypoxemia and hypotension, as defined in this study and others, did not result in an increase in intraoperative arrhythmias or mortality. The operators' focus should be on limiting the duration of the procedure with consideration given to a staged procedure, if warranted.

We also demonstrated that, despite the fact that 90% of patients had ASA class III or IV and the vast majority suffered from advanced malignancy, there was no

intraoperative mortality and the vast majority of patients (94.4%) were discharged home. This is consistent with results from prior smaller case series [20]. These findings are relevant for thoracic oncology programs as palliative care is now routinely integrated in the management of patients with advanced cancer. Rigid bronchoscopy, however, should not be misperceived as too aggressive an intervention for this patient population. Therapeutic bronchoscopy in patients with airway obstruction from malignancy is an effective and safe palliative intervention and in fact was proven to allow de-escalation of care in critically ill patients [39, 40], and can be used as a bridge to systemic oncologic care in patients who would otherwise not tolerate chemotherapy or radiotherapy [41]. Patients with symptoms from respiratory or cardiac complications of malignancy that are amenable to palliative procedures should be offered these interventions regardless of their disease stage or overall prognosis, as long as the palliative procedures can be safely performed without increasing the risk of death or prolonged hospital stay [42]. This is the case for malignant pleural effusion, pericardial tamponade, and massive pulmonary embolism, and we believe it should be the case for malignant airway obstruction as well.

Limitations of our study include the fact that it is a retrospective, single-center, single-operator study. We intentionally limited our analysis to the time frame when sugammadex was not standard of practice at our institution, and we only analyzed the practice of one rigid bronchoscopist to minimize the bias related to intraprocedural techniques but who prefers TIVA and SAV to controlled ventilation and NMB. It is noteworthy, however, that even after the introduction of sugammadex, the economic benefits of this drug are unknown. One paper that considered this matter was a survey assessing patterns of practice and experience with sugammadex. It included 11,863 anesthesia provider respondents in 183 countries; 5,510 (46%) reported that sugammadex was available and relevant to their practice, but the majority of these providers (72%) reported selective usage of sugammadex. Most (56%) had some form of restriction on sugammadex access primarily due to cost [15]. Furthermore, inadequate recovery from NMB due to inadequate reversal with sugammadex, among other factors, continues to occur in practice [43]. A direct comparative multi-institutional trial could clarify the cost-effectiveness of TIVA with SAV versus controlled ventilation with NMB and reversal agents. Our sample size, while not robust, compares favorably with prior reports on anesthesia for rigid bronchoscopy in adults [10, 19, 20]. Although our study did not show an impact of intraoperative hypoxemia and hypotension on postoperative complications, the definitions of these variables, while consistent with some other reports, are somewhat conservative. In our study intraoperative hypotension was defined as any systolic blood pressure less than 100 mm Hg at any time during the procedure, and we had a rate of 77% by using that definition. This is substantially higher than the rate found in another recent paper; however, there was no criterion given in that paper as to what was considered hypotension [38]. Although controversial, we did not systematically use or report on the bispectral index in regard to guiding anesthesia technique; however, there were no reports of patient anesthesia recall, nor did we document the use or values of end-tidal $CO_2$ levels.

Based on the results of our study and prior reports, we suggest that future prospective studies evaluate anesthesia techniques for rigid bronchoscopy for the following: (1) the use of SAV versus volume cycled and jet ventilation with NMB and reversal agents (e.g., sugammadex); (2) the association (or causative effect) of the use of thermal versus nonthermal ablative techniques and mortality with the assumption that thermal ablation prolongs the duration of anesthesia which could directly impact outcomes (including mortality); (3) the association (or causation) between postoperative hypoxemia and/or respiratory failure and 30-day mortality; and (4) the association between intraoperative end-tidal CO2 and arrhythmias, hemodynamic instability, procedural time, time to awakening, time in the operating room, postoperative respiratory failure, and 30-day mortality.

## Statement of Ethics

This study (IRB14-1541) was approved by the Institutional Review Board at the University of Chicago. A waiver of consent was obtained due to the retrospective nature of this study.

## Disclosure Statement

Dr. S. Murgu has acted as a paid educational consultant for Olympus, Cook Inc., Pinnacle Biologics, and Boston Scientific. The paper, including part of its essential substances or figures, has not been published elsewhere and is not under consideration for publication elsewhere.

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## Author Contributions

Concept and design: Dr. S. Murgu. Data acquisition and interpretation: Drs. B. Laxmanan, S. Stoy, K. Egressy, F. Farooqui, and R. Brunner. Writing the manuscript: Drs. S. Murgu, U. Chaddha, K. Hogarth, and M. Chaney. All authors approved the final version of the manuscript and are agreeable to be accountable for all aspects of the work.

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