

The Impact of Closed Endotracheal Suctioning Systems on Mechanical Ventilator Performance

Ashraf El Masry MD, Purris F Williams RRT, Daniel W Chipman RRT, Joseph P Kratochvil RRT, and Robert M Kacmarek PhD RRT FAARC

BACKGROUND: Closed endotracheal suctioning during mechanical ventilation is increasingly used, but its impact on ventilator function has not been fully studied. **METHODS:** We evaluated the impact of closed suctioning with 11 critical-care ventilators, during assisted ventilation in pressure-support mode, pressure-assist/control mode, volume-assist/control mode, and during continuous positive airway pressure, with 2 suctioning pressures (-120 mm Hg and approximately -200 mm Hg), and with 2 tidal volumes (450 mL and 900 mL). We continuously measured airway pressure, flow at the airway, and pressure distal to the catheter tip, before, during, and after a single 15-second period of continuous suctioning. **RESULTS:** No ventilator malfunctioned as a result of the closed suctioning. During suctioning, end-expiratory pressure markedly decreased in all modes, and peak flow increased in all modes except volume-assist/control ($p < 0.001$). Respiratory rate increased during suctioning in pressure- and volume-assist/control ($p < 0.001$) but not during pressure support or continuous positive airway pressure. Gas delivery was most altered during volume-assist/control with the smaller tidal volume ($p < 0.05$) and least altered during pressure-assist/control with the larger tidal volume. **CONCLUSION:** There are large differences between the ventilators evaluated ($p < 0.001$). Closed suctioning does not cause mechanical ventilator malfunction. Upon removal of the suction catheter, these ventilators resumed their pre-suctioning-procedure gas delivery within 2 breaths, and, during all the tested modes, all the ventilators maintained gas delivery. However, closed suctioning can decrease end-expiratory pressure during suctioning. *Key words:* airway suctioning, closed suctioning, mechanical ventilators, lung model. [Respir Care 2005;50(3):345–353. © 2005 Daedalus Enterprises]

Introduction

Intubated patients require periodic suctioning of tracheal secretions, because of their inability to spontaneously clear their airways. The most common suctioning technique used is “open suctioning,” which involves disconnecting the ventilator, then suctioning the patient’s airway. However, disconnecting the ventilator causes a large drop in airway pressure, loss of lung volume, and oxygen desaturation,^{1–3}

so open suctioning can be considered inappropriate for patients with acute respiratory distress syndrome.

Open suctioning has partly been replaced by closed suctioning systems, which allow uninterrupted ventilation during suctioning, thus decreasing the loss of lung volume and avoiding gas-exchange impairment while suctioning.^{1–7}

During closed suctioning, the generation of negative airway pressure and consequent loss of lung volume can

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occur when the flow from the ventilator is lower than the suction flow.^{8,9} Previous studies showed that the use of closed suctioning during volume-controlled ventilation leads to unpredictably high intrinsic positive end-expiratory pressure (PEEPi) during insertion of the suction catheter.¹⁰ In addition, the Siemens company issued a warning in relation to the development of negative ventilator circuit pressure during closed suctioning.¹¹ The warning states that the Siemens pressure transducers malfunction at ventilator circuit pressure of -100 cm H₂O. However, there are no data on the response of intensive-care ventilators to closed suctioning. Nor has the effect of closed suctioning on gas delivery during various ventilation modes been documented in detail. Indeed, the approach to ventilation most and least affected by closed suctioning has not been well defined.

We hypothesized that closed suctioning would not affect the operation of any ventilator during pressure-targeted ventilation and that gas delivery would be most altered during small-tidal-volume, volume-targeted ventilation. We compared the performance of 11 intensive-care ventilators during various ventilation modes (continuous positive airway pressure [CPAP], pressure support [PS], pressure-assist/control [PA/C], and volume-assist/control [VA/C]) during closed endotracheal suctioning, using a mechanical lung model. We defined ventilator malfunction as an inability to continue gas delivery during closed suctioning and an inability of the ventilator to resume the pre-suctioning gas delivery pattern within 5 breaths after suctioning.

Methods

Ventilators Evaluated

Eleven intensive-care mechanical ventilators were evaluated (Table 1). All ventilators were set up to be consistent with the manufacturers' recommendations, but without a circuit humidifier, to avoid the problem of condensate in the ventilator circuit.

Protocol

Each ventilator was evaluated during PA/C, VA/C, CPAP, and PS, except the Raphael, which does not have the VA/C mode; instead we evaluated the Raphael's pressure-regulated volume-control mode.

During PA/C and VA/C ventilation, we evaluated 2 sets of conditions:

1. V_T 450 mL, inspiratory time 1.0 s, PEEP 10 cm H₂O, and respiratory rate 10 breaths/min
2. V_T 900 mL, inspiratory time 1.5 s, PEEP 5 cm H₂O, respiratory rate 10 breaths/min

Table 1. Ventilators Evaluated

Manufacturer	Model(s)
Dräger Medical, Telford, Pennsylvania	Evita 4
Hamilton Medical, Reno, Nevada	Galileo Raphael
Puritan Bennett, Pleasanton, California	PB 840 PB 760 PB 7200
Respironics, Pittsburgh, Pennsylvania	Esprit
Siemens-Elema, Danvers, Massachusetts	Servo 900C Servo 300 Servo-i
Viasys Products, Palm Springs, California	Avea

During CPAP the ventilators were set at 10 cm H₂O positive pressure. During PS the ventilators were set to deliver 5 cm H₂O PEEP and pressure support of 10 cm H₂O above the PEEP level.

Each ventilation mode, with every ventilator, was evaluated before, during, and after closed suctioning. Suctioning was performed continuously for 15 s with regulated suction pressure (-120 mm Hg) and without regulation of suction pressure (approximately -200 mm Hg). The suction catheter was rapidly inserted into the airway, past the tip of the endotracheal tube (ETT). Once in place, suctioning was begun immediately. In all modes, the pre-suctioning inspiratory trigger sensitivity was set as sensitive as possible without causing auto-triggering, and the rise time for pressure-controlled ventilation was set to the manufacturer's default setting. When possible, the inspiratory termination criteria was set at 25% of peak flow. Apnea ventilation was turned off on all ventilators, and peak airway pressure (P_{peak}) alarms were set at maximum (about 100 cm H₂O). We chose these settings to ensure that we could identify differences between modes and ventilators.

Lung Model

A 2-chamber training/test lung (Michigan Instruments, Grand Rapids, Michigan) was used to simulate the respiratory system (Fig. 1). One chamber of the test lung (driving chamber) was attached to and powered by a Puritan Bennett (PB) 840 ventilator, the other chamber (experimental chamber) was attached to the ventilator being evaluated. The 2 chambers were not physically connected, but a small metal insert was incorporated that allowed the driving chamber to lift the experimental chamber, thus simulating spontaneous breathing but allowing free further movement of the experimental chamber. A 22 mm inner-diameter corrugated tube was attached to the lung model, and through that tube we placed an 8.0-mm inner-diameter ETT (Mallinckrodt, Glens Falls, New York). A 14 French

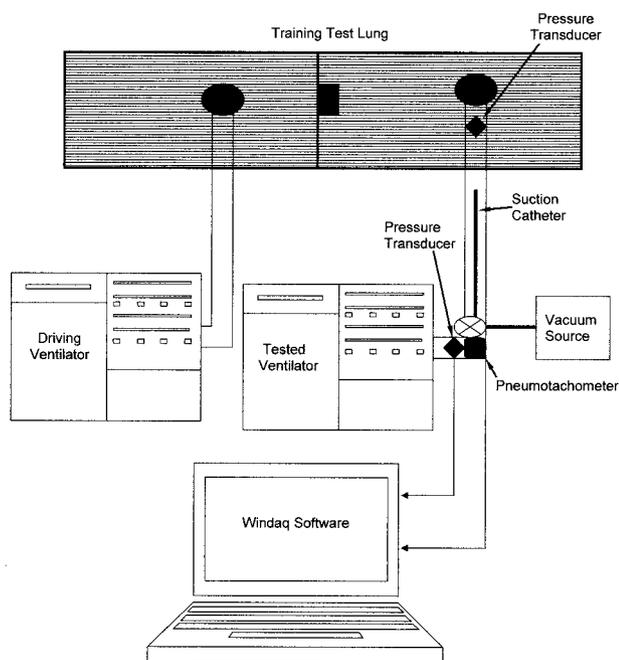


Fig. 1. Lung model and data-collection setup.

closed tracheal suctioning system (Trach Care, Ballard Medical Products, Draper, Utah) was placed between the ETT and the Y-piece of the tested ventilator (see Fig. 1). Lung model compliance was set at 60 mL/cm H₂O, except during PA/C and VA/C with small V_T (450 mL, PEEP 10 cm H₂O), during which the set compliance was decreased to 30 mL/cm H₂O. The lung model resistance was that created by the presence of the 8-mm inner-diameter ETT.

The lung model driving ventilator was set in the volume-controlled mode, delivering a V_T of 300 mL and a peak flow of 30 L/min. The driving ventilator respiratory rate was set at 20 breaths/min, except during PA/C and VA/C with high V_T (900 mL, PEEP 5 cm H₂O), during which the rate was set at 12 breaths/min. PEEP in the driving ventilator was set equal to or greater than the tested ventilator, to avoid separation of the 2 compartments at end-exhalation and to allow proper triggering. During CPAP and PS the V_T delivered by the driving ventilator was increased from 300 mL to 500 mL, to better simulate a moderate-size spontaneous breath.

Measurements and Calibration

A pneumotachometer (model 3700A, Hans Rudolph, Kansas City, Missouri) was placed at the Y-piece of the tested ventilator. The pressure difference across the pneumotachometer was measured (model 45-14-871 [± 2 cm H₂O], Validyne, Northridge, California), and converted to a flow signal with graphics software (Windaq, Data Instruments Incorporated, Akron, Ohio). The pneumotachometer

graph was calibrated at 0.5 L/s flow delivered by a precision flow meter (Brooks Instruments, Hatfield, Pennsylvania). Pressure at the Y-piece (airway) and distal to the tip of the suction catheter were measured with pressure transducers (model 45-32-871 [± 100 cm H₂O], Validyne, Northridge, California) calibrated at 20 cm H₂O with a water manometer. Pressure and flow signals were amplified (model 8805C, Hewlett Packard, Waltham, Massachusetts), digitized (at 100 Hz), recorded, and analyzed with graphics software (Windaq, Data Instruments Incorporated, Akron, Ohio). Flow through the suction catheter, at each suction pressure, was determined by attaching the suction catheter to the pneumotachometer and measuring flow at each of the pressure settings. This was performed with the catheter outside the ventilator circuit.

Measurements Recorded During the Experiments

Flow and airway pressure waveforms were recorded continuously. All waveforms were analyzed 10 s before closed suctioning was performed, during the 15-s suctioning period, and for 30 s after cessation of suctioning. We identified the peak and minimum airway pressures and peak flow before, during, and after suctioning. PEEP_i was evaluated by measuring the end-expiratory pressure distal to the tip of the suction catheter. Three successive breaths were used to determine flow rate and pressure before and after suctioning. Each breath during suctioning was analyzed. One series of measurements were made under each experimental condition.

Statistical Analysis

All values except respiratory rate during suctioning are reported as mean \pm SD. We used 1-way analysis of variance to compare P_{peak}, end-expiratory pressure, respiratory rate, and peak flow before, during, and after suctioning. In that analysis the dependent variables were P_{peak}, end-expiratory pressure, respiratory rate, and ventilator flow rate, and the independent variables were ventilator, mode, and suction pressure. Differences were considered statistically significant when $p < 0.05$. If a statistically significant difference was identified, we conducted post hoc analysis by performing Tukey's honest significant difference test. Statistical analysis was performed with statistics software (SPSS 11.5, SPSS, Chicago, Illinois).

Results

Ventilator Function

All ventilators continued to deliver gas in all modes during closed suctioning. No ventilator failed to re-establish the pre-suctioning gas-delivery pattern within 5 breaths

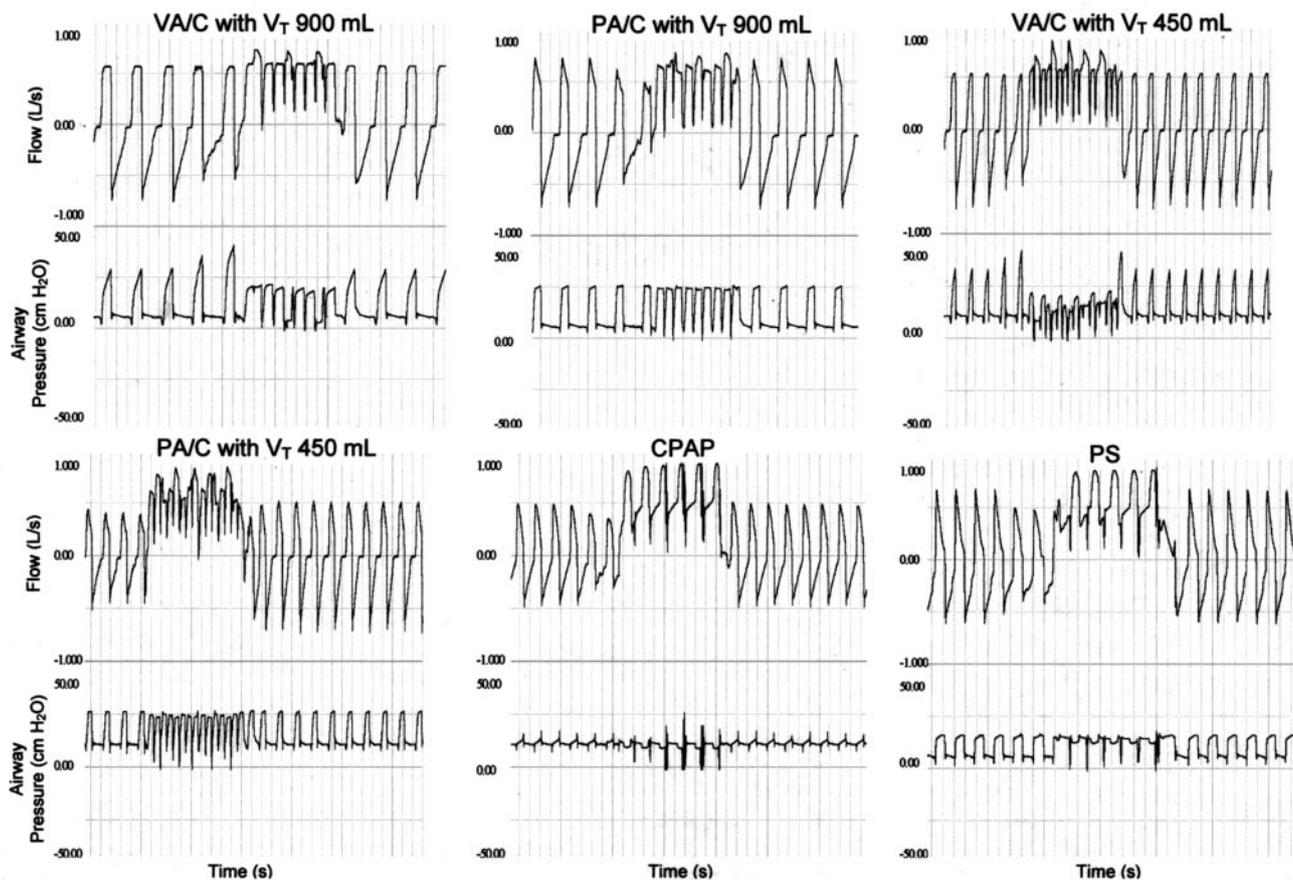


Fig. 2. Flow and airway pressure waveforms from the Servo 300 ventilator before, during, and after maximum suctioning pressure in 6 ventilation modes. VA/C = volume-assist/control. V_T = tidal volume. PA/C = pressure-assist/control. CPAP = continuous positive airway pressure. PS = pressure support.

after suctioning. There were no significant differences in peak airway, end-expiratory pressure, peak flow, or respiratory rate before and after suctioning with any ventilator, regardless of mode or suction pressure. In fact, under all experimental conditions all the ventilators resumed the pre-suctioning gas-delivery pattern within 2 breaths (Fig. 2).

Suctioning Differences With Individual Ventilators

For individual ventilators there were significant differences between P_{peak} during suctioning and the pre-suctioning and post-suctioning values. As the suction catheter was inserted, pressure increased during the volume modes but stayed the same during the pressure modes and CPAP. In most settings except CPAP, airway pressure stayed the same (PA/C, PS) or decreased (VA/C) with closed suctioning. During CPAP with some ventilators, there was a momentary spike in airway pressure with closed suctioning (see Fig. 2). However, during suctioning, P_{peak} did not significantly differ among ventilators, and none exceeded 40 cm H_2O .

With all the ventilators the end-expiratory pressure was significantly lower during suctioning than before or after suctioning ($p < 0.05$). During suctioning, the drop in end-expiratory pressure differed considerably among the ventilators ($p < 0.05$). The smallest drop in end-expiratory pressure was with the Servo 300; the greatest drop was with the PB 760 (Fig. 3).

Overall, peak flows were higher during suctioning than before or after suctioning ($p < 0.001$), except with the Evita 4 and Esprit. The during-suctioning increase in peak flow differed among the ventilators; the greatest increase was with the PB 840 (51.15 ± 6.95 L/min during suctioning vs 40.85 ± 11.88 L/min before suctioning [see Fig. 3]).

Suctioning and Ventilation Mode

Although different PEEP and compliance levels were used, P_{peak} did not differ between PA/C and VA/C at the given V_T settings. CPAP and PS had lower P_{peak} than the other modes ($p < 0.05$), but there was no difference between CPAP and

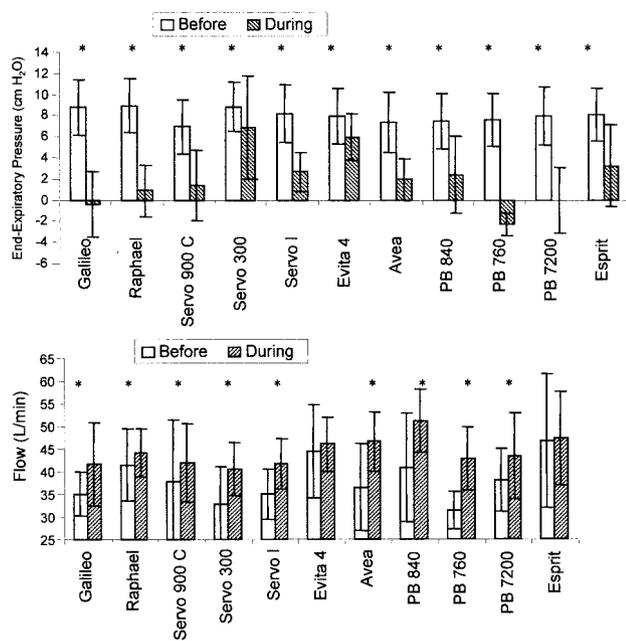


Fig. 3. Mean \pm SD end-expiratory pressure and peak flow during all 6 tested ventilation modes, at both tidal volumes and both suction pressures, with each ventilator evaluated, before suctioning (white bars) and during suctioning (hatched bars). * $p < 0.05$ before versus during suctioning.

PS. Pre-suctioning P_{peak} did not significantly differ from the during-suctioning and post-suctioning P_{peak} , for all modes except VA/C with V_T of 450 mL, during which P_{peak} dropped, from 24.81 ± 3.13 cm H₂O before suctioning to 10.03 ± 7.89 cm H₂O during suctioning.

During pressure-regulated volume-control on the Raphael ventilator, the during-suctioning P_{peak} did not significantly differ from the pre-suctioning or post-suctioning value: 23.6 ± 2.49 before and after suctioning vs 24.9 ± 3.62 during suctioning. Pressure-regulated volume-control appeared to function similar to the PA/C mode of the other ventilators.

End-expiratory pressure was significantly lower during suctioning than before or after suctioning ($p < 0.001$); the greatest drop was observed with VA/C 450 mL: 10.48 ± 0.46 cm H₂O before suctioning vs 0.40 ± 4.63 cm H₂O during suctioning (Fig. 4).

Ventilator flow increased considerably during suctioning in CPAP and also significantly increased during PS, VA/C 450 mL, and PA/C 450 mL ($p < 0.05$). Peak flow remained unchanged during VA/C 900 mL. Peak flow decreased significantly with PA/C 900 mL ($p < 0.05$) (Fig. 4).

Respiratory Rate

The during-suctioning respiratory rate increased between 40% and > 100% during PA/C and VA/C with all venti-

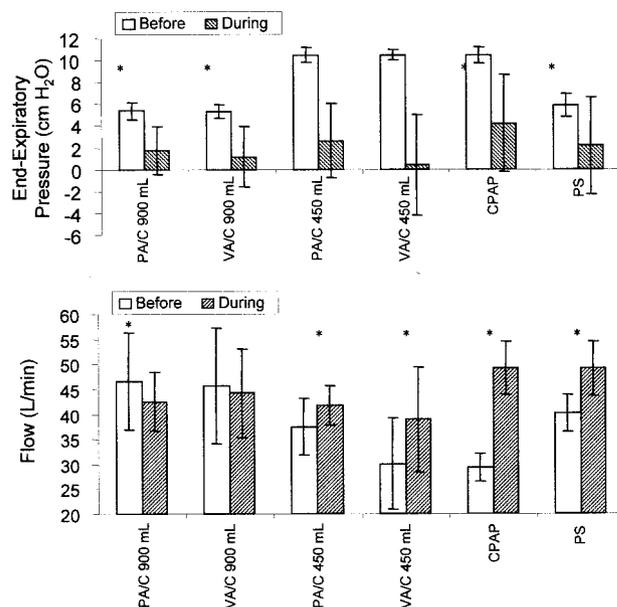


Fig. 4. Mean \pm SD end-expiratory pressure and peak flow for all 6 tested ventilation modes, regardless of ventilator, at both tidal volumes and both suction pressures, before suctioning (white bars) and during suctioning (hatched bars). * $p < 0.05$ before versus during suctioning.

lators except the Servo 900C (during PA/C 900 mL) and the Servo 300 (during VA/C 450 mL). However, during PS and CPAP there was little change in respiratory rate during suctioning (Table 2).

Suctioning and Suction Pressure

End-expiratory pressure decreased to a greater extent during maximum suction pressure (approximately -200 mm Hg) than during the lower suction pressure (-120 mm Hg) ($p < 0.05$). Peak flow was significantly higher at the maximum suction pressure than at -120 mm Hg ($p < 0.001$) (Fig. 5). Peak airway pressure did not significantly vary with suctioning pressure. Flow through the suction catheter was 28.8 L/min at suction pressure of -120 mm Hg, and 36.9 L/min at the maximum suction pressure.

Discussion

The most important findings of this study are:

1. All ventilators maintained gas delivery during closed suctioning.
2. All ventilators resumed their pre-suctioning gas delivery pattern within 1–2 breaths after suctioning ended.
3. The change in airway pressure from the pre-suctioning end-expiratory pressure level never exceeded 15 cm

Table 2. Respiratory Rate During Suctioning

Ventilator	Respiratory Rate (breaths/min)											
	PA/C-V _T 900*		VA/C - V _T 900*		PA/C - V _T 450†		VA/C - V _T 450†		CPAP‡		PS‡	
	-120 mm Hg	Max	-120 mm Hg	Max	-120 mm Hg	Max	-120 mm Hg	Max	-120 mm Hg	Max	-120 mm Hg	Max
Galileo	32	32	32	32	48	52	52	52	24	24	20	20
Raphael	24	20	24	24	28	28	32	32	24	24	24	24
Servo 900C	12	12	40	48	32	32	20	32	20	24	20	24
Servo 300	28	28	28	20	36	36	24	24	20	20	20	20
Servo-i	28	28	28	32	48	52	56	52	20	20	24	20
Evita 4	36	36	48	48	36	36	44	36	20	20	32	32
Avea	44	48	36	44	48	48	66	72	20	28	24	28
PB 840	32	32	28	36	44	44	36	36	20	20	20	20
PB 760	20	20	20	20	32	32	40	40	20	20	20	20
PB 7200	32	40	32	28	40	40	40	40	20	20	24	24
Esprit	40	48	36	40	48	44	44	44	24	24	20	24

PA/C = pressure assist/control

V_T = tidal volume

VA/C = volume assist/control

*Before PA/C and VA/C with V_T of 900 mL, the respiratory rate was 12 breaths/min.

†During PA/C, VA/C with V_T of 450 mL, CPAP, and PS the respiratory rate was 20 breaths/min.

Max = maximum suction pressure (approximately -200 mm Hg)

H₂O, and with most ventilators the maximum negative airway pressure was limited by the ventilator.

4. There were major differences among the ventilation modes for all the ventilators tested and among the ventilators evaluated.

Airway pressure during closed suctioning is affected by the external diameter of the suction catheter in relation to the inner diameter of the ETT, the flow through the suction catheter during suctioning, the flow of gas provided by the ventilator during suctioning, and the response of the ventilator to negative system pressure. It has been standard practice to limit the external catheter diameter to less than half of the inner-diameter of the ETT.¹²⁻¹⁴ In the present study we used a 14 French suction catheter and an 8-mm inner-diameter ETT, thus ensuring that the suction catheter radius was less than half the airway diameter. Clearly, use of a different size of catheter or ETT could have affected our results.

Similarly, suction flow during the suctioning period affects airway pressures. The greater the suction pressure and resulting flow and the longer the suctioning time, the greater the negative effect on airway pressure. We observed a greater decrease in end-expiratory pressure and a greater increase in peak flow at the maximum suction (approximately -200 mm Hg) than at -120 mm Hg suction pressure. This is because the flow through the suction catheter was 36.9 L/min at the maximum suction pressure versus 28.8 L/min at -120 mm Hg. With adult patients, current recommendations call for regulating suction pressure to between -100 mm Hg and -150 mm Hg.¹⁰ We

also based the duration of suctioning (15 s) on current guidelines.¹⁰ Any change in the way suctioning was performed may have produced different results.

Performance of Ventilators

All the ventilators maintained gas delivery during these evaluations, regardless of the ventilation mode tested or the suction pressure applied. However, there were marked differences in the various ventilators' response to closed suctioning, suction pressure, and ventilation modes. But no matter the effect on airway pressure, all the ventilators re-established airway pressure and flow waveforms within 1-2 breaths after withdrawal of the suction catheter (see Fig. 2).

The ventilator's ability to maintain a positive airway pressure during suctioning depends on ventilator flow during suctioning. During CPAP, PS, and PA/C, ventilator flow was always higher than the suction flow, and a positive airway pressure was present. A similar response was noted during VA/C 900 mL, except with the PB 7200 (at both -120 mm Hg and the maximum suction pressure) and the Galileo (at the maximum suction pressure). With those settings, the ventilator flow was less than the suction flow during maximum suction, and there was no positive airway pressure during suctioning. During VA/C 450 mL, at both suction pressures, some ventilators demonstrated negative end-expiratory airway pressure, and in all instances the suction flow exceeded the ventilator flow. The lowest airway pressures were with the Galileo (-3.18 ±

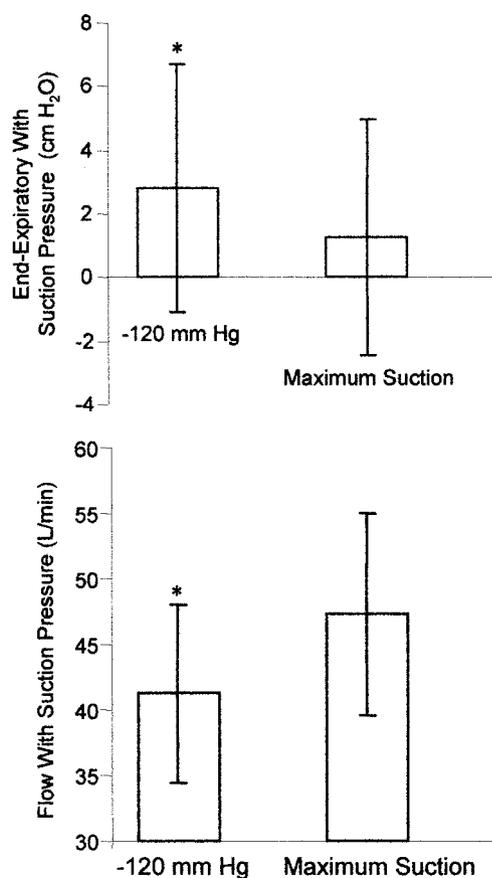


Fig. 5. Mean \pm SD end-expiratory pressure and peak flow for all the tested ventilators, all 6 tested ventilation modes, and both tested tidal volumes, with both suctioning pressures (-120 mm Hg and maximum suction pressure [approximately -200 mm Hg]). * $p < 0.05$ for -120 mm Hg versus maximum suction pressure.

0.0 cm H₂O), PB 760 (-2.65 ± 0.36 cm H₂O), and PB 7200 (-2.68 ± 0.70 cm H₂O) ventilators. With all of those ventilators there was a minimum pressure that was not exceeded. It would appear that at these pressure thresholds the ventilators' anti-suffocation valve opened, preventing a greater drop in airway pressure. The Servo 300 and Evita 4 maintained end-expiratory pressure, regardless of mode, near the set end-expiratory level.

Although this is not a clinical study, we would expect greater lung derecruitment and oxygen desaturation with the ventilators that are less able to maintain end-expiratory pressure during closed suctioning. Overall, the ventilators were most able to maintain airway pressure during PA/C 900 mL and -120 mm Hg suction pressure, and were least able to maintain airway pressure during VA/C 450 mL and the maximum suction pressure. That is, gas-delivery settings that maintain high gas flow in response to closed suctioning result in the least change in airway pressure. As a result, pressure-targeted modes would be preferred, and the higher the pressure target, the less effect closed suc-

tioning has on pressure. The same is true for large- V_T volume-controlled ventilation, in which peak flow is set high. Based on these evaluations of airway pressure changes, the Servo 300 and Evita 4 were the best-performing ventilators during closed suctioning.

Flow during VA/C 450 mL exceeded the set peak flow. We cannot fully explain this consistent finding, but we speculate that it may be that the opening of the anti-suffocation valve allowed more flow to enter the system, or the ventilator's attempt to maintain PEEP in this setting resulted in some additional flow during the onset of inspiration.

Auto-triggering was observed with almost all the ventilators during PA/C and VA/C, regardless of V_T , but was rarely observed during CPAP or PS. During assist/control ventilation, auto-triggering occurs whenever the airway pressure or flow criteria for triggering are met. With PS the breath is terminated when (1) inspiratory flow decreases to a specific level (in this study, 25% of peak flow), (2) pressure exceeds a set level, or (3) a time limit is reached. With CPAP the only mechanism to end a breath is the patient's transition to exhalation. It is difficult to determine the clinical relevance of auto-triggering. One might suspect it would cause patient-ventilator dyssynchrony, but it is difficult to imagine that auto-triggering would cause more dyssynchrony than suctioning. Clearly, the process of auto-triggering assists in maintaining airway pressure during suctioning in the assist/control mode. Clinical studies are needed to further clarify this issue.

The Siemens company has issued an alert regarding its 900 series and 300 series ventilators during closed suctioning. Siemens has indicated that airway pressure of >-100 cm H₂O could damage the ventilator's pressure transducers, causing the ventilator to malfunction. We found no evidence of any Siemens ventilator malfunctioning. In fact, airway pressures were never more negative than -5 cm H₂O, regardless of mode, V_T , suction pressure, or ventilator evaluated, and the pressure returned to the set PEEP level within 1–2 breaths after catheter removal. This was because all the ventilators provided sufficient flow during suctioning (pressure modes) or rapid triggering (volume modes) to prevent marked decreases in airway pressure.

Comparison to Other Studies

Our findings differed considerably from those of Stenqvist et al,¹⁰ who reported marked PEEPi with catheter insertion (up to 25 cm H₂O) during closed suctioning with the Servo 900C and Servo 300 ventilators. We observed only small (<1 cm H₂O) PEEPi levels. The explanation for these differences may be that Stenqvist et al used a narrower ETT (7 mm inner diameter) and simulated airway secretions (Xylocaine 2% gel),¹⁰ so the area available

for gas flow around the suction catheter was smaller in their protocol. In addition, we did not employ inverse-ratio ventilation. Our set ratios were $\leq 1:2$. We also rapidly inserted the suction catheter and immediately began suctioning. However, we did not observe a marked change in airway pressure (10–15 cm H₂O) below the pre-suctioning end-expiratory pressure. In addition, end-expiratory pressure returned to the set level within 1–2 breaths after catheter removal. Of critical importance in both our study and that of Stenqvist et al¹⁰ is the fact that no ventilator malfunction was observed under any set of experimental conditions.

In 16 patients following cardiac surgery, Frengley et al¹⁵ found minimal airway-pressure changes during closed suctioning with the Servo 300 ventilator. Following catheter insertion they observed the development of 2.7 ± 1.7 cm H₂O PEEP_i (consistent with our data) during volume-controlled ventilation, and about 1.5 cm H₂O PEEP_i during pressure ventilation. During suctioning, end-expiratory airway pressure was -4.9 ± 4.0 cm H₂O during volume-controlled ventilation and 0.8 ± 1.9 cm H₂O during pressure control ventilation. Frengley et al also observed no ventilator malfunction.¹⁵

Clinical Relevance

Our results indicate that (assuming a proper size suction catheter is used) there should be no concern regarding ventilator function during closed suctioning. These data are consistent with those of existing patient studies. There have been no reported ventilator malfunctions during closed suctioning of patients, and numerous studies have demonstrated patient benefit with closed-suctioning over open suctioning.^{1–6,16,17} No clinical comparison has established a benefit from open suctioning over closed suctioning. Every study^{1–3,5,6,15–17} that has compared the level of arterial desaturation with open versus closed suctioning has favored closed suctioning, except Carlton et al,⁴ who found no difference between the 2 suctioning methods with patients who required <10 cm H₂O PEEP. Similar data^{2,6,16} regarding heart rate and blood pressure change favor closed over open suctioning. In addition, Cereda et al² found a much greater end-expiratory lung-volume change with open suctioning (1.2 ± 0.7 L) than with closed suctioning (0.14 ± 0.1 L), as measured with inductive plethysmography. Brochard et al¹ observed a >300 -mL end-expiratory lung-volume change during open versus closed suctioning, as measured with computed tomography. Most recently, Maggiore et al,³ using inductive plethysmography with 6 patients with acute respiratory distress syndrome, noted a 1,645-mL change in functional residual capacity with open suctioning, versus a 123-mL change with closed suctioning.

Limitations

This was a lung-model study, so it could not simulate actual clinical conditions regarding airway pressure changes. However, circumstances were established that stressed each ventilator to perform under conditions at least equivalent to those experienced clinically. In addition, we did not evaluate every possible ventilation mode currently available on intensive-care ventilators, so we cannot comment on how modes we did not test would respond during closed suctioning. Because of the design of our lung model, we could not evaluate the effect of airway secretions being removed during the suctioning process. However, when secretions are removed, the effect of suction pressure on airway pressure is minimized and ventilatory performance is therefore less stressed. The peak flows used during VA/C were very low, in order to achieve the set inspiratory times of 1.0 s and 1.5 s. As a result we would expect VA/C to perform better if the inspiratory flows were set higher. We also did not directly measure the actual V_T delivered to the lung model. Because of active suction, the V_T was impossible to determine. In addition, we were unable to measure inspiratory and expiratory resistance during closed suctioning. Since we used limited ventilator settings, we cannot predict the impact of closed suctioning with any of the modes we studied if different ventilator settings are used.

Conclusions

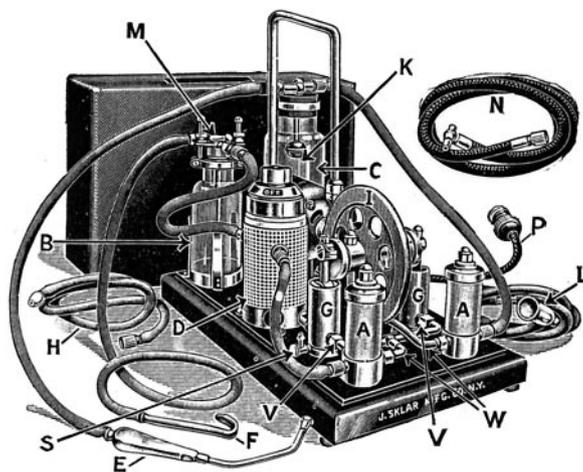
Closed suctioning does alter the delivery of PA/C, VA/C, CPAP, and PS during suctioning but does not cause ventilator malfunction. Upon completion of suctioning and removal of the suction catheter, the studied ventilators returned to their pre-suctioning waveforms within 1–2 breaths, and all the ventilators during all the modes maintained gas delivery during closed suctioning. Closed suctioning does decrease airway pressures, specifically end-expiratory pressure, but end-expiratory pressure is reestablished within 1–2 breaths after catheter removal.

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CLOSED SUCTIONING AND MECHANICAL VENTILATOR PERFORMANCE

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