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Peak expiratory flow during mechanical insufflation-exsufflation: endotracheal tube versus facemask

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Abstract

Background: Mechanical insufflation-exsufflation (MI-E) applied through the endotracheal tube (ETT) can effectively eliminate airway secretions in intubated patients. However, the effect of the interface (ETT vs. facemask) on expiratory airflow generated by MI-E has not been investigated. This study aimed to investigate the effect of the ETT on peak expiratory flow (PEF), along with other associated factors that could influence PEF generated by MI-E.

Methods: Intubated participants received two sessions of MI-E via ETT therapy per day for two consecutive days. One MI-E session consisted of five sets of either constant (+40/-40 cmH_2O) or incremental (+30/-30 to +50/-50 cmH_2O) pressure applications. Following extubation, MI-E sessions were repeated using facemask. Expiratory airflow during MI-E therapy was continuously measured and every PEF during each application was analysed using linear mixed-effect and generalised linear mixed models.

Results: A total of 12 participants (nine [75.0%] men; mean [SD] age, 74.0 [10.2] years) completed all MI-E sessions with both ETT and facemask interfaces. The PEF generated during MI-E treatment was influenced by the interface (ETT vs. facemask), pressure gradient, and number of session repetitions. Adjusted mean PEF values for MI-E via ETT and facemask at +40/-40 cmH_2O were -2.521 and -3.114 L/s, respectively, and -2.956 and -3.364 L/s at +50/-50 cmH_2O, respectively. At a pressure gradient of +40/-40 cmH_2O, only 172 of 528 MI-E trials via ETT (32.6%) achieved a PEF faster than -2.7 L/s, whereas 304 of 343 MI-E trials via facemask (88.6%) exceeded PEF < -2.7L/s.

Conclusions: MI-E via ETT generated slower PEF than via facemask, suggesting that a higher-pressure protocol should be prescribed for intubated patients. An insufflation-exsufflation pressure up to +50/-50 cmH_2O could be considered to produce a PEF faster than 2.7 L/s, and the applications were safe and feasible for patients under invasive mechanical ventilation.

Keywords: mechanical insufflation-exsufflation, cough assist, expiratory flow, endotracheal tube, mechanical ventilation, respiratory therapy

Introduction

Patients in the ICU receiving mechanical ventilation (MV) often require frequent removal of airway secretions. Accumulated mucus, without timely removal, aggravates airway obstruction that can induce hypoxemia, hypoventilation, pulmonary atelectasis, and ventilator-associated pneumonia.[1] Acute pulmonary infections and impaired mucociliary transport due to prolonged immobility, in addition to the use of sedatives, worsen the accumulation of large amounts of airway secretions in critically ill patients.[2]

Endotracheal suctioning through the endotracheal tube (ETT) has been commonly applied to maintain airway hygiene in the ICU. However, only the secretions from the larger proximal airways can be cleared using endotracheal suctioning, because negative pressure can only be directly applied within a limited area of the bronchial tree.[2, 3] Mechanical insufflation-exsufflation (MI-E) inflates the lungs using positive pressure and then abruptly shifts to negative pressure across all airways to simulate the physiologic cough, which facilitates the movement of secretions from the peripheral to the central airways.[4] Application of MI-E in the ICU could be another strategy to effectively remove secretions in intubated patients[5-7]; however, there is insufficient evidence regarding the efficiency of sputum removal using MI-E compared with conventional endotracheal suctioning. Previous studies have used different outcome measures and have drawn inconsistent conclusions about the effectiveness of MI-E in the ICU.[8,9] Additionally, the applied insufflation-exsufflation pressures ranged from +30/-30 cmH_2O to +50/-50 cmH_2O with no consensus regarding the optimal pressure settings.[3, 10-12] These differences in protocol hinder current research on the effectiveness of MI-E during critical care.

The ETT interface can reduce the diameter of airway at the main bronchi and increase the total airway resistance, which might result in slower expiratory airway flow compared with the facemask interface.[13] However, the effect of the ETT on expiratory airflow during MI-E therapy has not yet been examined. In this study, we compared peak expiratory flow (PEF) during MI-E therapy

through ETT before extubation, and through facemask after extubation, in the same participants. Through these comparisons, we investigated the effect of the ETT on PEF, along with other associated factors that could influence PEF generated by MI-E. The results of this study are expected to provide evidence upon which to base future protocols for MI-E therapy in intubated patients.

Methods

Study participants

We recruited subjects receiving MV in the ICUs of a single tertiary centre hospital who require MI-E therapy owing to large amount of secretions, i.e., patients who needed endotracheal suctioning via ETT more frequently than every 6 hours. Although, endotracheal suctioning is necessary whenever clinically indicated to remove secretions, frequent suctioning (>6 times per day) is known to increase the possibility of adverse events like hypoxemia, haemorrhagic secretions, and blood pressure or heart rate change.[14] When the patient lacked effective cough capacity and had abundant secretions, extubation had to be postponed due to a high risk of post-extubation respiratory failure and reintubation;[1,2] thus, MI-E was applied to remove secretions and maintain proper airway patency.

From June 2019 to July 2020, a total of 457 subjects were consulted for ICU rehabilitation treatment, and only intubated subjects on any mode of ventilation without planning extubation within the next 24 hours were recruited for MI-E therapy through ETT (n=242). Subjects deemed too unstable for MI-E therapy initiation (PEEP >8 cmH_2O, ratio of P_{aO2} to F_{IO2} <150 mmHg, RR >35/min, heart rate (HR) >130 bpm, systolic blood pressure <90 or >160 mmHg, and diastolic blood pressure <50 or >110 mmHg) (n=64); subjects with contraindications to MI-E such as active communicable respiratory infections, barotrauma or pneumothorax within 1 month (n=52); and subjects who declined or were unable to participate (n=78) were excluded from the study (e-Figure 1 of the

supplementary material, available at http://www.rcjournal.com).[10, 15, 16] A total of 21 subjects were enrolled as participants in the study to receive MI-E therapy through ETT and facemask. The Institutional Review Board (IRB) of the Ethical Committee of Seoul National University Hospital approved and monitored the study in accordance with the Declaration of Helsinki (IRB No. 1907-114-104).

MI-E protocol

After obtaining informed consents from the participants or their legal guardians who were substitute decision-makers, each participant was scheduled for two MI-E sessions via ETT therapy per day for two consecutive days. The participants were divided into two groups (details are presented in Figure 1). In group I, the pressure was increased from +30/-30 to +50/-50 cmH_2O in the first MI-E session; in group II, a constant pressure of +40/-40 cmH_2O was used for the entire first session. For the second session on day one, the pressure settings were reversed for each group in order to evaluate the effect of different pressure application strategies (constant vs. incremental) on airflow generated through the ETT in the same participants (Figure 1a). The same pressure settings as those used in the first session on day one were applied for both sessions on day two to evaluate the effects of the number of MI-E treatment sessions on airflow (Figure 1b). Since the timing of extubation varied according to individual medical conditions, not all participants completed four sessions of MI-E with flow measurements. If the extubation was successfully performed before the initial four successive MI-E sessions, only completed flow measurements were included in the analysis. Contrarily, the participants who were not extubated even after the four sessions had continued MI-E treatment via ETT until extubation using the incremental pressure settings. However, MI-E treatments after the initial four sessions during the intubation period were neither measured nor included in the analysis.

After extubation, MI-E via facemask with the same pressure protocols as those used on day one was employed to investigate the effect of the interface (ETT vs. facemask) on airflow (Figure 1c).

One cough cycle comprised 3 s of insufflation, 2 s of exsufflation, and 2 s of pause, with a total of five consecutive coughs (repetitions) within one set. All participants received a total of five sets per treatment session with a rest period of <2 min between each set. Longer insufflation followed by shorter exsufflation and 'low' inhale flow setting were chosen based on previous results from the lung-model analysis to simulate the physiology of a cough.[17-19] Further detailed information about the MI-E treatment protocol can be found in the supplementary material (available at http://www.rcjournal.com)

Measurements

The Cough Assist E70™ (Phillips-Respironics, USA) was serially connected to a flowmeter (Citrex™ H4 Gas Flow Analyser, IMT Analytics AG, Switzerland), a single-use antibacterial filter, and either the ETT or facemask interface (Figure 2). The flowmeter was calibrated and validated annually by IMT Analytics, wherein the confirmed maximal uncertainty error was ≤0.75% for all measurements. Insufflation-exsufflation airflow was measured every 0.001 s during the entire treatment session. The primary outcome was PEF (in L/s): the lowest value of airflow measured during exsufflation since the value was measured and analysed with negative signs (See e-Figure 2 of the supplementary material available at http://www.rcjournal.com).

The secondary outcomes were the feasibility and safety of MI-E therapy when using either ETT or facemask interface with pressures ranging from +30/-30 to +50/-50 cmH_2O. These outcomes were evaluated using the percentage of session completion and the number of adverse events that occurred during the application of MI-E therapy. Adverse events were defined as systolic blood pressure increase of >20%, mean arterial pressure decrease of >15% from baseline, HR ≥140 bpm or increased by >20% from baseline, SpO_2 <85% even after oxygen administered for a maximum of 2 min, RR increase of >50% from baseline and/or >35/min. Participants were also asked to report any discomfort (e.g., dyspnoea, dizziness, nausea, worsening of gastro-oesophageal reflux, chest or

abdominal discomfort) during or after MI-E therapy,[4, 15] and to report their satisfaction with the treatment using a 5-point Likert scale: from 1 = 'very dissatisfied' to 5 = 'very satisfied' if they were able to respond to the questions (Richmond Agitation-Sedation Scale[20] score between -1 and +1). Simple chest radiographs were evaluated daily until the day after the completion of the MI-E therapy sessions to confirm that no complications, such as pneumothorax or pneumomediastinum, had occurred.[16]

Information on demographic characteristics (age, sex, body mass index), reasons for ICU admission and admitted ICU type, severity of the current illness measured by the Acute Physiology and Chronic Health Evaluation score,[21] ETT diameter, and MV duration was obtained from medical records.

Statistical analysis

As repeated measurements from the same participant were correlated with each other, a linear mixed-effect model (LMM) was employed with PEF as the dependent variable.[22] The model included applied pressure, number of MI-E treatment sessions, number of coughs (repetitions) within each set, assigned group (group I or II), interface (ETT vs. facemask), and any relevant interactions between a given pressure gradient and interface or number of sessions on PEF. The variabilities between participants, such as the absolute value of the baseline expiratory airflow, were included as random effects. Additionally, a generalised linear mixed model (GLM) of binary logistic regression was applied to evaluate the variables related to sufficient exsufflation flow through MI-E treatment, defined as PEF <-2.7 L/s. The cut-off value of -2.7 L/s for PEF was chosen based on the study from JR Bach[23], which suggests that peak cough flow of 160 L/min (2.7 L/s), whether assisted or not, is the minimum expiratory airflow required to adequately clear secretions in subjects with artificial airways.[13, 23] Other clinical and demographic characteristics were analysed using descriptive statistics. Statistical analysis was performed using SPSS version 25 (SPSS, Inc., Chicago, IL), and a *p*-value

<0.05 was considered statistically significant.

Results

Demographics of participants

Of the 21 participants recruited, two (9.5%) were excluded because they could not cooperate with the insufflation-exsufflation cycle of MI-E therapy. That is, they could not coordinate their inspiration with 3 s of insufflation, and they coughed too early during this phase, such that no air remained to effectively cough out during the exsufflation phase.

The remaining 19 participants completed the MI-E therapy via ETT. However, three participants (two from group I and one from group II) discontinued additional MI-E treatment via facemask because they did not have substantial secretions after extubation anymore. Four participants (two from group I and two from group II) could not receive MI-E therapy via facemask because their treatment plan for critical care was changed from extubation to tracheostomy owing to a high risk of post-extubation respiratory failure. A total of 12 participants (six from each group) completed all the MI-E sessions with both ETT and facemask interfaces (See e-Figure 1 of the supplementary material available at http://www.rcjournal.com). The internal diameter of the ETT ranged from 6.5 to 8.0 mm. The participants' characteristics are presented in Table 1.

PEF differences according to interfaces: ETT vs. facemask

Adjusted mean PEF was calculated assuming that the covariables other than the pressure gradient (i.e., number of treatment sessions, assigned group for pressure setting protocol, and number of coughs within a set) were fixed to the average values. For each pressure gradient, PEF via ETT was always slower than that generated via facemask (Table 2). Figure 3 shows that the PEF generated

during MI-E became faster as a higher pressure gradient was applied whether via ETT or facemask. A comparison of the PEF according to the type of interface used, within the same participants, at each applied pressure is also provided in e-Figure 3 (supplementary materials available at http://www.rcjournal.com). When a pressure gradient of +40/-40 cmH_2O was applied, only 172 of 528 MI-E trials via ETT (32.6%) achieved a PEF faster than the -2.7 L/s cut-off value, whereas 304 of 343 MI-E trials via facemask (88.6%) exceeded the PEF cut-off value. Even at +50/-50 cmH_2O of pressure gradient, 66 of 85 MI-E via ETT trials (77.6%) reached a PEF <-2.7 L/s, whereas 55 of 60 MI-E via facemask trials (91.7%) reached the cut-off value.

Feasibility and safety of MI-E application through ETT

No adverse events with respect to haemodynamic instability were reported during or after the application of MI-E at all pressure stages to +50/-50 cmH_2O through both interfaces. Neither pneumothorax nor pneumomediastinum was reported from daily evaluation of simple chest radiographs during and after the MI-E treatment period. None of the participants rejected the completion of the incremental pressure protocols via both ETT and facemask. Among the eight participants who were able to answer the questions, no treatment-related discomfort was reported; however, one participant reported nausea after MI-E through the ETT, which resolved within 5 min. Those eight participants provided their responses for the Likert scale of satisfaction; average scores of 3.6 and 3.9 were reported for MI-E via ETT and facemask, respectively. When asked which interface they found more comfortable, four participants preferred ETT, three preferred facemask, and one considered both interfaces to be similarly comfortable.

Determinants of PEF during MI-E use

The LMM analysis demonstrated that the interface (ETT vs. facemask), pressure, and number of

treatment sessions were factors associated with PEF (Table 3). Compared with PEF generated at +30/-30 cmH_2O, the increasing pressure gradient generated faster PEF (negative number of effect estimates for PEF difference represents faster velocity). Compared to facemask, MI-E through ETT resulted in slower PEF (positive number of effect estimates for PEF difference represents slower velocity). Furthermore, the interaction between interface type and pressure was also correlated with PEF (Table 3). Therefore, the absolute amount of increase in the PEF owing to the increase in the pressure gradient differed depending on the interface. However, the assigned pressure setting protocol (Group I or II) was not associated with the velocity of the PEF. In the analysis of the GLM, the factors related to whether PEF exceeded the cut-off value of -2.7 L/s were number of treatment sessions, interface (ETT vs. facemask), and pressure—the same factors reported from the LMM analysis (Table 4).

Discussion

This study reveals that the PEF generated during MI-E treatment was influenced by the interface, pressure gradient, and number of treatment sessions. An ETT increases airway resistance since it is a long, narrow tube; therefore, the PEF through the ETT becomes slower in critically ill patients under MV care. This may hamper the efficiency of sputum removal via artificial airway; therefore, when applying MI-E through the ETT interface, a higher-pressure gradient of up to +50/-50 cmH_2O could be recommended to obtain a PEF equivalent to that when using the facemask interface.

Although several studies still selected a pressure of +40/-40 cmH_2O for MI-E through ETT,[3, 24, 25] more recent studies have reported the feasibility and safety of MI-E use via ETT with pressures up to +50/-50 cmH_2O.[10, 11] Additionally, our study reported that a pressure of +50/-50 cmH_2O was more beneficial in generating faster PEF and was safe and feasible for intubated participants. These results are in line with previous bench studies with a lung model, which recommended pressure higher than +40/-40 or +50/-50 cmH_2O in subjects with artificial airways or higher airway resistance.[13, 26]

Ventilator-induced lung injury (VILI) occurs when high lung volumes cause alveolar stretch injury and subsequent biologic and systemic reactions.[27] Since, the plateau pressure is considered to be a variable which reflects the risk of lung overdistension,[28] either a low tidal volume or low plateau pressure is conventionally preferred to prevent VILI. On the other hand, there has been little evidence about inducing VILI from intermittent short durations of high peak inspiratory pressure, such as in MI-E treatment. Meanwhile, many studies that applied MI-E using an insufflation pressure of 50 cmH_2O reported improved lung conditions immediately after the treatment.[10, 29] In terms of exsufflation, -50 cmH_2O is less negative pressure than that physiologically produced by a cough or negative pressure delivered through endotracheal suctioning (recommended as 95 to 200 cmH_2O).[30] Although the Cough Assist E70™ can produce negative pressures of up to -70 cmH_2O, only pressures within -50 cmH_2O were used in this study following previously reported protocols[3, 8-12] for participants admitted to the ICU. As shown in Table 2, when applying MI-E via ETT, even when using a pressure of +50/-50 cmH_2O, the PEF was still slower than when using a pressure of +40/-40 cmH_2O via facemask. For effective elimination of airway secretions, a negative pressure below -50 cmH_2O might be required. However, safety issues, such as atelectasis, when applying further negative pressure via ETT in subjects receiving MV, especially with the PEEP setting, remain to be investigated.

By analyzing the physiology of a cough, a PEF range of 160–180 L/min has been proposed as the cut-off value to achieve effective secretion elimination.[15, 23, 31-33] Therefore, a PEF of 2.7 L/s was regarded as the goal of minimum PEF generation during MI-E therapy in this study (Table 4). Irrespective of such absolute values of PEF or applied pressure, the expiratory flow bias,[19] i.e., the difference in the absolute value of airflow regardless of the in-exsufflation direction, has been suggested to be better correlated with the actual mucus displacement in a bench study simulating a patient with an artificial airway on MV.[19] In this study, the flow bias was larger with the ETT compared to the facemask (see e-Table 1 of the supplementary material available at http://www.rcjournal.com). If the flow bias rather than the PEF is regarded as the sole index of

effective sputum removal, then it is possible to interpret that the MI-E treatment through an ETT could be performed with lower pressure than a facemask. However, in this case as well, the pressure setting of +50/-50 cmH_2O is still preferable with the ETT as the expiratory flow bias was steadily increasing up to +50/-50 cmH_2O; meanwhile, +40/-50 cmH_2O might be enough for the facemask since the flow bias decreased when the insufflation pressure was increased from +40/-50 cmH_2O to +50/-50 cmH_2O. Additionally, these results suggest that unlike the protocols utilized in the previous studies,[9] it might be more appropriate to secure the insufflation volume[34] by increasing the insufflation time rather than the insufflation pressure because increasing the pressure increases the insufflation flow (flow =△pressure/resistance) and thus decreases the flow bias.

The result of a faster PEF with a facemask than an ETT in our study might be related not only with the applied interface, but also with the different time-points when the MI-E was applied. Difference in the participants' sedation levels and cooperation, lesser secretions, and decreased airway resistance, which could change within the study period, might have influenced the generated PEF. In this study, however, the MI-E therapy sessions could only be provided first through ETT and next through facemask after extubation; a reversed order was not possible in clinical settings.

Another limitation of this study is the lack of information regarding the amount of airway secretions eliminated and the clinical benefits such as changes in SpO_2 levels or success of MV weaning after MI-E application, which should be considered in future studies. In addition, MI-E application strategies other than pressure gradients were not included in this study. For example, the insufflation time affects the in-exsufflation volumes which might affect the PEF or expiratory flow bias, and eventually the efficiency of sputum removal.[34, 35] However, in this study, the insufflation time was fixed at 3 s. Lastly, limited sample size may have influenced the significance of interfaces on generated PEF; however, the post-hoc power analysis indicated statistically enough power for this study based on a large number of repetitive measurements within the same participants. A sample size of 12, with a total of 1,500 measurements, was found to achieve 100%, 95%, and 92% power for the

main effect of the interface, the main effect of the pressure, and their interaction effect, respectively. The minimum detectable difference was assumed to be 0.17 L/s (10 L/min)[35, 36], and a subject variance and a residual variance were assumed to be 0.08 and 0.05, respectively based on our study data.

MI-E through a tracheostomy tube was not evaluated; although, four out of the initially enrolled 21 subjects (19%) underwent tracheostomy after extubation. As MI-E can be successfully applied through the tracheostomy tube as well as the ETT,[6,23,24] future researches should also include the tracheotomised population to expand the use of MI-E in critical care.

Conclusions

The use of MI-E via ETT generated slower PEF than did the use of MI-E via facemask, suggesting that a higher-pressure protocol should be considered for intubated patients. An insufflation-exsufflation pressure of +50/-50 cmH_2O was necessary to produce a high PEF faster than 2.7 L/s and the applications were safe and feasible. The factors related to PEF generation by MI-E were pressure gradient, interface, and number of session repetitions.

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Figure 1.

Flowchart of the study to evaluate correlating factors with generated peak expiratory flow (PEF) from mechanical insufflation-exsufflation (MI-E)

(a) comparison of PEF based on the applied pressure, (b) comparison of PEF based on the increasing number of treatment sessions, and (c) comparison of PEF based on the interface (endotracheal tube vs. facemask).

Figure 2.

Measurement of airflow during mechanical insufflation-exsufflation using a flowmeter.

Figure 3.

Peak expiratory flow (PEF) during mechanical insufflation-exsufflation treatment according to pressure gradient and interface.

*Numbers represent mean (standard deviation).

Quick Look

Current Knowledge

Critically ill patients receiving mechanical ventilation prefer mechanical insufflation-exsufflation (MI-E) than endotracheal suctioning. The MI-E improves airway hygiene through artificial airway as well as through facemask. However, wide variations in the settings have been prescribed for MI-E via endotracheal tube without suggesting which pressure is sufficient to reach a peak expiratory flow of >2.7 L/s, which has been regarded as an efficient cough generated by MI-E.

What this paper contributes to our knowledge

The use of MI-E via endotracheal tube is safe and feasible with patients under invasive ventilation in the ICU. Generated peak expiratory flow is significantly slower through endotracheal tube than through facemask, and a higher pressure protocol should be considered for intubated patients. An in-exsufflation pressure of +50/-50 cmH_2O is necessary to reach peak expiratory flow of -2.7 L/s for efficient cough through endotracheal tube using MI-E.

Table 1. Characteristics of the participants.

Characteristics	Study Population (n=12)
Age (years)	74.0 ±10.2
Gender	
Male	9 (75.0%)
Female	3 (25.0%)
BMI	21.1 ± 3.16
APACHE II (at ICU admission)	19.5 ± 9.35
ICU type	
Medical	3 (25.0%)
Cardiovascular	7 (58.3%)
Surgical	2 (16.7%)
Main cause for ICU admission	
ARDS	5 (41.7%)
After thoracic surgery	7 (58.3%)
P/F ratio (mmHg)	286.14 ± 76.73
PEEP (cmH_2O)	5.42 ± 1.24
ETT size (mm); internal diameter	
6.5	1 (8.3%)
7.0	4 (33.3%)
7.5	6 (50.0%)
8.0	1 (8.3%)
Intubation period (day)	6.83 ± 3.69

Numbers are presented as mean± standard deviation or number(percentage)

*BMI: body mass index, APACHE: Acute Physiology and Chronic Health Evaluation, P/F ratio: ratio of P_{aO2} to F_{iO2}, ETT: endotracheal tube.

Table 2. Comparison of peak expiratory flow (PEF) during mechanical insufflation-exsufflation according to the interfaces: endotracheal tube vs. facemask.

Pressure (cmH_2O)	PEF via endotracheal tube (L/s)	PEF via facemask (L/s)
+30/-30	-2.181 [-2.372, -1.991]	-2.661 [-2.850, -2.472]
+30/-40	-2.369 [-2.559, -2.179]	-2.995 [-3.184, -2.807]
+40/-40	-2.521 [-2.700, -2.341]	-3.114 [-3.293, -2.935]
+40/-50	-2.731 [-2.921, -2.541]	-3.326 [-3.515, -3.137]
+50/-50	-2.956 [-3.146, -2.766]	-3.364 [-3.552, -3.175]

Numbers are adjusted mean PEF [95% confidence interval].

Adjusted mean PEF were calculated using other covariables (number of treatment session, assigned group for pressure setting protocol, and number of coughs with a set) assumed to be fixed as constant average values.

Table 3. Linear mixed-effect model analysis for peak expiratory flow (PEF).

Predictor	*p*-value	Effect estimates for PEF difference (L/s) [95% Confidence Interval]
Pressure setting protocol (Group I vs. II)	0.542	
Number of treatment session	<0.001*	
Repetitions within set	0.057	
Pressure	<0.001*	+30/-30 cmH_2O (reference)
+30/-40 cmH_2O		-0.365 [-0.578 ~ -0.153]†
+40/-40 cmH_2O		-0.500 [-0.666 ~ -0.334]
+40/-50 cmH_2O		-0.715 [-0.928 ~ -0.502]
+50/-50 cmH_2O		-0.852 [-1.065 ~ -0.639]
Interface	<0.001*	Facemask (reference)
Endotracheal tube		+0.480 [0.358 – 0.602]‡
Interaction		
Interface *Pressure	0.023*	
Number of treatment session *Pressure	<0.001*	

*p-value < 0.05.

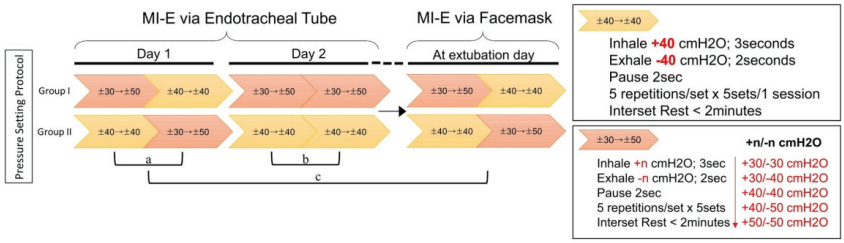
† Negative number of effect estimate for PEF difference represents faster velocity.

‡ Positive number of effect estimate for PEF difference represents slower velocity.

Table 4. Generalized linear mixed model analysis for predicting whether peak expiratory flow reaches 2.7L/s.

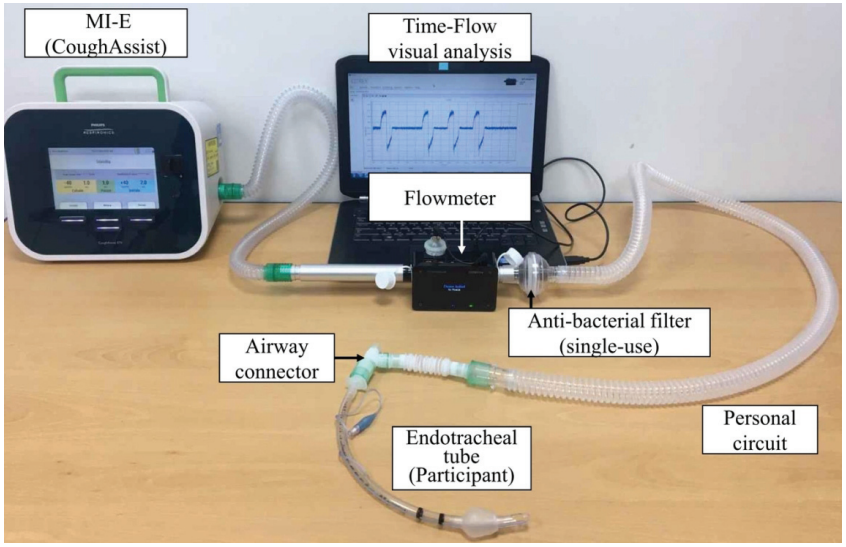
Predictor	*p*-value	odds ratio [95% Confidence Interval]
Pressure setting protocol (Group I vs. II)	0.718	
Number of treatment sessions	<0.001*	
Repetitions within set	0.306	
Pressure	<0.001*	+30/-30 cmH_2O (reference)
	+30/-40 cmH_2O	5.856 [1.883 – 18.21]
	+40/-40 cmH_2O	58.43 [22.73 – 150.2]
	+40/-50 cmH_2O	187.0 [54.27 – 644.4]
	+50/-50 cmH_2O	862.9 [235.4 – 3,162]
Interface	<0.001*	Facemask (reference)
	Endotracheal tube	0.006 [0.003 – 0.014]

*p-value < 0.05.



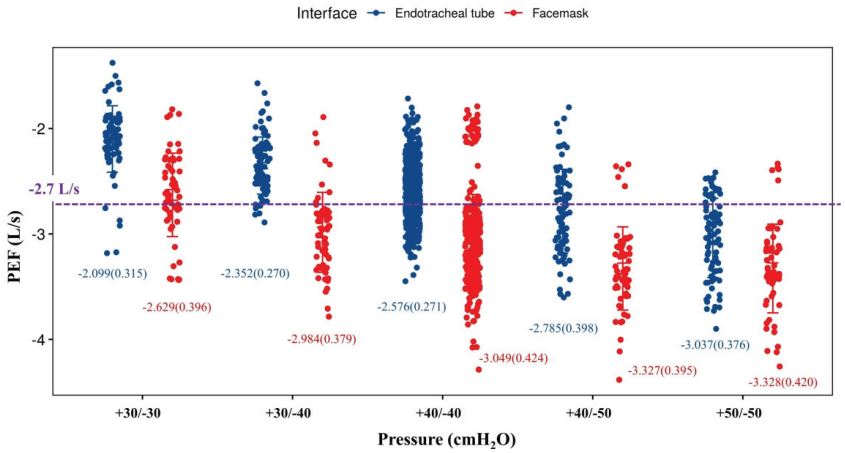
Flowchart of the study to evaluate correlating factors with generated peak expiratory flow (PEF) from mechanical insufflation-exsufflation (MI-E)
(a) comparison of PEF based on the applied pressure, (b) comparison of PEF based on the increasing number of treatment sessions, and (c) comparison of PEF based on the interface (endotracheal tube vs. facemask).

147x43mm (300 x 300 DPI)



Measurement of airflow during mechanical insufflation-exsufflation using a flowmeter.

110x71mm (300 x 300 DPI)



Peak expiratory flow (PEF) during mechanical insufflation-exsufflation treatment according to pressure gradient and interface.
*Numbers represent mean (standard deviation).

99x53mm (600 x 600 DPI)