Original Article

The Impact of Mechanical Ventilation Modes on Complications of Fiberoptic Bronchoscopy in Critically Ill Patients

Murat Küçük[ID][1], Yasin Levent Uğur[ID][2], Mehmet Celal Öztürk[ID][2], Bilgin Cömert[ID][3], Ali Necati Gökmen[ID][2], Begüm Ergan[ID][4]

[1]Division of Intensive Care, Department of Internal Medicine, Dokuz Eylül University, Faculty of Medicine, İzmir, Turkey
[2]Division of Intensive Care, Department of Anaesthesiology and Reanimation, Dokuz Eylül University, Faculty of Medicine, İzmir, Turkey
[3]Department of Internal Medicine and Critical Care, Medicana International Hospital, İzmir, Turkey
[4]Division of Intensive Care, Department of Pulmonary Diseases, Dokuz Eylül University, Faculty of Medicine, İzmir, Turkey

Abstract

OBJECTIVE: The effects of fiberoptic bronchoscopy are not elucidated in different mechanical ventilation modes. The present study aimed to evaluate the effects of fiberoptic bronchoscopy on lung mechanics, ventilation parameters, and gas exchange in 2 often-used modes, volume control and pressure control, in invasively ventilated patients followed up in the intensive care unit.

MATERIAL AND METHODS: Eligible patients were screened and included in the study after intensive care unit-fiberoptic bronchoscopy database search. Patients who underwent fiberoptic bronchoscopy under volume control and pressure control mechanical ventilation modes were compared. The primary outcome was the occurrence of any complication within the first 24 hours after the procedure, and secondary outcomes were changes in lung mechanics (dynamic lung compliance and airway resistance) and gas exchange (arterial partial pressures of oxygen and carbon dioxide).

RESULTS: A total of 61 patients (median age: 69 years, 60.7% male) were included. Twenty-nine (47.5%) patients were ventilated in volume control mode and 32 (52.5%) in pressure control mode during the fiberoptic bronchoscopy procedure, and the median (interquartile range) duration of the procedure was 9 [8-11] minutes. Baseline dynamic lung compliance, airway resistance, arterial partial pressures of oxygen and carbon dioxide, and the fraction of inspired O_2 were similar in both groups. After fiberoptic bronchoscopy, dynamic lung compliance decreased in both groups, and airway resistance and peak airway pressures increased but reached pre-fiberoptic bronchoscopy values at the 1st hour after the procedure. No significant differences were detected in both groups in terms of blood gas values and lung mechanics in the 1st and 24th hours after the procedure. In both groups, the 24th hour fraction of inspired O_2 was the same as the pre-fiberoptic bronchoscopy values, but the ratio of arterial partial pressure of oxygen and the fraction of inspired O_2 improved. No complications developed in patients within 24 hours after the procedure.

CONCLUSION: No differences were detected in terms of gas exchange and pulmonary mechanics, and complications in volume control and pressure control modes in critically ill intubated patients.

KEYWORDS: Fiberoptic bronchoscopy, mechanical ventilation, intensive care, mode
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INTRODUCTION

Fiberoptic bronchoscopy (FB) is increasingly used in intensive care units (ICU) for both diagnostic and therapeutic purposes because of its ease, bedside applicability, and low complication rates.[1] Fiberoptic bronchoscopy under mechanical ventilation (MV) in invasively ventilated critically ill patients has a relatively good safety profile even though it has several physiological complications, such as increased airway resistance (R_{aw}), hypoxemia, and hypercapnia.[2,3] While performing FB through the endotracheal tube (ETT), peak inspiratory pressure (PIP) and alveolar pressure may increase and affect many ventilation parameters, such as tidal volume (VT) flow rate and dynamic lung compliance (C_{dyn}). Moreover, during bronchoalveolar lavage (BAL), aspiration causes more deepened hypoxemia and decreases the end-expiratory lung volume and lung compliance, especially in patients with severe hypoxemia.[4] For this reason, it is necessary to think of proper MV settings before and during FB and consider setting readjustments in case needed.

Fiberoptic bronchoscopy can be performed in many MV modes depending on the patient's characteristics and needs. Volume control (VC) mode is the most used mode as it maintains VT and therefore minute ventilation. Another option is pressure control (PC) mode which is used very often in critically ill patients when there is the risk for high airway pressures. However, it is used to a lesser extent because of the high risk of decreased minute ventilation due to increased R_{aw}.

Corresponding author: Begüm Ergan, e-mail: begumergan@hotmail.com

Currently, there are no evidence-based recommendations for mode selection during FB procedure in invasively ventilated critically ill patients. Expert opinion is to perform FB in VC mode and with a possibility of reduced VT and allowing permissive hypercapnia.[1] In our center, we often perform FB for diagnostic and therapeutic purposes and our general approach is not to change MV mode while performing FB whenever possible. Our clinical observation was there was no superiority of VC mode over PC mode for early and late FB complications. Therefore, to test our hypothesis, we conducted the present study. The primary outcome was the occurrence of any hypoxemic complications within the first 24 hours after the FB procedure in invasively ventilated patients, and secondary outcomes were changes on lung mechanics (C_{dyn}–R_{aw}) and gas exchange (arterial partial pressures of oxygen [PaO_2] and carbon dioxide [$PaCO_2$])

MATERIAL AND METHODS

Study Population
This retrospective study was performed in adult ICU after the Dokuz Eylül University ethics committee approval (No. 2020/06-29). Intensive care unit-fiberoptic bronchoscopy (ICU-FB) database was screened for adult (≥18 years) patients who underwent FB and invasively ventilated either with VC or PC modes. Informed consent was waived because of the nature of the study.

Fiberoptic Bronchoscopy Procedure
Indication and the decision for FB were primarily determined by consulting intensivists. The study team had no contribution to the decision on making an FB indication. All procedures were performed by 1 intensivist–pulmonologist who had expertise in performing FB in critically ill patients of >15 years. According to local ICU-FB protocol, severe hemodynamic instability and bleeding diathesis were considered as the main contraindications to performing FB [1]. All patients were monitored for vital signs (electrocardiography, pulse oximetry, and blood pressure) during and after the procedure.

Variables
The demographic data of patients (age, gender, main reason for ICU admission, and reason for FB), Acute Physiology and Chronic Health Evaluation [APACHE] II score, Glasgow Coma Scale (GCS) score, Sequential Organ Failure Assessment

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MAIN POINTS

- Fiberoptic bronchoscopy (FB) is frequently used in practice in mechanical ventilation patients.

- The effects of mechanical ventilation modes on lung mechanics and frequency of complications during FB are not clear yet.

- Expert opinions suggest that adequate ventilation should be provided during the procedure and volume control (VC) mode should be preferred.

- In our study, no significant differences were found between the pressure control and VC modes, which are frequently used clinically during and after FB.

- Broad-based studies including other mechanical ventilation modes are needed.

(SOFA) score, and clinical characteristics (duration of MV, need for vasopressor therapy, and renal replacement therapy) were recorded. Patients were divided into 2 groups according to the ventilation modes as follows: the VC and PC groups.

Mechanical Ventilation Settings
All patients were ventilated with Dräger Evita Infinity V500 (Dräger Medical GmbH; Lübeck, Schleswig-Holstein, Germany) series ventilators. Ventilator settings were set by the primary consulting intensivist and were kept constant during FB except for fraction of inspired oxygen (FiO_2).

Usual ventilatory settings for VC mode were an average of 5-6 cmH_2O for positive end-expiratory pressure (PEEP), VT of 5-8 mL/predicted body weight, inspiration/expiration ratio of 1/2-3, and PIP alarm limit of 40 cmH_2O. For PC mode, inspiratory pressure was adjusted to VT calculated and lower alarm limit for minute ventilation was set to <4 L/min.

The ICU sedation protocol consisted of midazolam and fentanyl/remifentanil infusion before and during the procedure according to the depth of sedation that allows spontaneous breathing of patients as much as possible.

After the confirmation of ETT diameter to be >8.0 mm in the bronchoscope (5.9-mm outer-diameter Olympus BF 10 bronchoscope [Olympus, Tokyo, Japan]) was placed in ETT with a special adapter valve. For preoxygenation, 5-10 minutes before the procedure, FiO_2 was set at 0.9-1.0 and was kept in this setting throughout the procedure. All ventilator parameters set by the consulting intensivist were kept stable, and the inhaled and exhaled VTs and vital findings during the procedure were monitored and recorded closely. The duration of FB, the amount of fluid given and recovered for bronchial lavage, and BAL were noted. FiO_2 was decreased gradually to guarantee peripheral (pulse) oxygen saturation (SpO_2) >90% after FB. After FB procedure and at 1st and 24th hours, patients' vital signs (i.e., heart rate [HR], mean arterial pressure [MAP], and respiratory rate [RR]), arterial blood gas values, mechanical ventilator parameters, pulmonary mechanics, and PaO_2/FiO_2 values were recorded. Possible complications in the first 24 hours after FB, FB-related desaturation (SpO_2 <90), hemodynamic deterioration, barotrauma-related complications such as pneumothorax and/or pneumomediastinum, and bleeding were recorded.

Arterial blood gas values (PaO_2, $PaCO_2$), oxygen saturation (SaO_2) mechanical ventilator settings for PEEP, PIP, VT, FiO_2, C_{dyn}, and R_{aw} at the end of the procedure, for the 1st and 24th hours, were recorded (formula: C_{dyn} (mL/cmH_2O) = VT (mL)/[PIP (cmH_2O) − $PEEP$ (cmH_2O)]. Airway resistance was measured with 40 L/min square by using the following formula: R_{aw} (cmH_2O/L/s) = [$Peak\ inspiratory\ pressure$ (cmH_2O) − $plateau\ pressure$ (cmH_2O)]/$final\ inspiratory\ flow$ (L/s).

Statistical Analysis
Categorical variables were expressed as numbers and percentages. Continuous variables were expressed as the median and interquartile range. Categorical variables between groups were compared with chi-square or Fisher's exact test, continuous variables were compared with Mann–Whitney U test. Pre- and post-FB values for compliance and resistance

and arterial blood gas values were compared with Student's *t*-test. A 2-tailed *P*-value of <.05 was considered statistically significant. Statistical analysis was performed with Statistical Package for the Social Sciences version 26.0 (IBM Corporation, Armonk, NY, USA) program.

Clinic Characteristics and Outcomes of Patients
Of 61 patients (median age 69 years [61-69] and 37 [60.7%] of them being male), 32 (52.5%) underwent FB in PC mode and 29 (47.5%) in VC mode.

Patients in the VC group were older than the PC group, but the age did not significantly differ between the groups (77 [70-83] vs. 67 [63-76], respectively, *P* = .09). In the VC group, the median APACHE II value (24 [21-30] vs. 22 [18-26], respectively, *P* = .14), SOFA score (8 [5-8] vs. 6 [5-7], respectively, *P* = .08), and GCS (9 [7-11] vs. 8 [6-10], respectively, *P* = .36) were higher than the PC group; these parameters did not significantly differ between the groups. The main reasons for the ICU admission were respiratory failure (41%), sepsis/septic shock (18%), neurological disease (18%), postoperative (14.85), and trauma (8.2%). The reasons for the ICU admission did not significantly differ between the groups.

The indications for the FB did not particularly differ between the groups (Table 1).

On the day of FB procedure, the number of patients who needed vasopressors (14 [43.8%] vs. 10 [37.9%], respectively, *P* = .60), who were diagnosed with acute kidney injury (16 [50.0%] vs. 12 [41.4%], respectively, *P* = .60), and who underwent hemodialysis (6 [18.7%] vs. 2 [6.9%], respectively, *P* = .26) did not statistically differ between the groups.

The duration of invasive MV (20 [10-36] vs. 12 [9-28], respectively, *P* = .33), the length of ICU stay (22 [18-28] vs. 18 [15-32], respectively, *P* = .39), hospital mortality (23 [79.3%] vs. 19 [59.4%], respectively, *P* = .10), and ICU mortality (20 [68.9%] vs. 18 [56.3%], respectively, *P* = .42) were not statistically significant between the VC group and the PC group.

Median FB duration was similar in both groups, [10 min (8-13) for PC group vs. 9 min (8-10) for VC group; *P* = .11]. The amount of NaCl 0.09% used during bronchial washings [87 mL (50-100) for PC group and 80 mL (40-100) for VC group, (*P* = .47)] and recovered amounts [45 mL (35-65) for

Table 1. Baseline Characteristics of the Patients

Basic Variables	All Patients (n = 61)	PC Mode (n = 32)	VC Mode (n = 29)	*P*
Age	69 (61-79)	67 (63-76)	77 (70–83)	.09
Male sex	37 (60.7)	19 (51.4)	18 (62.1)	1.00
Apache II score	23 (19-29)	22 (18-26)	24 (21-30)	.14
SOFA[a] score	6 (5-8)	6 (5-7)	8 (5-9)	.08
GCS score	8 (7-11)	8 (6-10)	9 (7-11)	.36
Main reason for ICU admission				
Sepsis/septic shock	11 (18.0)	5 (15.6)	6 (20.7)	.74
Respiratory failure	25 (41.0)	14 (43.8)	11 (37.9)	.79
Postoperative	9 (14.8)	5 (15.6)	4 (13.8)	1.00
Neurological disease	11 (18.0)	5 (15.6)	6 (20.7)	.74
Trauma	5 (8.2)	3 (9.4)	2 (6.9)	1.00
Indications for FB				
Pneumonia	31 (50.8)	15 (46.8)	16 (55.2)	.54
Atelectasis	8 (13.1)	4 (12.5)	4 (13.8)	1.00
Hemoptysis	5 (8.2)	2 (6.3)	3 (10.3)	.66
Airway exploration	17 (27.9)	11 (34.4)	6 (20.7)	.26
Event on FB day				
Vasopressor need[b]	24 (39.3)	14 (43.8)	10 (37.9)	.60
AKI	28 (45.9)	16 (50.0)	12 (41.4)	.60
HD need	8 (13.1)	6 (18.7)	2 (6.9)	.26
Invasive MV duration (days)	14 (9-32)	12 (9-28)	20 (10-36)	.33
ICU length of stay (days)	20 (15-29)	18 (15-32)	22 (18-28)	.39
ICU mortality	38 (62.3)	18 (56.3)	20 (68.9)	.42
Hospital mortality	42 (68.9)	19 (59.4)	23 (79.3)	.10

All values are expressed as numbers (percentages) or median (interquartile range).
[a]SOFA score in the first day; [b]norepinephrine >0.15 µg/kg/min.
APACHE, Acute Physiology And Chronic Health Evaluation Scale; AKI, acute kidney injury; FB, fiberoptic bronchoscopy; GCS, Glasgow Coma Scale; HD, hemodialysis; PC, pressure control; MV, mechanical ventilation; SOFA, Sequential Organ Failure Assessment Scale; VC, volume control.

PC group and 40 mL (23-53) for VC group (P = .16)] were similar in both groups and did not reach a statistical significance.

No complications occurred during the FB procedure and in the next 24 hours.

Vital Signs, Lung Mechanics, Blood Gas, and Mechanical Ventilator Data

The vital parameters such as MAP, HR, RR were not significantly different between the groups before FB. Before the FB, the median FiO_2 value were higher in the VC group than the PC group (45% [40-52] vs. 40% [35-47] , respectively, P = .23) as well as the median SaO_2 (98% [95-98] vs. 96% [93-98], P = .41), PaO_2 (91 mmHg [78-110] vs. 85 mmHg [76-111], respectively, P = .68), and PaO_2/FiO_2 ratio (231 [178-254] vs. 203 [158-225], respectively, P = .12) were higher in the PC group than the VC group. All blood gas analysis values presented above were not statistically different between the groups.

Before the FB, the median VT (482 [421-581] vs. 450 [416-484] mL, respectively, P = .09) was higher in the PC group than the VC group, as well as, the median PIP (26 cmH_2O [21-29] vs. 23 cmH_2O [22-27], respectively, P = .36) was higher in the VC group than the PC group. The median PEEP value was similar between the groups (6 cmH_2O [5-7] vs. 6 cmH_2O [5-8], respectively, P = .50). The median value of C_{dyn}, R_{aw}, and the mechanical ventilator paramaters before the FB were not statistically significant between the groups. It was observed that median C_{dyn} was lower in the VC mode group than in the PC group immediately after FB (25.5 mL/cmH_2O [22.0-33.0] and 34.0 mL/cmH_2O [24.5-45.5], respectively); however, it did not reach a statistical significance (P = .06). It was observed that PIP increased immediately after FB was similar in both groups (delta pressure was 2.0 cmH_2O for PC and VC modes, P = .27). C_{dyn}, R_{aw}, and PIP reached similar values to baseline at the 1st hour after the procedure and kept constant till 24th hour (Table 2).

DISCUSSION

Currently, there are no clear evidence-based recommendations for MV mode selection during FB in invasively ventilated patients. In the current study, we aimed to investigate the effects of FB in the most commonly used MV modes in clinical practice. We found that FB can be performed safely without changing ventilatory settings. Second, FB induced similar but clinically non-significant changes in respiratory mechanics and gas exchange in both PC and VC modes.

In our study, we have kept all MV settings unchanged except for FiO_2 during FB. Fiberoptic bronchoscopy-related gas exchange abnormalities emerge at different rates in almost all critical patients. Fiberoptic bronchoscopy may cause up to a 30% decrease in oxygenation; this usually returns to the values before the procedure within 2 hours.[3] It was reported that there is a decrease of 4-38 mmHg (average 20 mmHg) in PaO_2 during FB.[5] The reason for this may be the intrapulmonary shunt formation, development of ventilation/perfusion disorder because of lavage fluid, and bronchospasm that is secondary to tracheal stimulation.[6] To prevent hypoxemia, we have preoxygenated patients and used FiO_2 to 0.9-1.0 throughout the procedure. We believe that this was a

successful approach in this cohort as none of the patients had any desaturation attacks and all FB procedures were performed without any interruption.

The optimal ventilation strategy during FB is still questionable. In a previous study, Meduri and Chastre[7] proposed a volume targeted ventilation strategy in which the ventilator is set to ensure adequate ventilation during FB for stable VT and therefore minute ventilation. However, they also noted that hyperinflation, barotrauma, pneumothorax, and hemodynamic deterioration due to expiratory flow limitation may occur and this may be dangerous, especially in patients with high PEEP need. An option to decrease the risk for barotrauma would be decreasing the PEEP level by 50%.[1] In our study, we observed that there was a slight decrease in VT and an insignificant increase in $PaCO_2$. However, both changes were clinically insignificant.

In this study, it was observed that FB was performed mostly for microbiological sampling for pneumonia and airway assessment including atelectasis. For that reason, only bronchial lavage was performed and we have avoided BAL due to the risks mentioned above. This approach might lead to non-significant differences in C_{dyn} and R_{aw} in both groups. The saline, which is not retrieved for bronchial lavage, might decrease the VT and worsen gas exchange because of increased ventilation–perfusion incompatibility.[8,9] Moreover, the lavage fluid might also cause inflammatory pulmonary edema inactivation of surfactant and may result in atelectasis and changes in respiratory mechanics.[10] Chou et al[11] showed that R_{aw} increased approximately up to 22% and C_{dyn} decreased 14% immediately after BAL. Klein et al[12] examined the post-BAL changes in 18 patients in MV and reported that there was a temporary increase in pulmonary resistance and a 20% decrease in compliance 8 minutes after the procedure. They also emphasized that compliance approached the initial values 3 hours after the procedure. These studies did not present the possible effects of any MV mode during FB.

İn our study, no complications were encountered in our patient group. Although FB is considered to be a safe procedure, the general complication rates vary between 4% and 10% in intensive care patients.[13,14] Complications may be related to patient characteristics (i.e., age, presence/degree of hypoxemia, comorbidities, and clotting abnormalities), procedural factors (i.e., the duration, sedation, and type of the procedure), and the experience of the operatör.[15] The most common complications are bronchospasm, hypoxemia, cardiac arrhythmias, hypotension, bleeding and hemoptysis, pneumothorax, myocardial infarction/pulmonary edema, and mortality.[16] Complications such as pneumothorax and subcutaneous emphysema can occur immediately after FB or after some time. This may be especially important for patients receiving MV support in ICU, and patients must be monitored for such delayed complications in the first 24 hours after the procedure.[16] We believe that the absence of any complications in our cohort is due to our center's expertise in FB. Another reason for the lower complication rate might be due to short procedural time. The median bronchoscopy duration in both MV modes was 9 minutes in our study and was lesser than generally reported in the literature.[17,18]

Table 2. Vital Signs, Lung Mechanics, Blood Gas Analysis, and Mechanical Ventilator Data Before FB, Immediately After FB, and on the 1st and 24th Hours After FB

Variables	Before FB			Immediately After FB			After FB 1st Hour			After FB 24th Hour		
	PC Mode	VC Mode	P	PC Mode	VC Mode	P	PC Mode	VC Mode	P	PC Mode	VC Mode	P
Vital signs												
MAP (mmHg)	72 (65-77)	70(68-75)	.22	75 (69-88)	72 (70-78)	.30	78 (71-82)	75 (73-82)	.22	75 (70-79)	72 (68-73)	.24
HR (/min)	90 (86-111)	95 (91-115)	.29	90 (74-113)	102 (95-118)	.28	97 (88-111)	96 (65-112)	.36	102 (92-112)	99 (86-108)	.18
RR (/min)	16 (145-22)	18 (16-19)	.31	18 (16-23)	20 (15-24)	.56	18 (15-24)	20 (16-24)	.23	18 (16-22)	23 (18-25)	.11
Arterial blood gas analysis												
pH	7.39 (7.32-7.43)	7.39 (7.34-7.43)	.88	7.36 (7.28-7.45)	7.34 (7.29-7.41)	.63	7.39 (7.30-7.44)	7.41 (7.31-7.41)	.77	7.39 (7.30-7.44)	7.41 (7.35-7.43)	.27
PaO_2 (mmHg)	91 (78-110)	85 (76-111)	.68	90 (74-161)	105 (83-208)	.09	92 (76-107)	85 (76-98)	.59	96 (77-113)	86 (81-104)	.37
$PaCO_2$ (mmHg)	41 (38-48)	45 (38-51)	.50	43 (38-49)	46 (39-54)	.12	43 (36-47)	46 (35-52)	.48	43 (38-48)	45 (35-52)	.68
SaO_2 (%)	98 (95-98)	96(93-98)	.41	98 (95-99)	99 (96-99)	.27	97 (95-98)	97 (95-98)	.47	98 (95-99)	97 (96-99)	.51
FiO_2 (%)	40 (35-47)	45 (40-52)	.23	50 (40-80)	80 (50-1.00)	.07	40 (35-50)	45 (40-50)	.37	40 (30-50)	45 (40-50)	.32
PaO_2/FiO_2	231 (178-254)	203 (158-225)	.12	200 (150-246)	205 (91-236)	.38	205 (150-268)	185 (150-240)	.26	240 (181-265)	211 (116-252)	.20
Mechanical ventilator data												
TV (mL)	482 (421-581)	450 (416-484)	.09	470 (440-553)	441 (411-480)	.28	475 (460-560)	450 (421-480)	.18	490 (431-550)	450 (401-557)	.27
PEEP (cmH_2O)	6 (5-7)	6 (5-8)	.50	6 (5-7)	6 (5-8)	.36	6 (5-7)	6 (5-8)	.36	6 (5-7)	6 (5-8)	.36
PIP (cmH_2O)	23 (22-27)	26 (21-29)	.36	25 (22-29)	28 (24-29)	.27	26 (23-31)	26 (23-30)	.96	23 (20-26)	24 (19-29)	.73
Lung mechanics												
C_{dyn} (mL/cmH_2O)	36 (27-50)	29 (23-43)	.33	34 (25-46)	26 (22-33)	.06	38 (26-41)	29 (23-41)	.17	36 (30-55)	31 (26-47)	.26
R_{aw} (cmH_2O/L/s)	12 (11-14)	13 (10-15)	.53	14 (10-17)	15 (12-18)	.26	14 (11-17)	14 (12-16)	.77	12 (11-16)	12 (8-17)	1.00

All values are expressed as median (interquartile range).

C_{dyn}, dynamic lung compliance; FiO_2, fraction of inspired oxygen; HCO_3, bicarbonate; HR, heart rate; MAP, mean arterial pressure; PaO_2, arterial partial oxygen pressure; $PaCO_2$, arterial partial carbon dioxide pressure; PEEP, positive end-expiratory pressure; PIP, peak inspiratory pressure; R_{aw}, airway resistance; RR, respiratory rate; SO_2, oxygen saturation; TV, tidal volume.

There are several limitations of this study. The most important limitation of our study was the limited number of patients and our results are preliminary. Moreover, the results cannot be generalized since the study provided single-center data. The second limitation is we only had evaluated the risk of FB and bronchial washing procedure; therefore, the risks of other interventions, such as BAL and transbronchial biopsy, were not evaluated. On the other hand, our study has some strengths. First, there are limited studies conducted in the literature to assess MV modes during FB in critically ill patients. Second, we think that our protocol of increasing FiO_2 and keeping MV settings unchanged during FB is a successful and much easy approach that can easily be used in clinical practice.

CONCLUSION

Fiberoptic bronchoscopy is an essential tool for diagnostic and therapeutic purposes in the ICU. However, FB in intubated, critically ill patients needs specific considerations as they are more prone to developing complications. So far, there is limited data for how to ventilate patients during FB. Usually, to sustain adequate ventilation, VC mode is recommended. However, our preliminary findings suggest that ventilatory modes do not affect the development of complications and neither have superiority over another. More studies are needed to understand the optimal ventilation strategy during FB in critically ill patients.

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