

The Effect of Closed System Suction on Airway Pressures when using the Servo 300 Ventilator

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ABSTRACT

Objectives: *To measure airway pressures during closed system suctioning with the ventilator set to three differing modes of ventilation.*

Methods: *Closed system suctioning was conducted in 16 patients following cardiac surgery. Suctioning was performed using a 14 French catheter with a vacuum level of -500 cmH₂O through an 8.0 mm internal diameter endotracheal tube. The lungs were mechanically ventilated with a Servo 300 ventilator set to one of three ventilation modes: volume-control, pressure-control or CPAP/pressure support. Airway pressures were measured via a 4 French electronic pressure transducer in both proximal and distal airways.*

Results: *Following insertion of the suction catheter, end-expiratory pressure increased significantly ($p < 0.001$) in both pressure-control and volume-control ventilation. This increase was greatest ($p = 0.018$) in volume-control mode (2.7 ± 1.7 cm H₂O). On performing a five second suction, airway pressure decreased in all modes, however the lowest airway pressure in volume-control mode (-4.9 ± 4.0 cmH₂O) was significantly ($p = 0.001$) less than the lowest airway pressure recorded in either pressure-control (0.8 ± 1.9 cmH₂O) or CPAP/pressure support (0.4 ± 2.8 cmH₂O) modes. In CPAP/pressure support mode, 13 of the 16 patients experienced a positive pressure 'breath' at the end of suctioning with airway pressures rising to 21 ± 1.6 cmH₂O.*

Conclusions: *Closed system suctioning in volume control ventilation may result in elevations of end-expiratory pressure following catheter insertion and subatmospheric airway pressures during suctioning. Pressure control ventilation produces less elevation of end-expiratory pressure following catheter insertion and is less likely to be associated with subatmospheric airway pressures during suctioning. CPAP/pressure support has no effect on end-expiratory pressure following catheter insertion and subatmospheric airway pressures are largely avoided during suctioning. (Critical Care and Resuscitation 2001; 3: 230-235)*

Key words: Endotracheal, suction, airway, PEEP, closed system suction

Closed system suctioning is a method of removing secretions from the tracheo-bronchial tree of patients requiring mechanical ventilation without disconnecting the ventilator. Putative benefits of closed system suctioning include maintenance of positive pressure ventilation, oxygen supply, and positive end-expiratory pressure (PEEP).¹ However, these benefits have been

disputed and bench test evaluations have demonstrated that substantial subatmospheric pressures can be generated during suctioning.^{2,3,4}

The degree of negative airway pressure generated by suctioning depends on the balance between the inspiratory gas flow and the rate at which gas is removed by suctioning. During closed system suctioning, the

inspiratory gas flow will in turn depend on the mode of ventilation and the ventilator settings. In bench-test evaluations, the largest falls in airway pressure are seen when closed system suctioning is conducted via large calibre suction catheters, with high suction vacuum pressures and volume controlled modes of ventilation are used.^{2,3} Furthermore, inserting a suction catheter down an endotracheal tube (ETT) elevates PEEP by increasing tube resistance, and unpredictably high levels of PEEP may be seen especially when volume controlled ventilation is being used.²

There has been only one published *in vivo* human study where airway pressures were measured during closed system suctioning.⁵ This study made no attempt to compare modes of ventilation. Moreover, a variety of endotracheal tube sizes were used and airway pressures were measured in the ventilator and not in the patients' airways.

Our aim was to measure the pressures recorded in patients' airways during closed system suctioning with the ventilator set to three differing modes of ventilation.

METHODS

Following institutional ethics committee approval and written informed consent, we recruited 16 patients undergoing cardiac surgery. Exclusion criteria were: any history of respiratory disease, New York Heart Association Class III or IV congestive heart failure, weight > 100 kg or < 60 kg, complicated intraoperative course, significant postoperative bleeding (> 200 mL/hr for 3 consecutive hours following return from theatre), significant post-operative coagulopathy (platelet count < $100 \times 10^9/\text{mm}^3$ or activated partial thromboplastin time > 50 seconds or activated clotting time > 150 seconds), significant post-operative haemodynamic instability (noradrenaline requirements > $0.5 \mu\text{g}/\text{kg}/\text{min}$ to maintain mean arterial pressure > 80 mmHg, or urine output < 30 mL/hr), or significant post-operative hypoxaemia (F_iO_2 > 60% or PEEP > 5 cmH₂O to maintain PaO_2 > 80 mmHg or SaO_2 > 95%).

All patients were sedated by continuous intravenous infusion of propofol and paralysis was ensured with intravenous vecuronium (0.1 - 0.2 mg/kg). Only 8.0 mm internal diameter endotracheal tubes were used and the endotracheal tube (ETT) position was checked by post-operative chest X-ray ensuring that the tip of the ETT lay at least 2 cm above the carina. All patients received 100% oxygen for the period of the trial using a Servo 300 ventilator (Seimens Elena, Solna, Sweden).

Suctioning was conducted with a commercially available 14 French (external circumference in mm or 4.6 mm external diameter) closed system suction catheter (Trach Care, Ballard Medical Products, Draper, Utah, USA) positioned between the ETT and the

ventilator circuit Y piece (figure 1).

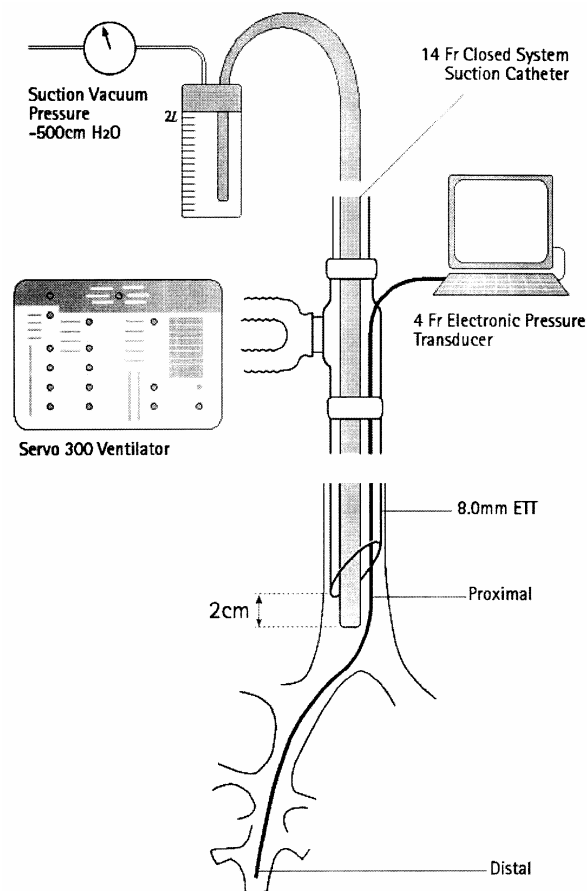


Figure 1. Experimental set-up. Initial suction flows 40 L/min. Suctioning conducted in both proximal and distal positions with ventilator set to volume-control (respiratory rate 12, tidal volume 500 mL, inspiratory:expiratory ratio 1:1, inspiratory pause 10%, PEEP 5 cmH₂O, trigger sensitivity -2 cmH₂O), pressure-control (respiratory rate 12, inspiratory pressure adjusted to achieve a tidal volume 500 mL, inspiratory:expiratory ratio 1:1, inspiratory pause 10%, PEEP 5 cmH₂O, trigger sensitivity -2 cmH₂O) and CPAP/pressure support (PEEP 5 cmH₂O, pressure support 20 cmH₂O, trigger sensitivity -2 cmH₂O).

A standard ejector vacuum device was used with suction pressures set to -500 cmH₂O. This generated an initial suction flow of 40 L/min. Airway pressures were recorded using a 4 French (1.35 mm external diameter) electronic pressure transducer (Camino, Integra Neuro Care, LLC, SanDiego, California, USA) which was introduced into the ETT via an airtight hole in the angle connection. Recordings of airway pressures were made using dedicated software (Picoscope 5.04.4, Pico Technology Ltd, 149-151 St Neots Rd, Hardwick, Cambs CB3 7QJ, United Kingdom). Our ventilator settings and suction duration were chosen as realistic parameters that, based on bench-test studies and a four patient pilot study, would be likely to demonstrate significant differences between the modes of ventilation

but without exposing the patients to dangerous falls in airway pressure.

Experimental protocol

We measured real time airway pressures during suctioning in both proximal and distal airways, and in each location in three modes of ventilation: continuous positive airway pressure (CPAP)/pressure support, volume-control and pressure-control. The pressure transducer was positioned at the end of the endotracheal tube. The ventilator was then set to either volume-control {respiratory rate (RR) 12, tidal volume (TV) 500 mL, inspiratory:expiratory (I:E) ratio 1:1, pause time 10%, PEEP 5 cmH₂O, trigger sensitivity -2 cmH₂O}, pressure-control {RR 12, inspiratory pressure adjusted to achieve TV 500 mL [7 - 17 cmH₂O], I:E ratio 1:1, PEEP 5 cmH₂O, trigger sensitivity -2 cmH₂O}, or CPAP/pressure support {PEEP 5 cmH₂O, pressure support 20 cmH₂O, trigger sensitivity -2 cmH₂O}. The suction catheter was then introduced until its tip lay 2 cm distal to the tip of the ETT and a five-second suction was applied. The suction catheter was then withdrawn. This sequence was then repeated using the other two modes of ventilation. The pressure transducer was then advanced until resistance was met (on most occasions approximately 10 - 12 cm distal to the end of the ETT), and withdrawn 1 cm or until a reliable respiratory waveform was seen. The above three suctioning sequences were then repeated. The order in which the ventilator modes were set was randomly selected, and at least 4 minutes was allowed between each five-second suction.

Data Analysis

During pressure-control and volume-control ventilation we recorded airway pressures for at least 2 breaths prior to the insertion of the suction catheter, during insertion of the suction catheter, at least five breaths following the insertion of the suction catheter, the five-second suction and at least 3 breaths following the completion of the suction. During CPAP/pressure support we recorded airway pressure prior to the insertion of the suction catheter, during insertion of the suction catheter, for at least 10 seconds following the insertion of the suction catheter, during the five-second suction, and for at least 10 seconds following the completion of suctioning.

From the pressure tracings obtained during the suctioning manoeuvre we obtained: end-expiratory pressure, change in end-expiratory pressure following insertion of the suction catheter, and lowest airway pressure obtained during the five-second suction. For recordings made in the CPAP/pressure support mode we recorded the peak pressure of the inspiration that

occurred on the completion of suctioning. We also calculated dynamic lung compliance from the pressure waveforms attained in volume-control prior to insertion of the suction catheter.

Statistics

Data are presented as mean \pm SD. Comparisons between measurements made in the three modes of ventilation were performed using the paired t-test with Bonferroni correction. Comparisons between proximal and distal measurements were made using the paired t-test.

RESULTS

Typical waveforms produced in each mode of ventilation are demonstrated (figure 2).

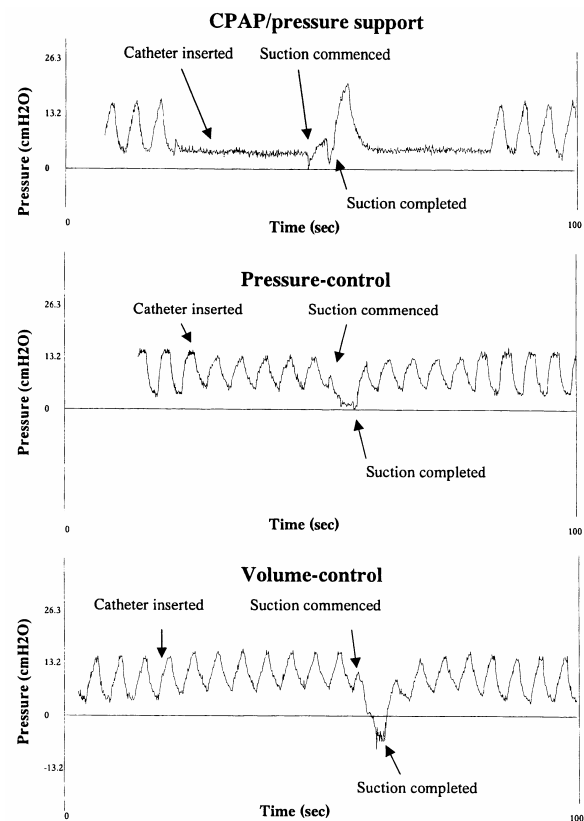


Figure 2. Typical waveforms seen during the suctioning sequence in three different ventilatory modes.

These waveforms were similar in both the proximal and the distal position. When all proximal pressure measurements were compared with their respective distal pressure measurements there were no significant differences ($p > 0.05$). Patients' dynamic lung compliances were calculated as 52.5 ± 14.3 mL/cmH₂O.

End-expiratory airway pressures prior to the insertion of the suction catheter did not differ between the three ventilatory modes ($p > 0.05$) (table 1). Follow-

ing insertion of the suction catheter end-expiratory pressure rose significantly ($p < 0.001$) in both pressure-control and volume-control modes. In the proximal position this rise was greatest ($p = 0.018$) in the volume-control mode (table 1, figure 3). Airway pressures decreased during suction in all ventilatory modes. Volume-control was associated with the greatest ($p = 0.001$) negative airway pressures (table 1, figure 4).

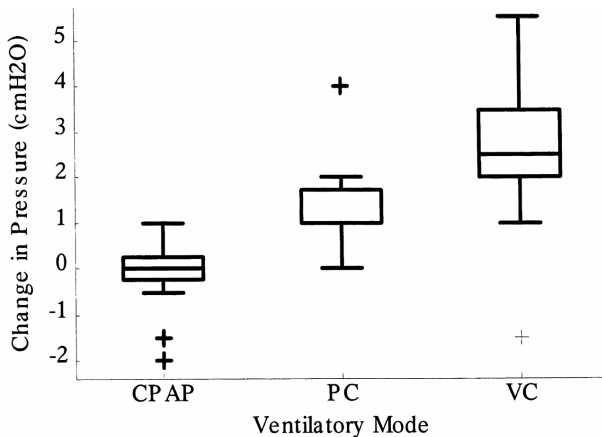


Figure 3. Change in end-expiratory pressure following catheter insertion (proximal position). Boxes = median (25th to 75th centiles), lines = 1.5 x interquartile range.

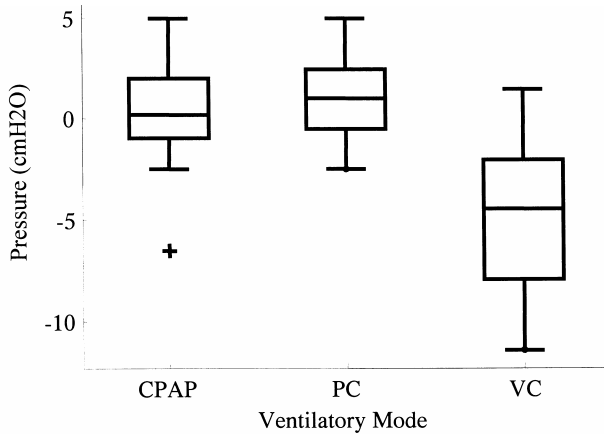


Figure 4. Lowest absolute airway pressure during a five-second suction (proximal position). Boxes = median (25th to 75th centiles), lines = 1.5 x interquartile range.

In volume-control ventilation one patient experienced a fall in airway pressure that exceeded -25 cmH₂O (in both proximal and distal measurements). However, the duration of this fall in airway pressure was less than 0.5 s and may have represented artefact. Accordingly, these values were not included in the analysis. This patient

had a respiratory system compliance (26 mL/cm H₂O) that was considerably less than every other patient (next lowest compliance 37 mL/cm H₂O), and it is possible that the falls in airway pressure seen in this patient were caused by poor compliance.

With the ventilator set to CPAP mode, 13 of the 16 patients experienced a positive pressure 'breath' which commenced at the completion of the endotracheal suctioning (figure 2). When measured in the proximal position airway pressures rose to 21.0 ± 1.6 cmH₂O (distal position 20.9 ± 1.6 cmH₂O).

DISCUSSION

We found that following insertion of the suction catheter end-expiratory pressure rose significantly ($p < 0.001$) in both pressure-control and volume-control modes. In the proximal position this rise was greatest ($p = 0.018$) during volume-control (2.7 ± 1.7 cmH₂O). On performing a five-second suction, the lowest airway pressure during volume-control (-4.9 ± 4.0 cmH₂O) was significantly ($p = 0.001$) less than lowest airway pressure in either pressure-control (0.8 ± 1.9 cmH₂O) or CPAP/pressure support modes (0.4 ± 2.8 cmH₂O). In CPAP/pressure support mode, 13 of the 16 patients experienced a positive pressure 'breath' at the end of suctioning with airway pressures rising to 21 ± 1.6 cmH₂O.

The degree of negative airway pressure generated during endotracheal suctioning will depend on the balance between the inspiratory gas flow and the rate at which gas is removed by suctioning. This, in turn, will be dependent on suction vacuum pressure and suction catheter size. With open suctioning the driving pressure is atmospheric pressure, "inspiratory" gas flow will therefore depend upon the available cross-sectional area of the endotracheal tube, which is determined by the relationship between the internal diameter of the endotracheal tube and the external diameter of the suction catheter. If the suction catheter completely occludes the endotracheal tube, no "inspiratory" gas flow will take place and, on suctioning, airway pressures will eventually approximate vacuum pressure.

Severe negative pressure pulmonary oedema has been reported when an endotracheal tube was connected directly to wall suction.⁶ It has been suggested that the external size of the suction catheter should be less than or equal to twice the size of internal diameter of the endotracheal tube.⁷ Despite this, *in vitro* studies have demonstrated that significant sub atmospheric airway pressures may be generated when open suctioning is performed.

Table 1. Comparison of pressure changes in the three ventilatory modes with measurement at both proximal and distal measurement points

	PEEP prior to catheter insertion		Change in PEEP following catheter insertion		Lowest absolute airway pressure during suctioning	
	<i>Proximal</i>	<i>Distal</i>	<i>Proximal</i>	<i>Distal</i>	<i>Proximal</i>	<i>Distal</i>
CPAP/ Pressure support	4.6 +/- 1.5	3.8 +/- 1.9	-0.1 +/- 0.9	0.2 +/- 0.7	0.4 +/- 2.8	0.6 +/- 1.9
Pressure Control	4.4 +/- 1.7	3.8 +/- 2.0	1.3 +/- 0.9 *	2.0 +/- 1.3 †	0.8 +/- 1.9	0.7 +/- 1.9
Volume Control	4.4 +/- 1.7	4.1 +/- 2.1	2.7 +/- 1.7 **	2.6 +/- 1.4 ††	-4.9 +/- 4.0 ‡	-6.3 +/- 5.4 ‡‡

* p=0.001 compared to CPAP/pressure support proximal

** p<0.001 compared to CPAP/pressure support proximal, and p=0.018 compared to pressure control proximal

† p<0.001 compared to CPAP/pressure support distal

†† p<0.001 compared to CPAP/pressure support distal

‡ p=0.001 compared to CPAP/pressure support proximal, and p<0.001 compared to pressure control proximal

‡‡ p<0.001 compared to CPAP/pressure support distal, and p<0.001 compared to pressure control distal

Stenqvist *et al* demonstrated that when a 14 French suction catheter was inserted in a size 7.0 mm endotracheal tube and suction pressures were set to -500 cmH₂O, suctioning resulted in an initial 'alveolar' pressure of -24 cmH₂O which increased to -15 cmH₂O during steady state suctioning.²

Closed system suctioning has been advocated as a means by which positive end expiratory pressure may be maintained during suctioning.¹ When closed system suctioning is performed, the inspiratory gas flow will not only depend upon the available cross sectional ETT area, but the inspiratory gas flow as defined by the ventilator settings. In theory, significant falls in airway pressure during closed system suctioning could occur in two situations, when volume controlled modes of ventilation are used and settings are such that inspiratory gas flows do not match suction gas flows, or in pressure dependent modes when the set driving pressure is not enough to overcome the increased tube resistance caused by the insertion of the suction catheter. In bench-test comparisons, the most significant falls in airway pressure are demonstrated in volume controlled modes.^{2,3}

There exist four *in vitro* bench-tests of pressure effects of closed system suctioning, three in an adult^{2,3,4} and one in a paediatric setting.⁸ Sparacino *et al* demonstrated that closed system suctioning via a 14 French suction catheter during volume-control ventilation (RR 12/min, TV 600 mL, PEEP 10 cmH₂O) could result in very high levels of negative pressure (-135 cmH₂O with Servo 300 and 9.0 mm ETT), while during pressure controlled ventilation pressure decayed below 0 cmH₂O only during trials via a 7 mm ETT.³ Taggart *et al* demonstrated that sustained negative airway pressures in excess of -50 cmH₂O were attained, with a variety of ventilators, when a volume-control mode of ventilation was used (RR 12, TV 800 mL), at

all tested peak inspiratory flow rates (i.e. 25, 40, 50, and 60 L/min).⁴ Stenqvist *et al* demonstrated that when suctioning was conducted through a 7.0 mm ETT with a 14 French catheter (initial suctioning flow > 40 L/min) and a Servo 900C ventilator was set to volume control (RR 20/min, minute ventilation 10 L/min, I:E ratio 1:1, PEEP 0 cmH₂O), alveolar pressure fell to 10 cm H₂O below the set PEEP level. Low tidal volumes, inverse I:E ratio and obstruction in the tube resulted in pressures down to -92 cmH₂O.

Closed system suctioning during pressure controlled ventilation had fewer effects.² In a study conducted on dogs, Higgins *et al* demonstrated that when a volume-control mode of ventilation was used and suctioning was conducted with a 14 French closed system suction catheter (flow rates 25 L/min) inserted in a 8.5 mm ETT, sustained falls in airway pressures to in excess of -50 cmH₂O were attained. When these same dogs underwent suctioning using pressure-controlled ventilation (pressure-control 5 cmH₂O) sustained airway pressures of -5 to -4 cmH₂O were achieved.⁹

To date, only one *in vivo* human study has been published in which airway pressures have been measured during closed system suctioning.⁵ That study was primarily designed to examine lung volume changes during endotracheal suctioning. A variety of endotracheal tube sizes (7.0 mm to 8.5 mm), a relatively small suction catheter (12 French) and a low suction vacuum pressure (100 mmHg) were used. Only pressure changes in volume controlled ventilation were examined, and airway pressures were measured at the ventilator and not in the patients' airways. Airway pressures are commonly measured in the ventilator apparatus. A variety of components including the ETT, swivel connector, humidification device, or 'secretions' all cause a variance in tube resistance making dynamic pressure measurements above the tube difficult to

interpret.¹⁰ The presence of a suction catheter will only accentuate this. Accordingly, in our study, we chose to measure airway pressures within the patients' airways.

The results of our study were consistent with previous bench-test evaluations. When the ventilator was set to volume-control mode and closed system suctioning was performed, there was a significant ($p = 0.001$) fall in airway pressure to subatmospheric values (-4.9 ± 4.0). In our study in volume-control mode the inspiratory flow rate can be calculated to be 15 L/min. With the Servo 300 ventilator, triggering occurs. Thus apart from the brief triggering period inspiratory flow can be considered to be maintained at 15 L/min during suctioning. This is less than the suction gas flow, which explains the subatmospheric pressures generated. While the degree of negative airway pressure we recorded was not as extreme as has been seen in bench-test evaluations, it is likely that more substantial sub atmospheric pressures would have been observed had we performed longer suctioning or had we set longer inspiratory times. For example, if the inspiratory time had been set to 67%, the inspiratory flow rate would be only 9 L/min.

In pressure-control mode the fall in airway pressure was less and pressures above atmospheric (but below PEEP) were maintained. The presence of the pressure transducer produced only a small reduction in cross sectional area of the ETT, to an ETT internal diameter equivalent of approximately 7.9 mm. However, the insertion of the 14 French suction catheter reduced the ETT internal diameter to the equivalent of approximately 6.4 mm. This represents a 2.3 fold increase in tube resistance. It is likely that with decreasing ETT size, more pronounced falls in airway pressure would be seen. For example, the insertion of the same sized suction catheter down a 7 mm internal diameter ETT would result in a 3.3 fold increase in tube resistance.

Through hindering expiration, the presence of a suction catheter down an ETT may significantly elevate end-expiratory pressure.² This effect is likely to be greater when volume controlled ventilation, smaller endotracheal tubes and longer I:E ratios are used, and when secretions are present within the ETT.² In a bench test evaluation when a Servo 900C was used in volume-control (minute ventilation 10 L/min, I:E ratio of 2:1, set PEEP 10 cmH₂O) and a size 14 French suction catheter was inserted down a 7 mm ETT, PEEP increased from 14 to 39 cmH₂O.² We also demonstrated this effect which in the proximal position was most significant ($p = 0.018$) in volume-control. With the ventilator set to

volume-control the insertion of the 14 French suction catheter increased end-expiratory pressure by 2.7 ± 1.7 cmH₂O.

CPAP mode has been advocated as an appropriate mode in which closed system endotracheal suctioning should be conducted.² In a bench-test evaluation there was no increase in end-expiratory pressure on catheter insertion and subatmospheric pressures were avoided during suctioning.² In our study, with the addition of 20 cmH₂O pressure support, only four patients experienced falls in airway pressure to subatmospheric values, and these were always less than 0.5 s in duration.

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