Physiologic Impact of Closed-System Endotracheal Suctioning in Spontaneously Breathing Patients Receiving Mechanical Ventilation

Christopher W Seymour MD, Brian J Cross MD, Colin R Cooke MD MSc, Robert L Gallop PhD, and Barry D Fuchs MD

BACKGROUND: Endotracheal suctioning is required but can have adverse effects, and could affect cardiorespiratory variables that are used to predict whether the patient is ready for extubation. METHODS: In a prospective cohort study in a university hospital’s medical intensive care unit, we measured the impact of closed-system suctioning on cardiopulmonary variables in spontaneously breathing patients weaning from mechanical ventilation. All spontaneously breathing, mechanically ventilated patients were screened for enrollment at the initiation of weaning from mechanical ventilation. Before, during, and after standardized closed-system endotracheal suctioning we measured minute volume, heart rate, arterial oxygen saturation, mean arterial pressure, respiratory frequency, oxygen saturation, and tidal volume. RESULTS: Twenty-nine patients were enrolled after a median of 5 (interquartile range [IQR] 3–9) ventilator days. Twenty-five patients (86%) were spontaneously breathing on pressure-support ventilation when suctioned. The median post-suctioning recovery time was > 5 min for minute volume, tidal volume, respiratory rate, and ratio of respiratory rate to tidal volume. The post-suctioning median values of the maximum deviations in the ventilatory variables were clinically important: minute volume –2.4 (IQR 1.6–3.7) L/min, respiratory rate 8 (IQR 2–14) breaths/min, tidal volume –175 (108–220) mL. Heart rate, mean arterial pressure, and oxygen saturation increased after suctioning (P < .05), but the increases were not clinically important. CONCLUSIONS: Post-suctioning changes in the measured variables persisted longer in these spontaneously breathing patients weaning from mechanical ventilation than in patients who are sedated and paralyzed. The effects of suctioning on cardiopulmonary function should be considered in practice and during the design of future studies on weaning and extubation prediction variables. Key words: endotracheal suctioning, cardiopulmonary, spontaneous breathing, weaning, mechanical ventilation, extubation, respiration, sputum, sedation.

Introduction

In mechanically ventilated patients, endotracheal suctioning is frequently required to clear secretions. Suctioning is generally considered safe, but can cause arterial hypoxemia, altered mean arterial pressure, and cardiac arrhythmia; can increase the risk of nosocomial pneumonia; can increase intracranial pressure; and can even cause cardiac arrest.1-6 Closed suctioning systems are used more frequently than open systems, in part because adverse effects on cardiopulmonary function are thought to be less common, although evidence is lacking.7

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The authors declare no conflicts of interest.

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mal effects on heart rate, respiratory rate, tidal volume \((V_T)\), airway pressure, and arterial oxygen saturation measured via pulse oximetry \((S_{pO_2})\). However, little is known about the impact of closed-system suctioning on the cardiopulmonary functioning of spontaneously breathing patients. In the absence of sedation and paralysis, when reflexive or reactive responses are not suppressed and ventilation is not fixed, we hypothesized that suctioning might cause substantial and sustained changes in respiratory pattern, volumes, and other variables that are important in assessing a patient's readiness for discontinuation of ventilatory support.

We prospectively measured the magnitude and duration of changes in cardiopulmonary variables and spontaneous respiratory pattern and volumes during after closed-system endotracheal suctioning in spontaneously breathing, mechanically ventilated patients.

**Methods**

This prospective study was performed in the medical intensive care unit (ICU) of the Hospital of the University of Pennsylvania, between October 2004 and March 2005, and the hospital's institutional review board approved the research protocol and waived the requirement for written informed consent.

**Patient Population**

All mechanically ventilated patients were screened for eligibility on consecutive days, by staff during morning rounds. Patients were eligible if they were > 18 years old, endotracheally intubated, on volume controlled continuous mandatory ventilation, volume controlled intermittent mandatory ventilation, or pressure support ventilation (PSV), required a fraction of inspired oxygen \((F_{I O_2}) \leq 0.55\), positive end-expiratory pressure \((P_{EEP}) \leq 5\) cm \(H_2O\), and making spontaneous respiratory efforts. Patients were excluded if there were any clinical events or practitioner interventions within 15 min prior to study enrollment (eg, a change in ventilator settings, hemodynamic instability that required vasopressors, administration of neuromuscular blockade, or if previously enrolled in this study).

**Suctioning**

At the time of enrollment, the closed-system endotracheal suctioning technique recommended by the American Association for Respiratory Care (AARC) was reviewed with the nurses and respiratory therapists. The AARC guidelines recommend: pre-oxygenation with 100% oxygen for at least 30 s prior to suctioning; universal precautions; duration of suctioning 10–15 s with catheter withdrawal and with the minimum negative pressure needed \((\leq 200\) mm Hg); and hyperoxygenation with 100% oxygen for 1 min following the suctioning. Data-collection occurred at the first necessary suctioning after study enrollment, and was performed by a nurse or respiratory therapist. The study staff documented their adherence to the AARC suctioning guidelines. Data collection occurred during one succioning episode per patient, and no systematic suctioning schedule was employed after enrollment. In all patients, suctioning was performed with a 14 French \((4.6\) mm inner diameter, 30.5 cm length) suction catheter (Ballard Medical Products, Draper, Utah). No hyperinflation or recruitment maneuvers were employed during or after suctioning. We used a closed suctioning system, so there no was interruption of the ventilator circuit during suctioning.

**Data Collection**

We measured minute volume \((V_E)\), \(V_T\), respiratory rate, mean arterial pressure, \(S_{pO_2}\), frequency \((f)\), and heart rate. Values were collected every minute for 15 min prior to, during, and for 30 min after suctioning. For every measured variable, the baseline value was defined as the median value during the 15-min pre-suctioning period (Fig. 1). During the post-suctioning period, recovery was defined as having 2 consecutive values fall within the 10–90% range surrounding the median baseline value. Time to recovery was defined as the duration from time zero after suctioning to the first minute of the 10–90% range window. If there was a biphasic response (ie, both positive and negative deflections from the median baseline), we report the maximum deviation (positive or negative) from baseline prior to recovery.

Respiratory rate, \(V_T\), and \(V_E\) were recorded with a data-collection device (VueLink, Philips Medical Systems, Bothell, Washington) that collects data from multiple devices. \(V_E\) and \(V_T\) were measured as expired volumes. The VueLink interfaced with the ventilator (either a 7200 or an 840, Puritan Bennett, Pleasanton, California) and with the cardiac monitor (M1097A, Philips Medical Systems, Bothell, Washington), which allowed one trending of data points. One-minute averages were automatically calculated from data sampled every 12 s. \(f/V_T\) was calculated post hoc at all time points, irrespective of ventilator settings. \(S_{pO_2}\) was recorded by the cardiac monitor. Mean arterial pressure was measured via a radial artery catheter (20G, Arrow International, Reading, Pennsylvania).

Because interventions and other clinical events can alter respiratory pattern and volumes, during the pre-suctioning baseline observation period all ventilator changes, medical/nursing interventions, and other clinical events and environmental stimuli (eg, additional non-protocol endotracheal suctioning; physical patient contact by a physician, nurse, or respiratory therapist; oral suctioning; or airway
manipulation) were recorded by the study staff, and patients who had such pre-suctioning events were excluded from the study. If such an event occurred after the suctioning episode, the data from after the event were censored. Minor, unimportant events (eg, blood draws from existing arterial or central lines; presence of family, nurse, or physician in the room without patient interaction or agitation; or administration of intravenous medications) were recorded but did not result in patient exclusion or data censoring.

Other data recorded included the time of suctioning, the reason for ICU admission and intubation, ventilator days, endotracheal tube (ETT) size, ventilation mode, presence of intrinsic PEEP, most recent Richmond Agitation-Sedation Scale score, most recent arterial blood gas values, and number of suctioning episodes in the preceding 8 hours. Effect of suctioning on serial measurements of Richmond Agitation-Sedation Scale was not studied. Practitioners were directly observed during the suctioning episode to record whether the patient was appropriately pre-oxygenated, the number of suctioning passes, and the negative pressure employed.

**Statistical Analysis**

Baseline values, time to recovery, and maximum positive or negative deviation of each variable are expressed as median and interquartile range (IQR), as assessed by the Shapiro-Wilk test. The post-suctioning median values were compared to the baseline values via the 2-sided, paired Student’s $t$ test or the Wilcoxon rank-sum test, as appropriate. We used univariate regression analysis to determine the association between other patient and suctioning procedure variables and the time to variable recovery. Differences were considered statistically significant when $P < .05$.

We considered a variable change clinically important if the value reached a published threshold that could impact clinical decisions and/or a $\geq 15\%$ change from baseline. Because volume-controlled ventilation influences post-suctioning $V_T$ and $V_{E}^{*}$, we conducted a sensitivity analysis, in which we excluded patients on volume-controlled ventilation, to determine its influence on the results. All analyses were performed using statistical software (NCSS 2000, NCSS, Kaysville, Utah).

**Results**

Of the 115 patients screened during the 5-month enrollment period, 50 met the inclusion criteria (Fig. 2). The
Table 1. Subject Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Median (IQR)</th>
<th>Male (n, %)</th>
<th>Pre-oxygenation (n, %)</th>
<th>Median (IQR) ventilation days prior to suctioning</th>
<th>Median (IQR) suctioning passes in the 8 h before enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median (IQR) Richmond Agitation-Sedation Scale score</td>
<td>–1 (–3 to 0)</td>
<td>16 (55)</td>
<td>29 (100)</td>
<td>5 (3–9)</td>
<td>3 (1–3)</td>
</tr>
<tr>
<td>Diagnostic category (n, %)*</td>
<td></td>
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<tr>
<td>Pulmonary</td>
<td>6 (21)</td>
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<tr>
<td>Cardiac</td>
<td>2 (7)</td>
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<tr>
<td>Gastrointestinal</td>
<td>5 (17)</td>
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<tr>
<td>Infectious disease</td>
<td>7 (24)</td>
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<tr>
<td>Other</td>
<td>9 (31)</td>
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<td></td>
<td></td>
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<tr>
<td>Number of suctioning passes</td>
<td>2 (1–2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nurse performed suctioning (n, %)</td>
<td>19 (65)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median (IQR) suctioning pressure (mm Hg)</td>
<td>200 (150–200)</td>
<td></td>
<td></td>
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<tr>
<td>Median (IQR) endotracheal tube diameter (mm)</td>
<td>8 (7.6–8.0)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Median (IQR) pressure-support (cm H2O)</td>
<td>7 (7–11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Median (IQR) FIO2</td>
<td>0.40 (0.40–0.40)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Median (IQR) PEEP (mm Hg)</td>
<td>5 (5–5)</td>
<td></td>
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</tr>
</tbody>
</table>

* Pulmonary category included pneumonia, chronic obstructive pulmonary disease, asthma, acute respiratory distress syndrome, pulmonary embolus, and hemoptysis. Cardiac category included congestive heart failure, cardiogenic shock, acute myocardial infarction, and arrhythmia. Gastrointestinal category included hepatic failure, cirrhosis, gastrointestinal bleed. Infectious disease category included sepsis, human immunodeficiency virus, acquired immune deficiency syndrome. Other included endocrine or metabolic disorder, seizure, and altered mental status.

IQR = interquartile range
FIO2 = fraction of inspired oxygen
PEEP = positive end-expiratory pressure

Table 2. Post-Suctioning Recovery Time and Maximum Deviations From Baseline

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Recovery Time (median, IQR min)</th>
<th>Maximum Deviation From Baseline (median, IQR)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSV</td>
<td>Whole Cohort (n = 29)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ventilation (V̇E)</td>
<td>7 (3–12) 7 (3–14)</td>
</tr>
<tr>
<td></td>
<td>Respiratory rate (f)</td>
<td>5 (2–8) 6 (2–8)</td>
</tr>
<tr>
<td></td>
<td>Minute volume (VT)</td>
<td>6 (3–15) 6 (3–17)</td>
</tr>
<tr>
<td></td>
<td>Heart rate (f/VT)</td>
<td>1 (1–8) 1 (1–9)</td>
</tr>
<tr>
<td></td>
<td>Mean arterial pressure (saturating)</td>
<td>4 (1–12) 5 (2–13)</td>
</tr>
<tr>
<td></td>
<td>Heart rate (VT)</td>
<td>4 (1–8) 4 (1–10)</td>
</tr>
</tbody>
</table>

* If both positive and negative deflections occurred, the reported value is in the direction of the largest deviation.

Recovery Time: PSV = pressure-support ventilation
Ventilation: V̇E = minute volume
f = frequency
f/VT = tidal volume

Figure 3 shows the recovery-time data standardized by the baseline values. V̇E decreased significantly for 2 min, and full recovery required a median 5 min. Respiratory rate increased by a median 8 breaths/min, and full recovery required 5 min. V̇E increased and decreased; the maximum negative deviation was 2.4 L/min, and full recovery required 7 min. f/VT significantly increased for 5 min. Figure 4 shows the change in non-normalized f/VT values.

Though the change in SPO2 and heart rate was less dramatic, both remained significantly different from baseline for up to 5 min. In the sensitivity analysis, after excluding the 4 patients on volume-controlled ventilation, there were no significant differences in recovery time or duration of post-suctioning differences in the PSV cohort.

None of the recovery times of any of the variables were univariately associated with the number of suction-catheter passes, the number of suctioning episodes in the 8 hours prior to the data-collection period, the negative pressure employed, the occurrence of directly observed minor stimuli, or the Richmond Agitation-Sedation Scale score (P > .05).

Discussion

In spontaneously breathing mechanically ventilated patients, standardized closed-system suctioning resulted in statistically significant and clinically important changes in the measured cardiac variables and respiratory pattern and volumes, and the changes persisted longer than has been reported in heavily sedated and paralyzed patients. To our primary reason for exclusion was extubation prior to data-collection (36%). One patient was excluded after enrollment because he was suctioned during the baseline period. There were 29 evaluable patients. Some post-suctioning data from some patients were censored because of clinical events prior to complete recovery of the measured variables. The censored data were: V̇E, 1 patient; respiratory rate, 2 patients; mean arterial pressure, 1 patient; heart rate, 1 patient.

Table 1 describes the study subjects. The median duration of ventilation prior to enrollment was 5 days. At the time of data-collection, 25 (86%) of the 29 subjects were on PSV, with minimal PEEP and FIO2, and large ETTs (median and interquartile-range inner diameter 8.0 (IQR 7.6–8.0) mm). Their median pre-suctioning Richmond Agitation-Sedation Scale score was –1 (drowsy but could stay awake in response to verbal stimuli).16 Sixty-five percent of the suctionings were performed by nurses. Fifty-two percent of the suctioning episodes had 2 suctioning passes. The median suction pressure was 200 mm Hg. The median pre-suctioning Pao2 was 38 (IQR 28–41) mm Hg.

Table 2 shows the recovery times and magnitudes of deviation from baseline, before and after exclusion of the 4 patients who were on volume-controlled ventilation. Figure 3 shows the recovery-time data standardized by the baseline values. V̇E decreased significantly for 2 min, and full recovery required a median 5 min. Respiratory rate increased by a median 8 breaths/min, and full recovery required 5 min. V̇E increased and decreased; the maximum negative deviation was 2.4 L/min, and full recovery required 7 min. f/VT significantly increased for 5 min. Figure 4 shows the change in non-normalized f/VT values.

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knowledge this is the first report to describe changes in $V_T$, $V_E$, and $f/V_T$ after closed-system suctioning in spontaneously breathing patients. The post-suctioning changes in mean arterial pressure, $S_{\text{SpO}_2}$, and heart rate were statistically significant but not clinically important.

Several studies have examined the physiologic effects of suctioning, in both animals and humans. Although suctioning has had long-lasting adverse effects in animal models, descriptions of the effects of suctioning on cardiopulmonary variables in human subjects have been limited to the period immediately following suctioning, and only in patients who were heavily sedated or paralyzed. The immediate effects observed were due to the magnitude of the loss in airway volume, the use of pre-oxygenation, and changes in airway pressure during the suctioning episode. In the present study, we evaluated the sustained cardiopulmonary responses to suctioning.

During closed-system suctioning, the immediate loss of lung volume relates both to technical factors (e.g., ETT diameter, negative pressure applied, suction catheter diameter, and ventilator settings) and to patient-related factors (e.g., presence of reactive airways disease, and degree of lung injury). In sedated and paralyzed patients with acute lung injury, with comparable suction catheters and negative pressure, the suctioning-induced decrease in end-expiratory lung volume ranged from 100 mL to 500 mL. That inter-subject variability may be explained by differences in respiratory mechanics; patients with less compliant lungs are more predisposed to alveolar de-recruitment. Although our patients required minimal $F_{\text{IO}_2}$ and PEEP, we found similar variability, but the changes lasted longer. That difference may be due to the level of sedation and the ventilator settings. In heavily sedated subjects, the post-suctioning recovery of lung volume occurs within 1 min. This was also found in sedated animals, although those prolonged post-suctioning $V_T$ decreases were in animals ventilated with pressure-controlled ventilation, not volume-controlled ventilation. This suggests that the longer $V_T$ recovery time in the present study may relate to the predominant use of PSV. Deep sedation also depresses both laryngeal and tracheal reflexes, which suggests that our less sedated patients may have had larger and longer changes due to stimulation by the suction catheter. In the only comparable trial of awake patients, Lee et al also found that respiratory rate increased for 5 min after closed-system suctioning, but the magnitude of the change (2 breaths/min) was less than we observed. Richmond Agitation-Sedation Scale scores were not reported in that study, and differences in sedation probably account for the difference in respiratory rate.

Suctioning also altered $V_E$ and $f/V_T$ for up to 7 min in our cohort. Specifically, $V_E$ tracked with the decrease in $V_T$ before increasing to above the baseline value, driven by post-suctioning tachypnea. We did not perform serial $P_{\text{CO}_2}$ measurements, but the absence of baseline hypercarbia implies that out patients were not underventilated prior to suctioning. The observed changes in $f/V_T$ and $V_E$ may impact clinical decisions, because these changes exceeded published threshold values for guiding decisions about discontinuing mechanical ventilation ($f/V_T > 105$).
There were small but statistically significant post-suctioning changes in heart rate and mean arterial pressure. Others have reported significant post-suctioning changes in heart rate, which immediately resolved after suctioning, but those studies had a very brief post-suctioning observation period (< 2 min) and the patients were sedated and paralyzed.8,10,19

Limitations

Changes in the ventilator settings can confound the relationship between the measured cardiopulmonary variables and the suctioning episode. Our sample size may also have limited our power to detect associations between recovery-time and other variables, such as Richmond Agitation-Sedation Scale score, number of suctioning passes, and suction pressure. Our methods of measuring the variables were chosen to model behavior in practice. We took the expired V_T value from the ventilator display, which is derived from direct breath-by-breath measurements, and such ventilator-measured V_T values are less accurate than can be obtained with a research pneumotachometer,12 but the values were automatically recorded, which has been successfully employed in prior studies of weaning indices.8,26-28 We did not record the ventilator expiratory-flow cycle criterion, and differences in that setting may have affected V_T.29 Also, we calculated f/V_T with a non-standard technique, while the patient was supported with PSV,12 which may have underestimated the true f/V_T.25 Continuous measurement rather than minute-to-minute changes might have provided more accurate trends. Measurement of arterial blood gases from arterial blood samples was not feasible, but might have provided more accurate measurements of gas exchange; however, the clinical importance of post-suctioning PaO_2 changes in patients with preserved SpO_2 is unknown.

To standardize our protocol and encourage uniform suctioning technique by all study staff, we used the AARC suctioning guideline. Because we instructed the staff in the AARC guidelines, our results might underestimate the effects of different suctioning procedures in routine ICU practice. To exclude effects from stimulations other than the suctioning episode, we monitored the patient and the patient’s surroundings via direct observation of patient activity and stimulation before, during, and after the suctioning episode. Although there were both major and minor episodes of patient stimulation, and corresponding data were excluded or truncated, it is possible that we missed some stimulation events that altered our findings.

The post-suctioning changes and delayed recovery of cardiorespiratory variables in spontaneously breathing patients may have implications for both routine clinical practice and research studies in the ICU. Because empirical suctioning may occur prior to initiating spontaneous breath-
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...ing trials, suctioning-induced rapid shallow breathing may confound measurements that are used to predict the likelihood of weaning/extubation success. In addition, suctioning could cause unexpected tachypnea and reduced V_T if the patient is suctioned at the time of ETT removal. Prior studies of weaning/extubation prediction indices have not controlled for the potential effects of suctioning, which might have impacted the consistency and interpretation of their results.

Conclusions

We observed significant and sustained alterations in cardiac variables and respiratory pattern and volumes after closed-system suctioning in spontaneously breathing, mechanically ventilated patients. The changes lasted longer than in sedated and paralyzed patients. The clinical importance of these findings remains unknown, but the timing of suctioning may need to be considered when assessing patient readiness to tolerate weaning or extubation, and may need standardization in future studies of weaning and extubation prediction variables.

ACKNOWLEDGMENTS

We thank David J Pierson MD FAARC, Division of Pulmonary and Critical Care Medicine, Harborview Medical Center, University of Washington, Seattle, Washington, and Michael A Grippi MD, Pulmonary, Allergy, and Critical Care Division, University of Pennsylvania Health System, Philadelphia, Pennsylvania, for their detailed comments and review of this manuscript.

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