

# Humidified rapid-insufflation ventilatory exchange is a means of oxygenation during rigid bronchoscopy: A case series

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## Abstract

Humidified rapid-insufflation ventilatory exchange (HRIVE) is an option for maintenance of oxygenation. This technique allows for oxygenation while the patient is apnoeic due to continuous positive airway pressure and gas exchange through flow-dependent dead space flushing. There is no study about the usage of HRIVE during rigid bronchoscopy. This retrospective study looked at rigid bronchoscopy cases utilizing HRIVE. Data points assessing adequacy of oxygenation and ventilation were recorded at time points: oxygen saturation ( $SpO_2$ ), partial pressure of oxygen ( $PaO_2$ ) and partial pressure of carbon dioxide ( $PaCO_2$ ). Our nine cases had an average baseline  $SpO_2$  of 99.26%, 95.56% at 10 min into HRIVE and 95.27% at the end of HRIVE. The average baseline  $PaO_2$  was 309.01 mmHg, 124.99 mmHg at 10 min into HRIVE and 128.17 mmHg at the end of HRIVE. The average baseline  $PaCO_2$  was 43.26 mmHg, 68.76 mmHg at 10 min into HRIVE and 75.52 mmHg at the end of HRIVE. The average pre-HRIVE end-tidal  $CO_2$  ( $ETCO_2$ ) was 38.56 mmHg and the average post-HRIVE  $ETCO_2$  was 61.22 mmHg. The average baseline pH was 7.36, 7.22 at 10 min into HRIVE and 7.19 at the end of HRIVE. In this small cohort study, HRIVE was able to maintain adequate oxygenation via the rigid bronchoscope in a select group of patients. Hypercapnia and respiratory acidosis did result after 10 min, which may predispose certain patient populations to complications. HRIVE potentially offers an additional option of oxygenation via the rigid bronchoscope.

## KEYWORDS

HRIVE, humidified rapid-insufflation ventilatory exchange, oxygenation, rigid bronchoscopy

## INTRODUCTION

During rigid bronchoscopy, ensuring adequate oxygenation and ventilation is a challenge for the anaesthesiologist. Common means of ventilation include controlled ventilation via a bag-valve mask or the anaesthesia machine or low- or high-frequency jet ventilation. Controlled ventilation requires interruptions during the procedure. Jet ventilation is frequently utilized during rigid bronchoscopy due to the ability to maintain ventilation with interruption; however, its limiting factors include provider experience and the significant cost associated if utilizing a high-frequency jet ventilator.<sup>1</sup>

Humidified rapid-insufflation ventilatory exchange (HRIVE, known as THRIVE when used via the transnasal approach) is an option of maintenance of oxygenation. Its use primarily has been described during difficult airway management, as well as during hypopharyngeal and laryngotracheal surgery, and endoscopies.<sup>2-5</sup> This technique allows for increased oxygenation while the patient is apnoeic due to continuous positive airway pressure and gas exchange through flow-dependent dead space flushing.<sup>3</sup> Oxygenation utilizing HRIVE supports a significantly higher apnoea time compared to preoxygenation with 100% oxygen using a tight-fitting face mask with supplemental oxygen via nasal cannula.<sup>6</sup> In some patient populations, HRIVE has been shown

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to maintain oxygen saturation ( $SpO_2$ ) at nearly 100% at 12 min of apnoea.<sup>6</sup> With removal of the transnasal portion of the device, oxygenation via HRIVE is theoretically possible via the rigid bronchoscope when the device is attached to the side port due to the usage of heated and humidified high-flow oxygen (>60 L/min). It is a standard of care in apnoeic oxygenation in vocal cord and ENT procedures.

Currently, there is no study about the usage of HRIVE during rigid bronchoscopy in the adult population. The purpose of this study was to determine the feasibility of using HRIVE during rigid bronchoscopy procedures. Primary outcome was level of oxygen saturation during the procedure. Secondary outcomes were partial pressure of arterial oxygen and carbon dioxide, pH and adverse outcomes.

## CASE SERIES

### Materials and methods

This retrospective study looked at rigid bronchoscopy cases utilizing HRIVE. Baseline patient demographics recorded were age, gender, American Society of Anesthesiology (ASA) status, Charlson comorbidity score, body mass index, smoking status and indication for rigid bronchoscopy. For data collection, the medical and anaesthesia records were utilized.

### Anaesthetic and procedural management

Anaesthesia during rigid bronchoscopy using HRIVE utilized the following process. After informed consent was obtained, the patient was brought back to the bronchoscopy suite. The patient was positioned supine on the operating room table, arms at side, with all pressure points checked. After the application of standard ASA monitors and a period of preoxygenation, anaesthesia was induced with propofol at a dose of 1–2 mg intravenously, and a laryngeal mask airway (LMA) was placed. An arterial line was placed in the radial artery using sterile technique. The maintenance anaesthetic was propofol infusion with a typical dose range of 100–200 mcg/kg/min. Neuromuscular blockade was utilized with rocuronium titrated utilizing a twitch monitor to

a train-of-four (TOF) of 2 or less. In preparation for placement of the rigid bronchoscope, the patient was placed on 100% fraction of inspired oxygen in the air ( $FiO_2$ ) and hyperventilated in preparation for the use of HRIVE. After the removal of the LMA, the rigid bronchoscope (Storz, El Segundo, CA) was placed in the airway and the HRIVE (Fisher and Paykel, Irvine, CA) was attached to the bronchoscope side port and run at the max flow rate of 70 L/min and at 100%  $FiO_2$  (Figure 1). Arterial blood gases were measured at baseline prior to rigid bronchoscope placement, every 10 min and upon removal of the scope. Upon completion of the procedure, the rigid bronchoscope was removed, the LMA was replaced, neuromuscular blockade was reversed with sugammadex dosed based on TOF count and the patient was emerged from anaesthesia and taken into the post-operative unit for observation.

### Intraprocedural data collection

The following data were recorded at the beginning of the procedure, every 10 min into the procedure and at the end of the procedure, right before the reinsertion of LMA:  $SpO_2$ , partial pressure of oxygen ( $PaO_2$ ), partial pressure of carbon dioxide ( $PaCO_2$ ) and pH. Other variables to be collected include length of time of rigid bronchoscopy procedure, pre-rigid end-tidal  $CO_2$  ( $ETCO_2$ ) and post-rigid  $ETCO_2$ . Adverse outcomes assessed included arrhythmia, severe hypotension (median arterial blood pressure < 60 mmHg for >5 min), oxygen desaturation during the rigid bronchoscopy procedure, aspiration and any respiratory complication post-operatively.

### Statistical analysis

Descriptive statistics were utilized to broadly analyse the sample.

### Results

We included nine cases who underwent a procedure with rigid bronchoscopy for stent placement or removal for



FIGURE 1 Humidified rapid-insufflation ventilatory exchange attachment to the rigid bronchoscope

tracheobronchomalacia. Table 1 summarizes the patient demographics and procedure characteristics. Table 2 summarizes the results.

The average duration of the HRIVE across all nine procedures was 23.89 min [standard deviation (SD): ±10.89]. The averages of arterial SpO<sub>2</sub> were the following: baseline SpO<sub>2</sub> was 99.26% (SD: ±0.7), SpO<sub>2</sub> at 10 min into HRIVE was 95.56% (SD: ±2.91) and SpO<sub>2</sub> at the end of HRIVE was

95.27% (SD: ±2.97). The change of SpO<sub>2</sub> over time is shown in Figure 2. The averages of partial pressure of arterial O<sub>2</sub> (PaO<sub>2</sub>) were the following: PaO<sub>2</sub> at baseline was 309.01 mmHg (SD: ±73.27), PaO<sub>2</sub> at 10 min into HRIVE was 124.99 mmHg (SD: ±48.89) and PaO<sub>2</sub> at the end of HRIVE was 128.17 mmHg (SD: ±48.81). The change of PaO<sub>2</sub> over time is shown in Figure 3. The averages of partial pressure of arterial CO<sub>2</sub> (PaCO<sub>2</sub>) were the following: PaCO<sub>2</sub>

TABLE 1 Patient demographics and procedure characteristics

Patient	Age	Gender	ASA status	Charlson comorbidity score	BMI (kg/m <sup>2</sup> )	Smoking status	Indication of rigid bronchoscopy	Length of HRIVE (min)	Adverse event
1	61	M	3	2	30.8	Never smoker	Stent placement for TBM	40	None
2	81	F	3	8	30.7	Ex-smoker	Stent removal	13	None
3	53	F	3	1	37.4	Active smoker	Stent placement for TBM	43	None
4	53	F	3	1	37.4	Active smoker	Stent removal	16	None
5	49	M	3	2	27.2	Never smoker	Stent placement for TBM	28	None
6	61	F	3	3	35.48	Never smoker	Stent removal	12	O <sub>2</sub> desaturation requiring manual ventilation via the rigid bronchoscope. The patient fully recovered
7	69	F	3	3	28.2	Never smoker	Stent removal	14	None
8	70	F	3	4	22.16	Ex-smoker	Stent placement for TBM	23	None
9	70	F	3	4	22.16	Ex-smoker	Stent removal	26	None

Abbreviations: ASA, American Society of Anesthesiology; BMI, body mass index; F, female; HRIVE, humidified rapid-insufflation ventilatory exchange; M, male; TBM, tracheobronchomalacia.

TABLE 2 Results in mean ± SD

	SpO <sub>2</sub> (%)	PaO <sub>2</sub> (mmHg)	PaCO <sub>2</sub> (mmHg)	pH	ETCO <sub>2</sub>
Baseline	99.26 ± 0.7	309.01 ± 73.27	43.43 ± 4.89	7.36 ± 0.03	38.56 ± 4.88
At 10 min	95.55 ± 2.91	124.99 ± 48.88	68.76 ± 14.58	7.22 ± 0.06	—
At the end of HRIVE	95.27 ± 2.97	128.17 ± 48.81	75.52 ± 21.27	7.19 ± 0.09	61.22 ± 13.22

Abbreviations: ETCO<sub>2</sub>, end-tidal CO<sub>2</sub>; HRIVE, humidified rapid-insufflation ventilatory exchange; PaCO<sub>2</sub>, partial pressure of carbon dioxide; PaO<sub>2</sub>, partial pressure of oxygen; SpO<sub>2</sub>, oxygen saturation.

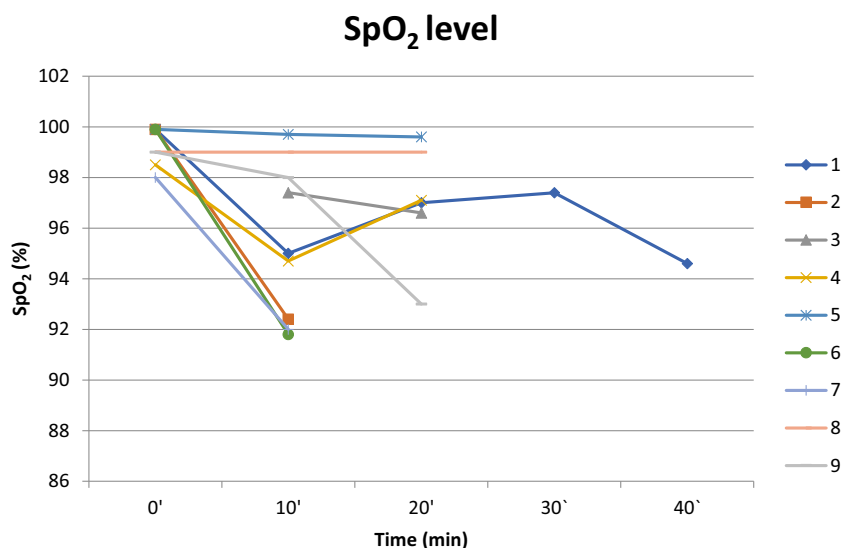
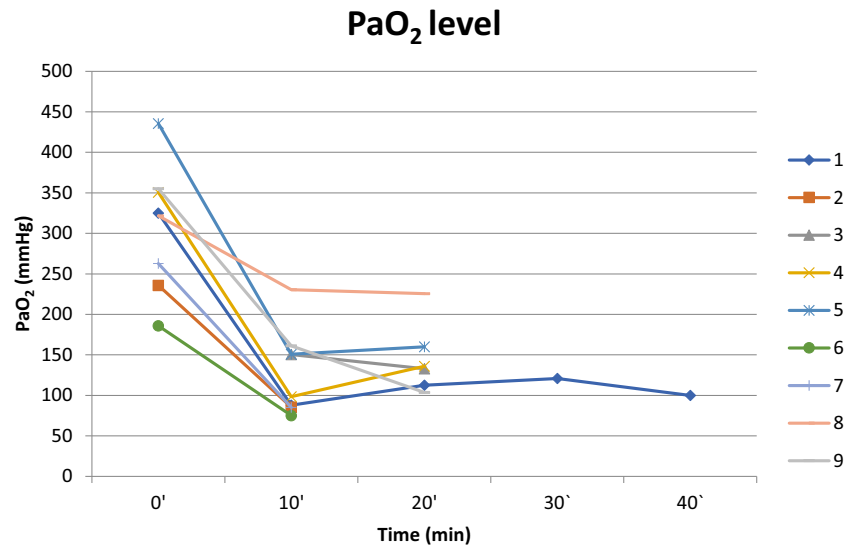
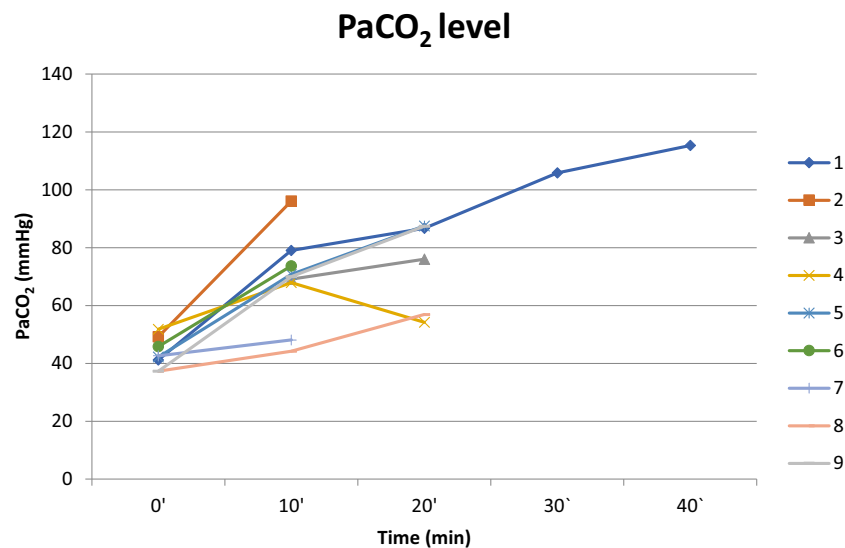


FIGURE 2 Change in oxygen saturation during humidified rapid-insufflation ventilatory exchange via rigid bronchoscopy by the patients



**FIGURE 3** Change in partial pressure of oxygen (PaO<sub>2</sub>) level during humidified rapid-insufflation ventilatory exchange via rigid bronchoscopy by the patients



**FIGURE 4** Change in partial pressure of carbon dioxide (PaCO<sub>2</sub>) level during humidified rapid-insufflation ventilatory exchange via rigid bronchoscopy by the patients

at baseline was 43.26 mmHg (SD:  $\pm 4.89$ ), PaCO<sub>2</sub> at 10 min into HRIVE was 68.76 mmHg (SD:  $\pm 14.58$ ) and PaCO<sub>2</sub> at the end of HRIVE was 75.52 mmHg (SD:  $\pm 21.27$ ). The change of PaCO<sub>2</sub> over time is shown in Figure 4. The average pre-HRIVE ETCO<sub>2</sub> was 38.56 mmHg (SD:  $\pm 4.88$ ) and the average post-HRIVE ETCO<sub>2</sub> was 61.22 mmHg (SD:  $\pm 13.22$ ). Figure 5 shows the change in ETCO<sub>2</sub> over time. The average values of pH were the following: pH at baseline was 7.36 (SD:  $\pm 0.03$ ), pH at 10 min into HRIVE was 7.22 (SD:  $\pm 0.06$ ) and pH at the end of HRIVE was 7.19 (SD:  $\pm 0.09$ ). Figure 6 shows the change in pH over time. The patient during procedure 6 had a short period of O<sub>2</sub> desaturation at the beginning of the procedure. After manually ventilating the patient via the rigid bronchoscope, the

patient fully recovered, and was able to maintain oxygenation on HRIVE. No other adverse outcomes occurred.

## DISCUSSION

In this small cohort study, HRIVE was able to maintain adequate oxygenation via the rigid bronchoscope in a select group of patients. Our team is aware that the findings of the study cannot be generalized and we want to highlight here that HRIVE now potentially offers an option of oxygenation for the anaesthesiologist via the rigid bronchoscope in a select group of patients as detailed under limitations. This allows for continuous oxygenation without interruption of

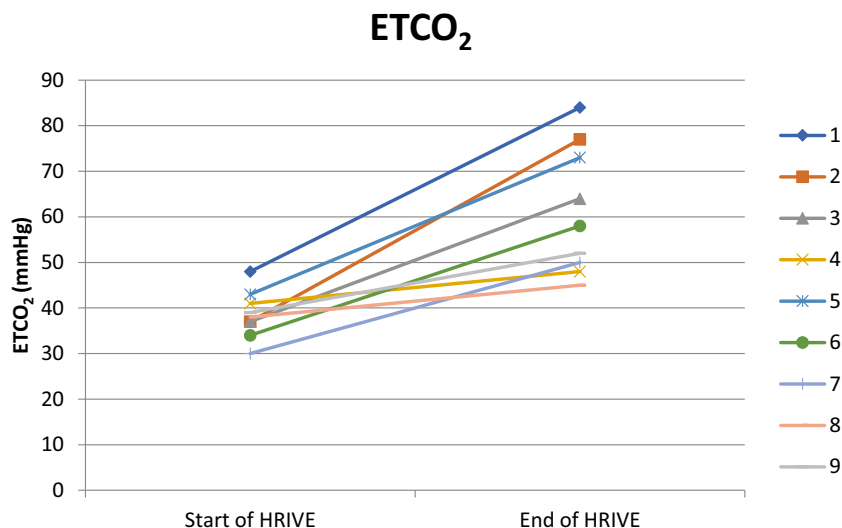


FIGURE 5 Change in end-tidal CO<sub>2</sub> (ETCO<sub>2</sub>) level during humidified rapid-insufflation ventilatory exchange via rigid bronchoscopy by the patients

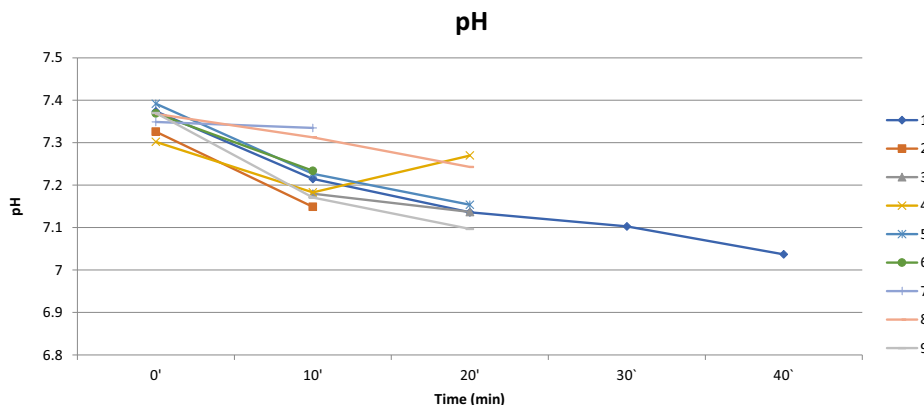


FIGURE 6 Change in arterial pH during humidified rapid-insufflation ventilatory exchange via rigid bronchoscopy by the patients

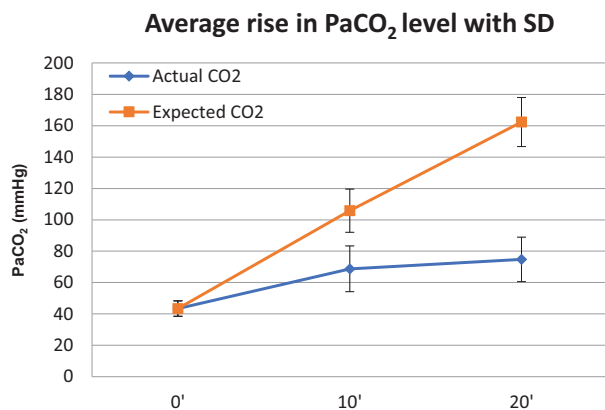
the short procedure (preferably less than 10 min), a cost-effective option compared to high-frequency jet ventilation, and a less labour-intensive option compared to low-frequency jet ventilation. This result is similar to older studies evaluating apnoeic oxygenation, in which the majority of patients tolerated at least 15 min of apnoea.<sup>7</sup> However, procedures using rigid bronchoscope may often take longer; thus, a rescue equipment such as a manual or high-frequency jet ventilation is needed.

When looking closely at the results, there are several considerations for the anaesthesiologist. First, while SpO<sub>2</sub> was maintained in all cases, there was a significant drop in PaO<sub>2</sub> while utilizing the HRIVE on 100% FiO<sub>2</sub>. While there was no significant desaturation in our procedures, the low PaO<sub>2</sub>/FiO<sub>2</sub> gradient may be significant in patients with pre-existing lung disease or hypoxaemia at baseline and may result in more desaturation when utilizing HRIVE.

In addition, hypercapnia and respiratory acidosis did result after 10 min and progressively worsened as the length of time using HRIVE increased. Acute respiratory acidosis

can affect many organ systems.<sup>8</sup> Clinical manifestations are predominantly neurological: vasodilatation of the cerebral vessels and increase of cerebral blood flow, blood volume and pressure.<sup>9</sup> The effects of hypercapnia on cardiovascular system are release of circulating catecholamines and direct peripheral vasodilatation.<sup>10,11</sup> Acute hypercapnia may increase pulmonary arterial pressure; however, no significant correlation was found between changes in pH and pulmonary haemodynamic values.<sup>12</sup> Hypercapnia is associated with sodium and water retention, especially in the presence of right ventricular dysfunction.<sup>13</sup> For the above-mentioned reasons, the usage of HRIVE can predispose patients to increased risk with pre-existing intracranial or cardiac pathology, pulmonary hypertension or right ventricular dysfunction.

A recent preliminary study on THRIVE found similar results concerning PaCO<sub>2</sub> and pH. To that effect, they suggested using short periods of intermittent controlled ventilation after a period of apnoea to help eliminate carbon dioxide.<sup>6</sup> In our patients, we maintained HRIVE with the



**FIGURE 7** Expected partial pressure of carbon dioxide (PaCO<sub>2</sub>) levels compared to the actual PaCO<sub>2</sub> rise with each SD for each data point

rigid bronchoscope in place, and manually ventilated them after the rigid bronchoscope was removed. Interestingly, the measured PaCO<sub>2</sub> levels are lower than the expected PaCO<sub>2</sub> levels in our patient cohort, demonstrating that the functional mechanism of HRIVE does allow for some degree of CO<sub>2</sub> clearance (Figure 7). The interaction between entrained and highly turbulent supraglottic flow vortices created by high-flow oxygen and cardiogenic oscillations might be responsible for this mechanism.<sup>14</sup>

The limitations of the study include the following. It is important to highlight that the selection of cases may bias the results in terms of potential adverse events. These patients had no known neurological and cardiac comorbidities, who are less likely to experience complications due to the expected hypercarbia. None of the cases utilized laser or thermal therapy, as 100% FiO<sub>2</sub> required by HRIVE may have increased the risk of airway fire.<sup>15</sup> In addition, none of the cases required biopsies or debulking as the hypercarbia may lead to increased pulmonary artery pressures, predisposing a patient to haemorrhage.<sup>16</sup> In our study, none of the patients had severe hypercapnia at baseline, which is important to consider as the majority of patients requiring rigid bronchoscopy have limited lung capacity, with some of them being already hypercapnic at baseline. It is important to highlight again that procedures using a rigid bronchoscope may often take longer and that ventilation via HRIVE requires rescue modalities to be present, such as jet or manual ventilation, as well as trained personnel in using these methods.

While we are aware that no generalized recommendations can be made based on both this small sample size and select patient cohort, we believe HRIVE can be considered a potential option for maintenance of oxygenation in rigid bronchoscope cases in select populations, if the equipment is readily available with rescue modalities and well-trained personnel. To summarize this select patient population, when there is a lack of jet ventilation capability and the patient has no known neurological and cardiac comorbidities and no baseline severe hypercapnia, cold therapies

are used, no biopsy or debulking is required and the procedure requires short period of time (preferably less than 10 min). More research is needed on applications of HRIVE during rigid bronchoscopic procedures.

## CONFLICT OF INTEREST

None declared.

## AUTHOR CONTRIBUTION

Each author substantially contributed to this work by (1) the conception or design of the work, the acquisition, analysis or interpretation of data for the work; (2) drafting the work or revising it critically for important intellectual content; and (3) final approval of the version to be published.

## ETHICS STATEMENT

This study was reviewed and determined to be exempt from the requirement of Institutional Review Board (IRB) approval by the appropriate ethics authority with IRB ID number 19-002092. The reviewer approved waiver of HIPAA authorization in accordance with applicable Health Insurance Portability and Accountability Act (HIPAA) regulations.

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