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RESEARCH ARTICLE

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Safe and effective pressure of endotracheal tube suctioning based on sputum viscosity grades during artificial airway open suctioning procedures: A double-blind randomized controlled trial

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Abstract

Background: Endotracheal tube suctioning is an effective measure to ensure airway patency during mechanical ventilation; however, inappropriate suction pressure often leads to many adverse effects.

Aims: This study aimed to investigate safe and effective suction pressures and intracatheter pressure ranges during artificial airway open suctioning procedures.

Study Design: In this double-blind randomized controlled trial, 438 patients receiving mechanical ventilation in China were divided into nine groups according to their sputum viscosity grades and suction pressure. A random sampling method was used to select one of the three pressure groups (low-, medium- and high-pressure groups). Registered intensive care unit (ICU) nurses performed open suction manoeuvres of the artificial airway based on the pressures set by the researchers. Two teaching supervisors observed and recorded the sputum viscosity, suction pressure, minimum intracatheter pressure, maximum intracatheter pressure, heart rate, mean arterial pressure, pulse oxygen saturation, airway mucosal bleeding and sputum sound improvement score.

Results: This study finally included 438 patients. The results showed that the safe and effective suction pressures were 80–120 mmHg for grade I sputum viscosity, 150 mmHg for grade II sputum viscosity and 200 mmHg for grade III sputum viscosity in open suction procedures for ICU patients. These pressure values were associated with the lowest changes in heart rate, mean arterial pressure and pulse oxygen saturation; the lowest incidence of airway mucosal bleeding; and the highest sputum sound improvement score.

Conclusions: In an open suction procedure, accurate setting of safe and effective suction pressure for sputum of different viscosity grades can not only achieve the suction effect but also have minimal impact on the vital signs and airway mucosal bleeding of patients.

Relevance to Clinical Practice: The findings can guide critical care nurses to accurately select safe and effective initial suction pressure values rather than use general ranges when performing artificial airway open suctioning procedures.

KEYWORDS
endotracheal tube, pressure, sputum, suction, viscosity grade

1 | INTRODUCTION

Endotracheal tube (ETT) suctioning is essential in the management of patients with tracheal tubes, as it can clear respiratory secretions and ensure the patency of the artificial airway.[1] However, its potential risks include haemodynamic instability,[2] impaired gas exchange,[3] negative pressure pulmonary oedema and bronchoconstriction.[4] The most common clinical complications of ETT blockage include hypoxia, changes in heart rate and blood pressure, cardiac arrhythmia and respiratory arrest, as well as cardiac arrest and death.[5] A study conducted by Jongerden et al. showed that heart rate and mean arterial pressure increased significantly when using open and closed techniques for artificial airway suctioning.[6] Seymour et al. found that heart rate, mean arterial pressure and rapid shallow breathing index increased significantly after ETT suctioning.[7]

These adverse effects are related to negative pressure levels and the suction method.[8] According to the American Association for Respiratory Care (AARC) Clinical Practice Guidelines,[9] efforts should be made to set the suction pressure as low as possible during suctioning for the safe and effective removal of secretions. The AARC has recommended that the negative pressure for sputum suction should be controlled within the range of 80–120 mmHg in adults, and it may be increased in those with viscous sputum but should not exceed 200 mmHg.[10] Tenaillon et al. reported that a negative suction pressure between 200 and 400 mmHg is safe for endotracheal suction,[11] and Morrow et al. showed that a negative suction pressure of 200–360 mmHg augments the amount of suctioned secretions.[12] However, Basic Nursing Science (sixth edition) suggested that the suction pressure range for artificial airway suctioning was 300–400 mmHg in China.[13] These recommendations give a range of pressure options for suctioning. However, they do not make a clear distinction between the precise values of suction pressure for different patients, and no difference is demarcated between the range of suction pressures for closed and open suctioning.

The suction pressure must be set properly because insufficient intracatheter pressure in ETT suctioning may lead to ineffective and unclean removal of secretions, whereas excessive intracatheter pressure may lead to complications such as haemodynamic instability, impaired gas exchange, consolidation and atelectasis.[14,15] The intracatheter pressure is mainly obtained by setting a certain suction pressure. Bülbül Maraş et al. showed that the initial negative pressure on the suction device cannot reliably evaluate the actual negative pressure applied to the lungs.[16] Kiraly et al. and Morrow et al. noted that the intracatheter pressures mainly depend on the suction pressure, duration of the procedure, suction catheter size and ETT size.[17,18]

Although factors affecting the intracatheter pressure have been investigated in previous studies, the effect of sputum viscosity grade on suction pressure has rarely been considered. When secretions accumulate or crust, the diameter of the tracheal tube may change unpredictably,[19] which may lead to a larger negative pressure during suction. According to Poiseuille's law of physical mechanics, the higher the sputum viscosity grade, the greater the negative pressure required for suctioning; this is also in line with the AARC Clinical Practice Guidelines.[10] However, the guidelines neither define sputum viscosity grade nor specify the range of suction pressures that should be used in accordance with sputum viscosity. Wang et al. and Yang et al.

What is known about the topic

- Many modifiable factors influence intracatheter pressures, such as suction pressure, limiting the duration of the procedure, suction catheter size, endotracheal tube size and sputum viscosity grades.
- The 2022 American Association for Respiratory Care Clinical Practice Guidelines consider the effect of sputum viscosity grades on suction pressure, but do not go so far as to define sputum viscosity grades. In China, it was determined that the sputum viscosity can be divided into three grades.
- Current literature and guidelines only recommend a range of pressure options during sputum suction procedures, and few studies have discussed the safe and effective suction pressure in terms of sputum viscosity grades.

What this paper adds

- This study indicated that there were different intracatheter pressure ranges for different sputum viscosities during artificial airway open suctioning procedure.
- This study found that the higher the sputum viscosity grade, the greater the suction pressure required.
- This study showed that 80–120 mmHg in grade I of sputum viscosity, 150 mmHg in grade II and 200 mmHg in grade III were more safe and effective in open suction procedures for intensive care unit patients.

divided sputum viscosity into grades I, II and III, which guided critical care nurses in strengthening airway management.[20,21]

Open and closed suction are common systems in artificial airway suctioning procedures. Currently, strong evidence regarding the different pressures required for open and closed systems is lacking. The AARC guidelines showed no statistically significant difference in the quantity of secretions removed using open and closed suction systems.[22] A study found no significant difference in outcomes such as heart rate, breathing frequency and pulse oxygen saturation (SpO_2) between the closed and open suction systems.[10] In addition, open suction systems are less expensive and widely used around the world in the average patient.

Therefore, we conducted a double-blind randomized controlled trial to investigate the safe and effective suction pressure and intracatheter pressure range for the sputum of critically ill patients with different viscosity grades during artificial airway open suction procedures. This will guide critical care nurses in accurately selecting safe and effective suction pressure values rather than general ranges.

2 | AIMS AND OBJECTIVES OF THE STUDY

This study aimed to investigate safe and effective suction pressures and intracatheter pressure ranges during artificial airway open suctioning procedures, which could guide critical care nurses to accurately select safe and effective initial suction pressure values rather than use general ranges.

3 | DESIGN AND METHODS

3.1 | Study design

This double-blind, randomized controlled trial was conducted at a hospital in Wuhan, Hubei Province, China.

3.2 | Setting and sample

Patients aged 17–84 years who received mechanical ventilation in intensive care units (ICUs) were enrolled between May 2020 and December 2020. The inclusion criteria were as follows: intubation with an oral or nasal tube (7.5 mm), duration of ventilation ≥24 h, Riker Sedation-Agitation Scale score ≤4, stable vital signs and normal bleeding and clotting times. The exclusion criteria were as follows: asthma, injury or bleeding of the airway mucosa before suction, serious hypoxaemia, sudden change in condition during the suctioning process (termination of the operation as directed by the doctor) and refusal to participate in this study. The sample size was calculated using the G-power 3.1.9.3 program. The sample size ratio of the three groups was 1:1:1. A power of 80% and a level of significance of 0.05 showed that 60 patients had to be included in each group. Considering a loss rate of 20%, the three groups were calculated as 255 patients in total.

3.3 | Data collection tools

The ETT size of 7–8 mm has been recommended in the adult population.[13] To reduce the effect of confounding variables, sputum aspirators (7A-23D, electric suction device of Yuwell Medical, China), ETT size of 7.5 mm and suction catheter size of 12F (4.0 mm) were used in this study.

3.3.1 | Sputum viscosity grade

The sputum viscosity grade determined the suction pressure in this study. Wang et al. and Yang et al. reported that sputum viscosity can be divided into grades I–III, as defined by the same method. Therefore, sputum viscosity grades in this study were defined as grades I, II and III.

3.3.2 | Sputum suction pressure

Three levels of suction pressure were set for each sputum viscosity grade according to the AARC and Basic Nursing Science (sixth edition)[9,13]: (1) grade I: 80 mmHg (group I-80), 100 mmHg (group I-100), 120 mmHg (group I-120); (2) grade II: 120 mmHg (group II-120), 150 mmHg (group II-150), 200 mmHg (group II-200); and (3) grade III: 200 mmHg (group III-200), 300 mmHg (group III-300), 400 mmHg (group III-400).

3.3.3 | Outcome measures

(1) Intracatheter pressure was defined as the range of pressure fluctuations displayed on the suction device, which can reliably evaluate the actual suction catheter pressure applied to the lungs, and was recorded by two teaching supervisors as the registered nurse performed artificial airway suctioning. (2) Vital signs included: the change in heart rate (ΔHR = heart rate after suction − heart rate before suction); the change in mean arterial pressure (ΔMBP = mean arterial pressure after suction − mean arterial pressure before suction); the change in pulse oxygen saturation (ΔSpO_2 = pulse oxygen saturation before suction − pulse oxygen saturation after suction). (3) Mucosal bleeding included macroscopic bloodshots or bloody sputum during sputum suction. (4) Sputum sound improvement score was assessed by two teaching supervisors and calculated as 1 point if it did not improve, 2 points if it diminished and 3 points if it disappeared.[23]

3.4 | Data collection methods

Three roles were involved in this study: investigator, registered ICU nurse and teaching supervisor. The investigator was responsible for assessing the sputum viscosity of the patients and prescribing the suction pressure, as well as performing data analysis and quality control throughout the study. The registered ICU nurses were mainly

responsible for the open suctioning procedure. All nurses who participated in this study were charge nurses and were trained in the open suctioning procedure. The teaching supervisor was mainly responsible for assessing the outcome indicators. Three assessment groups were set up each day, each including one investigator and two teaching supervisors, and the sputum suctioning operation was performed by the registered nurses on duty.

First, when patients met the inclusion criteria and were enrolled, the investigator assessed the sputum viscosity grade based on the visual evaluation of secretions in the artificial airway, breath sounds,[24] the effect of airway humidification and records of sputum quantity and characteristics in the previous 24 h. The investigator then instructed the registered nurse to perform sputum suction. A random sampling method was used to select one of the three pressures, such that a folded paper was placed in an urn for each of the low-, medium- and high-pressure groups and a paper was randomly drawn. Second, registered ICU nurses performed open suction manoeuvres of the artificial airway according to the pressure selected by the investigator. Finally, two teaching supervisors observed and recorded the changes in suction pressure, vital signs and mucosal bleeding during sputum suction and evaluated the suction effect together at the end. Notably, all patients were only included in the study for one episode of suction, and neither the registered ICU nurses nor the supervisors knew the sputum viscosity grade of any individual patient.

The artificial airway open suctioning procedure consisted of five steps. Step 1 provided 100% oxygen for 60 s before sputum suction, utilizing the temporary preoxygenation protocol of the ventilator. Step 2 blocked the suction catheters to adjust the suction pressure. Step 3 involved wearing sterile gloves to connect the suction catheter. In step 4, the open suction system was used to remove secretions from the artificial airway. Step 5 involved a shallow artificial airway suction procedure in which the suction catheter was inserted no further than the end of the ETT. The duration of the procedure was limited and no more than 15 s, and 100% oxygen was given for 60 s after the procedure.[9]

3.5 | Data analysis

The results were processed with SPSS 24.0 statistical software, and the data conformed to the normal distribution. Data were analysed using the Kolmogorov–Smirnov test for normality and results were reported as mean ± standard deviation (SD) or number (proportion). The comparison of multiple groups was performed by ANOVA, and the comparison of two groups was performed by *t*-test; the enumeration data were analysed by the chi-squared test. The difference was statistically significant by two-tailed analysis with $p < .05$ (SPSS version 24.0 for Windows; IBM Corporation, Armonk, NY, USA).

3.6 | Ethical considerations

Ethics approval from the Tongji Hospital Ethical Research Committee was obtained before conducting the study (No. TJ-IRB20191228). This study complied with the principles of the Helsinki Declaration. Verbal and written consent of participants was obtained for the study; meanwhile, for the participants who lacked the capacity to give consent, legal representatives of participants would give information and consent.

4 | RESULTS

A total of 438 patients were enrolled in the study (Figure 1), including 231 males and 207 females. The age ranged from 17 to 84 years, with a mean of 61.02 ± 18.56 years.

Table 1 shows the ranges of the suction pressure, minimum intracatheter pressure and maximum intracatheter pressure in the different groups. The maximum suction pressure was close to the suction pressure, but the minimum suction pressure was significantly reduced compared with the suction pressure. Further comparison among groups showed that the minimum suction pressure ($t = 3.032$, $p = .003$) and maximum suction pressure ($t = 6.236$, $p < .001$) of group I-120 were significantly lower than those of group II-120, and the pressures of group II-200 were significantly lower than those of group III-200 ($t = 7.082$, $p < .001$ and $t = 2.454$, $p = .016$, respectively).

Table 2 shows no significant differences in vital signs, including ΔHR ($p = .177$), ΔMBP ($p = .199$) and ΔSpO_2 ($p = .373$) between the grade I sputum groups. However, the main vital signs significantly increased after suctioning. Although higher suction pressures incurred a risk of mucosal bleeding, this study did not show a statistically significant difference in mucosal bleeding between the groups ($p = .760$). No significant differences in sputum sound improvement scores were observed among the three groups ($p = .217$).

Table 3 shows no significant differences in ΔHR ($p = .054$), ΔMBP ($p = .322$) or mucosal bleeding ($p = .810$) between the grade II sputum groups. However, significant differences in ΔSpO_2 were observed ($p < .001$). In particular, the ΔSpO_2 values of groups II-120 ($t = -5.163$, $p < .001$) and group II-150 ($t = -3.203$, $p = .002$) were significantly lower than that of group II-200. In addition, significant differences in sputum sound improvement scores were observed among the three groups ($p < .001$). The sputum sound improvement scores of groups II-150 ($t = 3.620$, $p < .001$) and II-200 ($t = 5.190$, $p < .001$) were significantly higher than that of group II-120.

As expected, significant differences in ΔHR ($p < .001$), ΔMBP ($p < .001$) and ΔSpO_2 ($p < .001$) were observed among the three grade III sputum groups. Table 4 shows that the greater the suction pressure, the more significant the changes in vital signs. Further comparison between the groups showed that the values of ΔHR ($t = -4.071$, $p < .001$), ΔMBP ($t = -5.571$, $p < .001$) and ΔSpO_2 ($t = -3.901$, $p < .001$) in group III-200 were significantly lower than those in group III-400 and that the values of ΔMBP in group III-200 were significantly lower than those in group III-300 ($t = -3.250$, $p = 0.002$).

5 | DISCUSSION

As shown in Table 1, the range of effective suction pressure for the nine groups fluctuated between the minimum and maximum

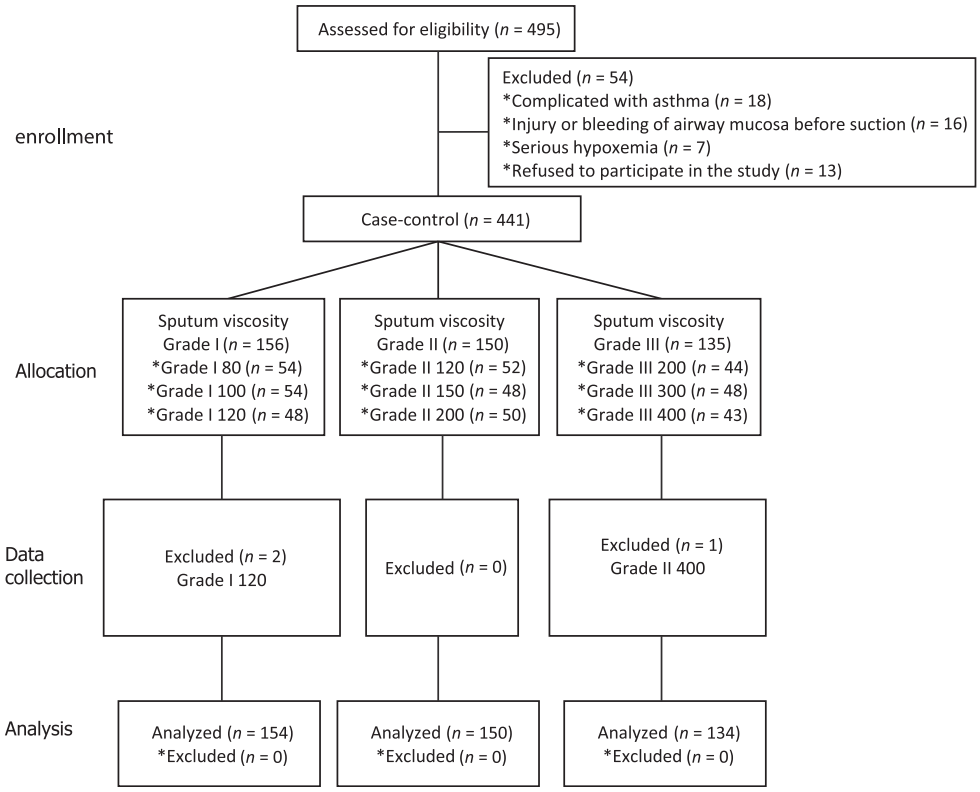

FIGURE 1 Recruitment CONSORT flowchart.

TABLE 1 Changes in suction pressure, minimum intracatheter pressure and maximum intracatheter pressure in different groups.

Groups	Case	Suction pressure (mmHg)	Minimum intracatheter pressure (mmHg)	Maximum intracatheter pressure (mmHg)
I-80	54	80	39.74 ± 1.91	74.85 ± 2.77
I-100	54	100	47.96 ± 1.98	90.04 ± 3.32
I-120	46	120	55.89 ± 2.58	107.15 ± 4.27
II-120	52	120	57.50 ± 2.65	112.65 ± 4.44
II-150	48	150	59.88 ± 2.70	143.08 ± 4.93
II-200	50	200	75.36 ± 2.93	186.64 ± 5.72
III-200	44	200	79.80 ± 3.14	189.64 ± 6.12
III-300	48	300	95.83 ± 3.38	280.88 ± 8.54
III-400	42	400	118.38 ± 4.60	376.60 ± 13.90

Note: Values are presented as mean ± standard deviation (SD).

TABLE 2 Comparison of vital signs, mucosal bleeding and sputum sound improvement score in grade I sputum groups.

Variable	I-80 ($n = 54$)	I-100 ($n = 54$)	I-120 ($n = 46$)	Statistic test	*p*-value
Vital signs					
ΔHR, bpm	4.76 ± 1.23	5.20 ± 1.32	5.35 ± 1.51	1.752[a]	.177
ΔMBP, mmHg	4.48 ± 1.06	4.59 ± 1.19	4.91 ± 1.43	1.634[a]	.199
ΔSpO_2, %	3.11 ± 0.95	3.24 ± 0.99	3.39 ± 1.04	0.994[a]	.373
Mucosal bleeding	1 (2%)	2 (4%)	2 (4%)	0.548[b]	.760
Sputum sound improvement score	2.50 ± 0.51	2.57 ± 0.50	2.67 ± 0.47	1.543[a]	.217

Note: Values are presented as either mean ± standard deviation (SD) or number (proportion).
[a]ANOVA.
[b]Chi-squared test.

TABLE 3 Comparison of vital signs, mucosal bleeding and sputum sound improvement score in grade II sputum groups.

Variable	II-120 ($n = 52$)	II-150 ($n = 48$)	II-200 ($n = 50$)	Statistic test	p-value
Vital signs					
ΔHR, bpm	5.31 ± 1.55	5.88 ± 1.61	6.06 ± 1.71	2.983[a]	.054
ΔMBP, mmHg	5.10 ± 1.46	5.42 ± 1.74	5.58 ± 1.74	1.143[a]	.322
ΔSpO_2, %	3.27 ± 0.99	3.67 ± 1.00	4.36 ± 1.14	14.177[a]	<.001
Mucosal bleeding	2 (4%)	2 (4%)	1 (2%)	0.422[b]	.810
Sputum sound improvement score	2.17 ± 0.51	2.54 ± 0.50	2.68 ± 0.47	14.240[a]	<.001

Note: Values are presented as either mean ± standard deviation (SD) or number (proportion).
[a]ANOVA.
[b]Chi-squared test.

TABLE 4 Comparison of vital signs, mucosal bleeding and sputum sound improvement score in grade III sputum groups.

Variable	III-200 ($n = 44$)	III-300 ($n = 48$)	III-400 ($n = 42$)	Statistic test	p-value
Vital signs					
ΔHR, bpm	6.14 ± 1.71	6.29 ± 1.77	7.79 ± 2.04	10.541[a]	<.001
ΔMBP, mmHg	5.75 ± 1.82	7.06 ± 2.04	8.10 ± 2.08	15.151[a]	<.001
ΔSpO_2, %	4.36 ± 1.16	4.52 ± 1.22	5.45 ± 1.42	9.267[a]	<.001
Mucosal bleeding	2 (5%)	2 (4%)	5 (12%)	2.634[b]	.268
Sputum sound improvement score	2.73 ± 0.45	2.81 ± 0.39	2.86 ± 0.35	1.166[a]	.315

Note: Values are presented as either mean ± standard deviation (SD) or number (proportion).
[a]ANOVA.
[b]Chi-squared test.

intracatheter pressures. When suction pressure increased, the corresponding intracatheter pressure range also increased. In addition, statistically significant differences were found between groups I-120 and II-120 and between groups II-200 and III-200 at the same suction pressures (120 and 200 mmHg). This study showed that the higher the sputum viscosity grade, the greater the suction pressure required.

As shown in Table 2, a suction pressure of 80–120 mmHg is safe and effective for grade I sputum, which is in accordance with the AARC Clinical Practice Guidelines. This pressure range not only achieves the suction effect but also has less impact on the vital signs of the patient and causes less mucosal bleeding. Considering that the suction pressure should be set as low as possible, when the suction pressure of 80 mmHg was selected, the average intracatheter pressure ranged from 39.74 to 74.85 mmHg, which was lower than the ranges seen in groups I-100 and I-120. This study showed that the preferred suction pressure for grade I sputum should be 80 mmHg, gradually increasing to 120 mmHg only when the suction pressure is insufficient.

For grade II sputum, Table 3 shows that groups II-150 and II-200 had the same sputum sound improvement score which was higher than that of group II-120, indicating that the higher the suction pressure, the more timely and effective the clearance of airway secretions. However, group II-200 had a greater effect on ΔSpO_2, resulting in more severe hypoxia in the body. It has been suggested that the higher the suction pressure, the more gas in the lung will be attracted, resulting in further collapse of the alveoli and reducing the effective exchange of gas.[25] Accordingly, this study found that the suction pressure of 150 mmHg can be selected for suction of grade II sputum, with the corresponding intracatheter pressure ranging from 59.88 to 143.08 mmHg. This pressure can achieve a higher suction effect and has little effect on the pulse oxygen saturation of the patient.

As shown in Table 4, significant differences in the vital signs were observed between the grade III sputum groups, indicating that excessive suction pressure seriously affected the vital signs of the patient. This result is consistent with the conclusions of Mohammadpour et al.[26] and Uğraş et al.[27] Suctioning complications were defined as any incidents occurring within 5 min, which include a decrease in SpO_2 exceeding 5% during suctioning compared with pre-suctioning.[16] We found that ΔSpO_2 decreased by 5.45% in group III-400, indicating that this pressure value must be avoided to prevent complications. For grade III sputum, a suction pressure of 200–400 mmHg can achieve the same sputum sound improvement score and does not increase the incidence of mucosal bleeding when shallow artificial airway suctioning is applied. Therefore, this study concluded that for grade III sputum, the preferred suction pressure should be 200 mmHg. This pressure not only achieved an effective suction effect but also significantly reduced the changes in vital signs during suctioning.

6 | LIMITATIONS

This study was limited by the fact that it was conducted in only four ICUs in one hospital and that artificial airway open suctioning procedures were performed, along with the use of only 7.5–mm ETTs and

12F suction catheters as experimental materials. Additionally, only three suction pressure groups were established based on the grades of sputum viscosity. Although Wang et al. and Yang et al. reported that sputum viscosity can divided into three grades, it can be argued that this grading method has only been reported in the Netherlands, the United Kingdom, Greece, Italy and China.

7 | IMPLICATIONS FOR PRACTICE AND FURTHER RESEARCH

At present, there are few studies on the safe and effective pressure of ETT suctioning based on sputum viscosity grades in the real world. An important reason is that there is no standardized tool to evaluate sputum viscosity grades, resulting in inconsistent methods of sputum viscosity grading on a global scale. The aim of this study was to investigate the safe and effective suction pressure based on the sputum viscosity grades in China and to help critical care nurses to quickly and accurately set the value of suction pressure rather than use general ranges. Unfortunately, this study only focused on open sputum suctioning, and several suction pressures were chosen. Therefore, future studies and clinical practice can define sputum viscosity grades and use closed suction to investigate the safe and effective pressure of ETT suctioning.

8 | CONCLUSIONS

The results of this investigation showed that the safe and effective suction pressures for sputum with different viscosities were 80–120 mmHg (grade I), 150 mmHg (grade II) and 200 mmHg (grade III). The suction pressure was gradually increased only when it was found to be insufficient. This study helps critical care nurses to quickly and accurately set the value of suction pressure rather than use general ranges during artificial airway open suctioning to achieve effective clearance of airway secretions.

AUTHOR CONTRIBUTIONS

Weiquan Liu contributed to conceptualization, methodology, software, validation, formal analysis, data curation, writing—original draft, project administration. Chunling Guo contributed to methodology, software, formal analysis, investigation, data curation, project administration, writing—review and editing. Miqi Li contributed to writing—review and editing. Jie Xiong contributed to resources, conceptualization, methodology, validation, and supervision.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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