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Use of Cough Peak Flow Measured by a Ventilator to Predict Re-Intubation When a Spirometer Is Unavailable

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BACKGROUND: A ventilator includes the function to measure flow velocity. We aimed to compare the predictive accuracy for re-intubation diagnosed by cough peak flow (CPF) measured by a spirometer and a ventilator. METHODS: Endotracheally intubated subjects who passed a spontaneous breathing trial were enrolled. Before extubation, CPF was measured by a spirometer and a ventilator, respectively. Re-intubation was recorded at 72 h after extubation. RESULTS: A total of 126 subjects were enrolled. Among them, 15 subjects (12%) experienced re-intubation. CPF was lower in re-intubated subjects than those without re-intubation (measured by a spirometer: 54 ± 30 L/min vs 86 ± 37 L/min, $P < .001$; and measured by a ventilator: 50 ± 22 L/min vs 80 ± 26 L/min, $P < .001$). CPF measured by a spirometer and a ventilator had similar area under the curve of receiver operating characteristic (0.79 vs 0.83, $P = .26$). When a CPF of 56.4 L/min was measured by a spirometer as cutoff value, the sensitivity and specificity to distinguish re-intubation was 73 and 87%, respectively. When it was measured by a ventilator, the cutoff value, sensitivity, and specificity were 56 L/min, 73%, and 85%, respectively. CONCLUSIONS: CPF measurement by a ventilator was convenient, affordable, and safe. It had a predictive accuracy for re-intubation similar to that of a spirometer. *Key words: cough peak flow; spontaneous breathing trial; extubation; re-intubation.* [Respir Care 0;0(0):1–•. © 0 Daedalus Enterprises]

Introduction

Extubation is recommended when a patient passes a spontaneous breathing trial (SBT).[1-3] However, re-intubation frequently happens in ICUs. The prevalence of re-intubation within 48–72 h after planned extubation is 9–17% (average value of 13%).[4-7] In addition, re-intubation is associated with an 8-fold increase in nosocomial pneumonia and a 3-fold increase in hospital death.[8] Thus, it is very important to decrease re-intubation. The first step is to identify patients at high risk for re-intubation.

Cough strength is strongly associated with re-intubation; patients with a weak cough are more likely to experience re-intubation.[5,9-20] Cough peak flow (CPF) is commonly used to reflect cough strength because it is an objective measurement. A flow meter is the most common device to measure CPF. However, not all ICUs provide a flow meter to measure CPF; some of them use a semiquantitative cough strength assessment.[5,9-13] However, a semiquantitative assessment is not as accurate as an objective assessment. Thus, a device existing in all ICUs serving as an objective measurement of cough strength is needed.

Invasive mechanical ventilators exist in all ICUs. The ventilator itself includes an internal flow meter that can objectively measure CPF. Thus, we aimed to explore whether the predictive accuracy of re-intubation diagnosed by cough peak flow measured by a ventilator was the same as that of a spirometer.

Methods

This was a prospective observational study performed in a respiratory ICU of a teaching hospital from September 2014 to July 2016. Endotracheally intubated patients with

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a successful SBT were eligible for this study. However, patients with age <18 years and inability to cough on command were excluded. We also excluded patients who had undergone tracheotomy. Informed consent was obtained from the subjects or their families. The ethics committee and institutional review board of the First Affiliated Hospital of Chongqing Medical University approved this study.

Subjects were managed per our hospital's protocol. Strategies to prevent ventilator-associated pneumonia (eg, elevation of the head of the bed) were used in all subjects. Antibiotics were administered according to the results of culture and the attending physicians' experience in patients with pneumonia. Anticoagulant therapy and thrombolytic therapy were used in subjects with pulmonary embolism. Bronchodilators were used in subjects with asthma or bronchospasm. Mucus-controlling agents were used in subjects with excessive viscous mucus secretions. Adjustment of parameters and liberation from mechanical ventilation were mainly managed by attending physicians and respiratory therapists. Every morning, the sedation was interrupted to judge whether subjects required sedation again or had reached the criteria for a weaning test.

Criteria for the weaning test were as follows: improvement of the underlying cause of acute respiratory failure, P_{aO_2} ≥60 mm Hg with F_{IO_2} ≤0.5, PEEP ≤5 cm H_2O, temperature ≤38°C, systolic blood pressure between 90 and 180 mm Hg (without vasopressor therapy or with only a low-dose vasopressor, such as dopamine or dobutamine ≤5 μg/kg/min), heart rate ≤140 beats/min, and breathing frequency ≤30 breaths/min.[15] If the criteria for the weaning test were reached, we performed an SBT for 120 min. Low-level pressure support was used for an SBT (6 cm H_2O for an inner diameter of the endotracheal tube ≥7.5 mm and 8 cm H_2O for <7.5 mm). However, subjects who presented with one of the following criteria were defined as SBT failure: breathing frequency ≥35 breaths/min, frequency/tidal volume (rapid shallow breathing index) >105, S_{pO_2} <90% at F_{IO_2} ≥0.5, heart rate ≥140 or ≤50 beats/min, systolic blood pressure ≥180 or ≤90 mm Hg, acute respiratory acidosis with increasing in P_{aCO_2} ≥10 mm Hg, diminishing consciousness or diaphoresis, and clinical signs indicating respiratory muscle fatigue, labored breathing, or both.[15]

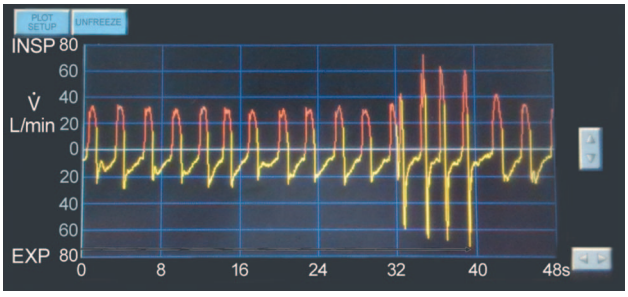

Fig. 1. Ventilator screenshot of cough peak flow when a subject was coached to cough.

QUICK LOOK

Current knowledge

Cough peak flow is a strong predictor of re-intubation when a patient successfully completes a spontaneous breathing trial. A flow meter is commonly used to measure cough peak flow, but not all ICUs provide a flow meter to measure cough peak flow.

What this paper contributes to our knowledge

Cough peak flow measured by a ventilator was positively associated with re-intubation. The predictive accuracy of re-intubation was similar when cough peak flow was measured by a ventilator compared with when it was measured by a spirometer.

When a subject successfully completed an SBT, we collected demographics such as age, sex, diagnosis, and physiological variables. Before removal of the endotracheal tube, we measured CPF. Before measurement, the head of the bed was elevated at 30–45°, and secretions were removed by suction. First, we measured CPF using the internal flow meter of the ventilator. (PB840, Covidien, Mansfield, Massachusetts). The parameters of the ventilator were the same as those in an SBT. We coached the subject to cough with as much effort as possible. At the same time, we froze the waveform of the flow velocity. Then we visually picked the peak of the flow velocity from the graph and kept the number to single digits (Fig. 1). We repeated the measurements 3 times. The best of 3 values was recorded. After measurements, subjects were ventilated with comfortable settings for 5 min as the washout time. Finally, we measured CPF using a spirometer (Chestgraph HI-101, Chest MI, Tokyo, Japan). We disconnected the ventilator, connected the spirometer to the endotracheal tube, and coached the subject to cough with as much effort as possible. We again recorded the best of 3 values.

After extubation, subjects were followed up to discharge or death in hospital. The re-intubation was recorded at 72 h after extubation. Re-intubation criteria were as follows: respiratory or cardiac arrest, inability to correct dyspnea, failure to maintain P_{aO_2} >60 mm Hg with supplemental oxygen >10 L/min, hemodynamic instability without response to fluids and vasoactive agents, and development of conditions necessitating intubation to protect the airway (coma or seizure disorders) or to manage copious tracheal secretions.

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Statistical analysis was performed with MedCalc (Ostend, Belgium). An unpaired Student *t* test was used to analyze normally distributed continuous variables, a Mann-Whitney U test was used to analyze non-normally distributed continuous variables, and the chi-square or Fisher exact test was used to analyze categorical variables. The difference between CPF measured by a spirometer and that measured by a ventilator was analyzed using a paired Student *t* test. The ability to predict re-intubation diagnosed by CPF was determined using the area under the curve of receiver operating characteristic. The Hanley and McNeil method was used to compare the predictive accuracy of re-intubation diagnosed by CPF measured by a spirometer and a ventilator.[21] A *P* value of $<.05$ was considered to indicate statistical significance.

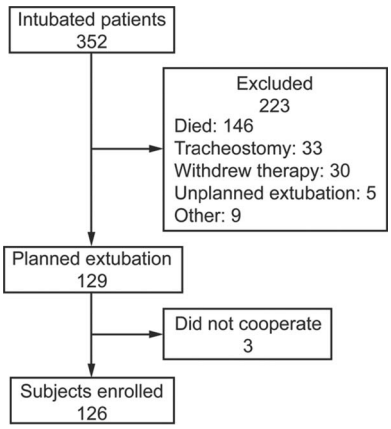

Fig. 2. Flow chart.

Results

A total of 126 subjects were enrolled in this study (Fig. 2). Among them, 15 subjects (12%) experienced re-intubation within 72 h after extubation (Table 1). There were no differences in sex, diagnosis, physiological variables, and arterial blood gas tests before extubation between subjects with and without re-intubation. However, subjects who were re-intubated were older and had longer intubation periods before extubation than those who underwent a successful extubation. They also had lower CPF than successfully extubated subjects, whether the CPF was measured by a spirometer or a ventilator. Further, re-intubated subjects had higher hospital mortality (Table 2).

CPF measured by a spirometer was slightly higher than that measured by a ventilator (82 ± 38 L/min vs 77 ± 27 L/min, $P = .008$). However, there was a positive correlation between CPF measured by a ventilator and a spirometer (Fig. 3). The optimal cutoff value, sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio, and negative likelihood ratio were summarized in Table 3. The area under the curve of receiver

Table 1. Data Collected Just Before Extubation Between Subjects With and Without Re-Intubation

Characteristics	Re-Intubation ($n = 15$, 12%)	No Re-Intubation ($n = 111$, 88%)	*P*
Age, mean ± SD y	77 ± 13	66 ± 14	0.006
Female sex, %	13	22	.52
Diagnosis, *n* (%)			
COPD exacerbation	4 (27)	48 (43)	.27
Pneumonia	5 (33)	26 (23)	.52
ARDS	4 (27)	13 (12)	.12
Asthma	0 (0)	3 (3)	>.99
Pulmonary embolism	1 (7)	4 (4)	.46
Pulmonary cancer	1 (7)	4 (4)	.46
Others	0 (0)	13 (12)	.36
Breathing frequency, mean ± SD breaths/min	24 ± 8	21 ± 6	.13
Rapid shallow breathing index, mean ± SD breaths/min/L	62 ± 31	48 ± 24	.053
Heart rate, mean ± SD beats/min	98 ± 12	96 ± 17	.73
Systolic blood pressure, mean ± SD mm Hg	126 ± 19	132 ± 20	.23
Diastolic blood pressure, mean ± SD mm Hg	71 ± 8	74 ± 12	.30
Intubation periods, mean ± SD d	9.3 ± 4.4	4.9 ± 4.1	<.001
Arterial blood gas tests, mean ± SD			
pH	7.44 ± 0.03	7.43 ± 0.06	.47
P_{aCO_2}, mm Hg	44 ± 9	47 ± 12	.49
P_{aO_2}/F_{IO_2}, mm Hg	281 ± 108	248 ± 83	.16
CPF measured by a spirometer, mean ± SD L/min	54 ± 30	86 ± 37	<.001
CPF measured by a ventilator, mean ± SD L/min	50 ± 22	80 ± 26	<.001

CPF = cough peak flow

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Table 2. Outcomes Between Subjects With and Without Re-intubation

Outcomes	Re-Intubation (n = 15, 12%)	No Re-Intubation (n = 111, 88%)	P
Hospital stay, median (IQR) d	19 (12–25)	17 (11–24)	.34
ICU stay, mean ± d	16 ± 9	11 ± 9	.046
Postextubation hospital stay, median (IQR) d	4 (2–10)	9 (5–16)	.063
Postextubation ICU stay, median (IQR) d	4 (1–10)	4 (1–7)	.62
Hospital mortality, n (%)	12 (80)	9 (8)	<.001

IQR = interquartile range

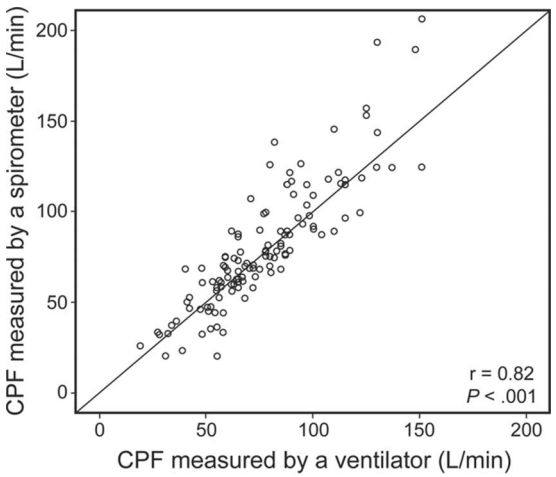

Fig. 3. Correlation between cough peak flow (CPF) measured by a ventilator and a spirometer.

operating characteristic was similar between CPF measured by a spirometer and a ventilator (P = .26) (Fig. 4).

Discussion

The current study shows that CPF had high sensitivity and specificity to predict re-intubation in subjects with planned extubation. It could be measured by a spirometer or a ventilator. CPF measured by a spirometer was slightly higher than that measured by a ventilator. However, the 2 methods had similar predictive accuracy for re-intubation. Further, measuring CPF with a ventilator did not lead to any additional costs.

Previous studies have demonstrated that cough strength is strongly associated with re-intubation.[5,9-20] Our study also confirmed this relationship. However, our research differed from previous studies, since we used 2 methods to assess cough strength (a spirometer and a ventilator), and found the 2 methods had similar predictive accuracy for re-intubation. It provided more choices for caregivers when they assessed the cough strength.

Cough strength can be assessed by a semiquantitative measurement. The method we usually used was a scale rated by the caregivers as follows: 0 = no cough on command, 1 = audible movement of air through the endotracheal tube but no audible cough, 2 = weakly (barely) audible cough, 3 = clearly audible cough, 4 = stronger cough, and 5 = multiple sequential strong coughs.[12] Patients with a score of ≤2 were classified as having a weak cough. However, semiquantitative measurement of cough strength was mainly based on the experience of the caregivers. Different caregivers, especially inexperienced ones, may grade differently when they rate the same patient. Thus, semiquantitative measurement of cough strength is not accurate.

Cough strength also can be assessed by a quantitative measurement. We usually used a flow meter to measure CPF. To the best of our knowledge, 3 studies have found that the optimal cutoff value of CPF was 60 L/min.[16,17,20] Another study found that the optimal cutoff value was 58.5 L/min.[19] In the current study, we found that the optimal cutoff values were 56.4 and 56 L/min when measured by a spirometer and a ventilator, respectively. The values were very close to those identified in previous studies, which indicates that CPF has good repeatability. Thus, the quantitative measurement of cough strength may be more accurate than semiquantitative measurement.

Quantitative measurement of cough strength required a flow meter. To the best of our knowledge, all of the studies used an additional flow meter and a bacterial filter to quantitatively measure cough strength.[14-20] Before measurement, the ventilator was disconnected. It interrupted ventilation and oxygen delivery. This may result in hypoventilation and hypoxemia. Further, the risk for hospital infection may increase when the ventilator is disconnected and the patient coughs, especially in patients with respiratory infectious disease, such as tuberculosis. Moreover, the additional flow meter and bacterial filter add cost, although the cost is not high. In addition, not all ICUs provide an additional flow meter to measure cough strength. However, a ventilator is available in all ICUs, and they include an internal flow meter. This internal flow meter can be used to measure flow velocity. In our study, we used the internal flow meter of the ventilator to measure CPF and found that it had the same predictive accuracy for re-intubation as an additional flow meter. Thus, CPF mea-

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Table 3. Analysis of Cough Peak Flow by Receiver Operating Characteristic Curves

CPF Measured by	Optimal Cutoff Value (L/min)	SE (%)	SP (%)	AUC (95% CI)	Positive Predictive Value (%)	Negative Predictive Value (%)	Positive Likelihood Ratio	Negative Likelihood Ratio
Spirometer	56.4	73	87	0.79 (0.71–0.86)	42.3	96.0	5.43	0.31
Ventilator	56.0	73	85	0.83 (0.75–0.89)	39.3	95.9	4.79	0.31

CPF = cough peak flow
SE = sensitivity
SP = specificity
AUC = area under the curve

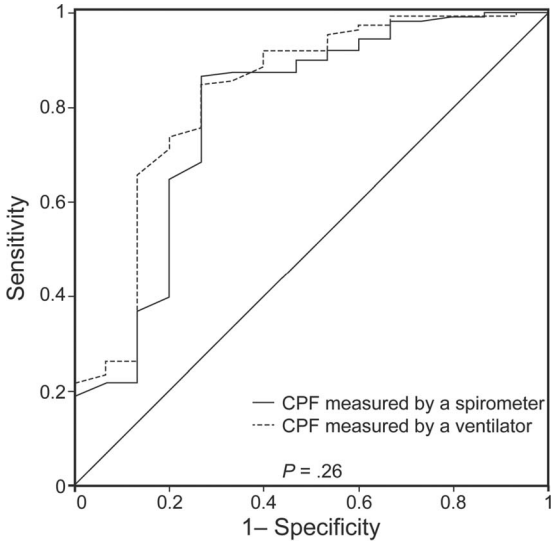

Fig. 4. Predictive accuracy of re-intubation diagnosed by cough peak flow (CPF) when it was measured by a spirometer and a ventilator.

sured by a ventilator is a good method to assess cough strength.

We found that CPF measured by a ventilator was slightly lower than that measured by a spirometer. It is possible that the difference resulted from transducer placement. The transducer was placed at the end of the endotracheal tube when CPF was measured by a spirometer. However, the flow meter is at the inside of the ventilator, with the flow signal transmitted through the ventilator circuit. Usually, the length of the ventilator circuit is 1–2 m. Thus, a long circuit may result in attenuation of the flow signal and subsequently result in a lower CPF measured by a ventilator than that measured by a spirometer.

Our study has several limitations. First, CPF was read from the graph of the ventilator when we coached the subject to cough (Fig. 1). However, some ventilators do not include the function of graph display. So, these types of ventilators cannot be used to measure CPF. Second, the length of the circuit differs between different ventilators. A longer length of ventilator circuit may lead to more attenuation of the flow signal and produce a lower CPF. However, we did not investigate the association between the length of the ventilator circuit and the attenuation of the flow signal. Thus, this issue needs further exploration. Third, this is a single-center study with a small sample size. The confirmation of predictive accuracy for re-intubation diagnosed by CPF measured by a ventilator is encouraged at other centers using a larger sample size. Fourth, weak cough is only one risk factor for re-intubation. Other risk factors include advanced age and prolonged mechanical ventilation preceding extubation.[22,23] Thus, the decision of extubation should reference not only cough strength, but also other risk factors, such as age and duration of mechanical ventilation.

Conclusions

CPF measured by a ventilator had a predictive accuracy for re-intubation similar to that of a spirometer. Because this measurement has no additional cost and ventilators are present in all ICUs, it can be widely used to measure cough strength in planned extubation patients.

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