

The Effect of Suction Method, Catheter Size, and Suction Pressure on Lung Volume Changes During Endotracheal Suction in Piglets

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ABSTRACT: We aimed to identify the effect of suction pressure and catheter size on change in lung volume during open and closed endotracheal suction. Anesthetized piglets ($n = 12$) were intubated with a 4.0-mm endotracheal tube. Lung injury was induced with saline lavage. Three suction methods (open, closed in-line, and closed with a side-port adaptor) were performed in random order using 6, 7, and 8 French gauge (FG) catheters, at vacuum pressures of 80, 140, and 200 mm Hg. Lung volume change was measured with respiratory inductive plethysmography. Overall, open suction resulted in greater lung volume loss during and at 60-s postsuction than either closed method ($p < 0.001$). When open and closed methods were analyzed separately, volume change was independent of catheter size and suction pressure with open suction. With closed suction, volume loss increased with larger catheter sizes and higher suction pressures ($p < 0.001$). With an 8-FG catheter and suction pressure of 140 or 200 mm Hg, volume loss was equivalent with open and closed suction. Lung volume changes are influenced by catheter size and suction pressure, as well as suction method. With commonly used suction pressures and catheter sizes, closed suction has no advantage in preventing loss of volume in this animal model. (*Pediatr Res* 66: 405–410, 2009)

Endotracheal tube (ETT) suction is performed periodically in patients receiving mechanical ventilation, to maintain a patent airway and facilitate ventilation. Although necessary, it is associated with adverse sequelae including atelectasis, hypoxia, and cardiovascular instability (1–4), attributed in part to loss of lung volume. Volume loss can arise from breaking the ventilator circuit for “open” suction and aspiration of gas after application of negative pressure. Closed suction techniques, performed without disconnecting the ventilator circuit, have been widely adopted to reduce the adverse effects of suction (5).

Two closed suction techniques are available: in-line systems, in which a suction catheter, enclosed in a plastic sheath,

is incorporated into the ventilator circuit; and side-port adaptors, Y-shaped connectors placed between the ETT and the ventilator circuit, through which a suction catheter is passed. Few studies have compared the two methods, and there is little evidence to support the use of one over the other (6–8). Both techniques have been shown to result in greater physiologic stability in neonates (9,10), and less loss of lung volume in adults (7,11) and children (12) than open suction, although large volume losses have been recorded with both closed and open methods (7,12,13). In the only neonatal study to date comparing lung volume changes, there was no difference in volume loss between open and closed suction during either conventional or high-frequency oscillatory ventilation (HFOV), and wide variation in losses with both methods (14).

The contribution to volume loss of factors other than suction method remains to be elucidated. At least *in vitro*, suction catheter size and suction pressure have been implicated in determining tracheal pressure during suction (15–17), the presumed precursor to volume loss. Whether tracheal pressure changes result in clinically observable effects is unclear (4,18–20) and there is no consensus on appropriate catheter sizes or suction pressures for clinical use in children or neonates (21–27). No studies have investigated the impact of these factors on lung volume changes.

The aim of this study was to investigate the effect of suction method (open, closed in-line, and closed with a side-port adaptor), catheter size, and suction pressure on lung volume changes during endotracheal suction. Comparisons were made during both conventional, time-cycled pressure-limited ventilation (TCPLV) and HFOV.

MATERIALS AND METHODS

The study procedures were approved by the Murdoch Childrens Research Institute Animal Ethics Committee. It was not feasible to conduct the study in

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Abbreviations: ΔV_L , change in end-expiratory lung volume; ΔV_{L60} , change in end-expiratory lung volume 60 seconds after suction; ETT, endotracheal tube; FG, French gauge; HFOV, high-frequency oscillatory ventilation; P_{aw} , mean airway pressure; PEEP, positive end-expiratory pressure; PIP, peak inspiratory pressure; RIP, respiratory inductive plethysmography; TCPLV, time-cycled pressure-limited ventilation

human infants, as the protocol required multiple episodes of suction in a short timeframe, together with repeated alveolar derecruitment and recruitment, and thus an animal model was used. Two-wk-old piglets ($n = 12$) were anesthetized with isoflurane and intubated with a 4.0-mm cuffed ETT; the cuff was then inflated until no leak was detected. Anesthesia was maintained with propofol 10 mg/kg/h and morphine 0.6 mg/kg/h, and muscle relaxation achieved with pancuronium 0.15 mg/kg/h. TCPLV (Bear Cub; Viasys Healthcare, Yorba Linda, CA) was established with initial settings rate 30, inspiratory time 0.5 s, positive end-expiratory pressure (PEEP) 5 cm H₂O, and peak inspiratory pressure (PIP) to maintain tidal volume at 10 mL/kg. Inspired oxygen fraction was maintained at 1.0 throughout the experiment, in accordance with recommendations for endotracheal suction in infants and children (22). A pneumotachograph (Florian respiratory monitor, Acutronic Medical Systems, Zug, Switzerland) was placed proximal to the ETT. Lung injury was induced with repeat saline lavage until the alveolar-arterial oxygen difference was ≥ 400 mm Hg for 30 min.

Measurements. End-expiratory lung volume change (ΔV_L) was estimated with a low-pass filtered, DC-coupled respiratory inductive plethysmograph (RIP) (Respirace 200; Noninvasive Monitoring Systems Inc., North Bay Village, FL), sampling at 200 Hz using the method we have described previously (28,29). Once thermally stable (30), the voltage signal was calibrated during 15 ventilator inflations on TCPLV to the tidal volume measured by the pneumotachograph, and a calibrated volume signal obtained from the sum of the abdominal and chest RIP voltages (31).

Experimental protocol. Before commencing the experimental series, the pressure-volume (PV) relationship of the lung was mapped with RIP by increasing PIP and PEEP in increments of 5 cm H₂O until the upper inflection point was passed and no further end-expiratory recruitment was achieved (total lung capacity), then decreasing at the same rate until the PEEP was 0 cm H₂O, mapping the deflation limb and identifying the point of maximal curvature (closing pressure) (29,32). Each limb of the PV relationship was mapped over a 3-min period. Lung volume data were displayed and recorded continuously throughout the process using a custom-built data acquisition program designed with LabVIEW 6.0 (National Instruments, Austin, TX). The recording provided a template that was displayed on a computer screen for the duration of the experiment, with real-time PV recordings superimposed, thus, enabling guidance of ventilation changes. The lung was then rerecruited through total lung capacity and ventilation established on the deflation limb, with PEEP 2 cm H₂O above the identified closing pressure, and PIP set to maintain the premapping PIP-PEEP difference (33,34).

Suction episodes were then performed using all permutations of three methods (open, in-line, and side-port adaptor) and three catheter sizes (6, 7, and 8 French gauge [FG]), in random order. Randomisation was performed using a dedicated randomisation program (Graphpad software, San Diego, CA). The full range of procedures could not be performed in all animals; thus, in six animals the above permutations were performed twice, at vacuum pressures of 80 and 200 mm Hg (11 and 27 kPa), applied in random order, and in the remaining six animals all episodes were performed at a vacuum pressure of 140 mm Hg (19 kPa). The in-line system was the Ballard Trachcare (Kimberly-Clark, Roswell, GA) and the side-port adaptor a Neo-LINK universal adaptor (Viasys MedSystems, Wheeling, IL), which contains a self-sealing valve that permits catheter entry without opening the circuit to atmosphere. The same disposable catheters (Mallinkrodt, Rowville, Victoria, Australia) were used for open and side-port adaptor suction. Both types of catheter are 30 cm in length and have one end and two side holes of identical size. The 6-, 7-, and 8-FG catheters have external diameters of 2, 2.3, and 2.7 mm, respectively, and thus occlude 25%, 34%, and 44% of the 4.0-mm ETT luminal cross-sectional area. As reported previously (15), gas flow through each of the catheters increases in a nonlinear fashion with increasing suction pressure, consistent with turbulent flow.

In all cases, the suction catheter was passed to the tip of the ETT without suction, and suction subsequently applied for 6 s, the typical duration of suction in our institutions, while withdrawing the catheter. Between episodes, lung rerecruitment was performed as required, as described earlier, to maintain lung volume at the same point on the PV relationship, as determined by the prerecorded template (33,34). Suction episodes were performed at ~5-min intervals.

HFOV was then commenced (3100A high-frequency oscillator; Sensor-medics, Yorba Linda, CA). The PV relationship was mapped as before, by adjusting the mean airway pressure (P_{aw}) in steps of 3 cm H₂O, and ventilation was subsequently established on the deflation limb, 2 cm H₂O above closing pressure (33). Between suction episodes, P_{aw} was adjusted as required to rerecruit through total lung capacity and maintain ventilation at the same point. Frequency was fixed at 10 Hz, and amplitude set to maintain P_{CO_2} at 35–55 cm H₂O. The suction episodes were repeated as described earlier. In total, six animals received 36 episodes of suction, and six received 18 episodes. The entire experiment lasted for ~4 h in each animal.

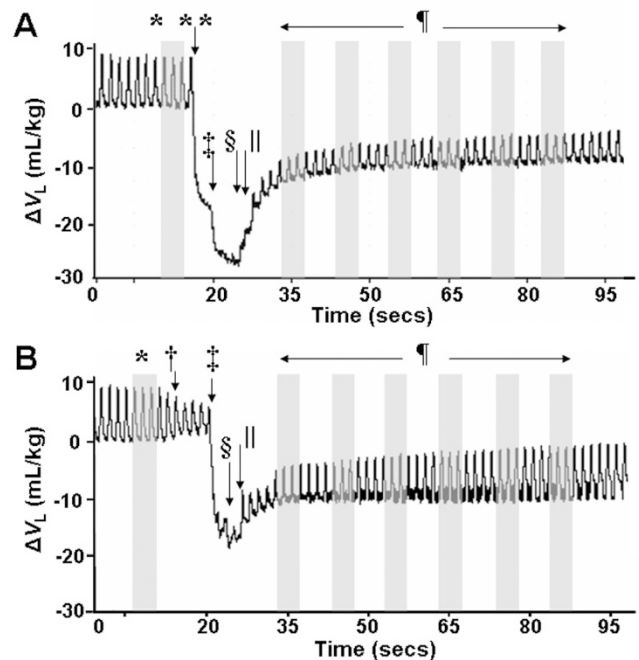


Figure 1. Calibrated RIP tracings of representative episodes of open suction (A) and in-line suction (B) during TCPLV, showing key time points at which end-expiratory lung volume (EELV) was determined. *Baseline EELV; **disconnection of the ventilator circuit (open suction); †insertion of suction catheter (closed suction); ‡suction onset; §point of minimum volume during the procedure; ||end of the procedure, defined as reconnection of the ventilator circuit (open suction) or complete withdrawal of the catheter (closed suction); ¶10-s intervals from completion of the procedure. All measurements are expressed as change in volume relative to baseline EELV (ΔV_L). Arrows indicate single-point measurements. Gray bars indicate EELV averaged over 3 ventilator inflations (TCPLV) or 3 s (HFOV).

Data collection and analysis. Lung volume data were recorded continuously from 15 s before each suction procedure until 90 s after its completion. Each RIP recording was examined and ΔV_L determined at critical time points using a data processing program designed with LabVIEW 6.0 (Fig. 1). The main points of comparison were the minimum volume and the residual volume loss still evident at 60 s after completion of the procedure ($\Delta V_{L,60}$). Univariate ANOVA was used to examine the overall effect of each of the three suction variables in turn. Combined effects, including interactions, were then examined using multiway ANOVA. Logistic regression was used to predict recovery of lung volume to $\geq 90\%$ of baseline. All statistical analyses were performed using Stata 8.0 (Stata Corporation, College Station, TX).

RESULTS

The 12 animals had a weight (mean \pm SD) of 5.02 ± 0.54 kg. Alveolar-arterial oxygen difference before experimentation was 548 ± 91 mm Hg during TCPLV and 445 ± 135 mm Hg during HFOV. During TCPLV, PIP was 26.7 ± 4.7 cm H₂O and PEEP 8.9 ± 1.2 cm H₂O. During HFOV, P_{aw} was 24.7 ± 3.7 cm H₂O. Animals suctioned with a pressure of 140 mm Hg were ventilated with higher pressures than those in the other group (PIP 30.0 ± 1.1 versus 23.4 ± 4.7 ; PEEP 9.7 ± 1.0 versus 8.1 ± 0.8 ; and P_{aw} 27.2 ± 1.3 versus 22.2 ± 3.7) but in all other respects, the groups were similar. There was no association between ventilator pressures and volume loss.

Univariate analysis. Figure 2 shows the effect of each suction variable on ΔV_L over time, using pooled data from all experimental permutations. All suction techniques resulted in significant changes in lung volume during both TCPLV and

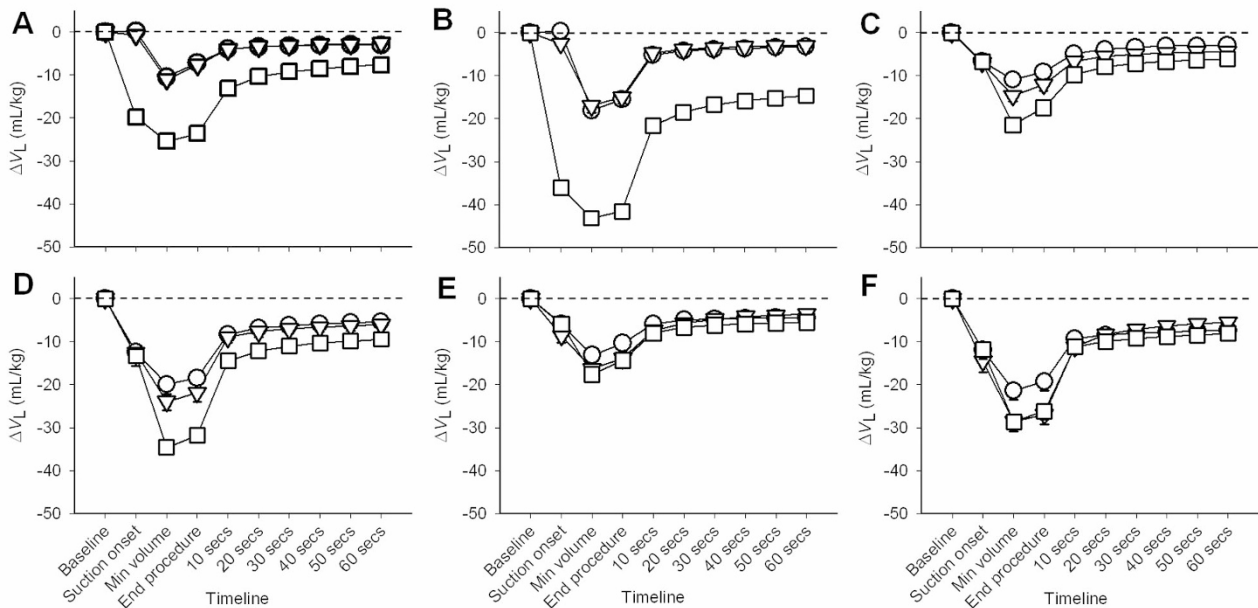


Figure 2. ΔV_L over time during TCPLV (panels A, C, and E) and HFOV (panels B, D, and F). Each data point represents mean \pm SEM for all experimental permutations of suction method (panels A and B), catheter size (panels C and D), and suction pressure (panels E and F) ($n = 36$ per data point). Panels A and B, ΔV_L with different suction methods. Circles, closed suction with in-line catheter; triangles, closed suction with side-port adaptor; and squares, open suction. Panels C and D, ΔV_L with different catheter sizes. Circles, 6 FG; triangles, 7 FG; squares, 8 FG. Panels E and F, ΔV_L with different suction pressures. Circles, 80 mm Hg; triangles, 140 mm Hg; squares, 200 mm Hg. TCPLV, time-cycled pressure-limited ventilation; HFOV, high-frequency oscillatory ventilation.

HFOV ($p < 0.0001$, repeated measures ANOVA). Similar patterns of ΔV_L were noted during both ventilation modes, with greater volume losses overall recorded during HFOV.

Open suction resulted in greater loss of volume and lower values of ΔV_{L60} than either closed method during both TCPLV (Fig. 2A) and HFOV (Fig. 2B) ($p < 0.0001$, all comparisons). The majority of volume loss with open suction ($77.2 \pm 12.2\%$ of the total during TCPLV and $83.4 \pm 10.1\%$ during HFOV, mean \pm SD) occurred during disconnection of the ventilator circuit before suction. No differences were found between the two closed suction methods, and data from the two methods were combined for further statistical analysis.

Catheter size influenced ΔV_L during both TCPLV (Fig. 2C) and HFOV (Fig. 2D). The 8-FG catheter resulted in lower minimum volume ($p < 0.0001$ both ventilation modes) and ΔV_{L60} ($p < 0.0001$ TCPLV, $p = 0.0012$ HFOV) than either the 6-FG or the 7-FG.

Suction pressure did not influence either minimum volume or ΔV_{L60} during TCPLV (Fig. 2E). During HFOV (Fig. 2F), smaller losses resulted from a pressure of 80 mm Hg than the other two pressures ($p = 0.028$). ΔV_{L60} did not differ between pressures.

Multivariate analysis. Discrete data from each combination of catheter size, suction method, and suction pressure are shown in Figure 3, with values for minimum volume and ΔV_{L60} displayed in Table 1. Analysis of the separate and combined effects of suction variables on lung volume revealed a different pattern for open and closed suction. With open suction, neither catheter size nor suction pressure influenced either minimum volume or ΔV_{L60} during either ventilation mode. With closed suction, volume loss increased with increasing catheter size and suction pressure ($p < 0.001$ all

comparisons), with the interaction between catheter size and pressure of borderline significance ($p = 0.054$) during TCPLV and highly significant during HFOV ($p = 0.0001$). ΔV_{L60} was independently affected by catheter size ($p < 0.0001$ TCPLV and HFOV) and suction pressure ($p = 0.004$ TCPLV; $p = 0.0058$ HFOV).

With an 8-FG catheter, volume loss was equivalent with open and closed suction at vacuum pressures of 140 and 200 mm Hg during both TCPLV and HFOV. At 80 mm Hg, closed suction resulted in less volume loss than open suction. During TCPLV, ΔV_{L60} did not differ between open and closed suction; during HFOV, ΔV_{L60} was higher with closed suction than open only at a vacuum pressure of 80 mm Hg.

At 60 s after completion of the suction procedure, lung volume was restored to $\geq 90\%$ of baseline in 46 episodes (28.6%) during TCPLV and 47 episodes (29.2%) during HFOV. Results of the logistic regression are shown in Table 2. During TCPLV, closed suction was more likely to be associated with restoration of lung volume, but this effect was modified by increasing catheter size; catheter size itself had no independent effect. Increasing suction pressure slightly reduced the probability of lung volume being restored, whereas increasing PIP increased its probability. During HFOV, restoration of lung volume was more likely to occur during closed suction, and with increasing P_{aw} . There was a trend toward an increase in restoration of lung volume with both 6- and 7-FG catheters compared with the 8-FG but this did not reach statistical significance.

DISCUSSION

This study examined the individual and combined effects of suction variables on lung volume. Overall, open suction resulted

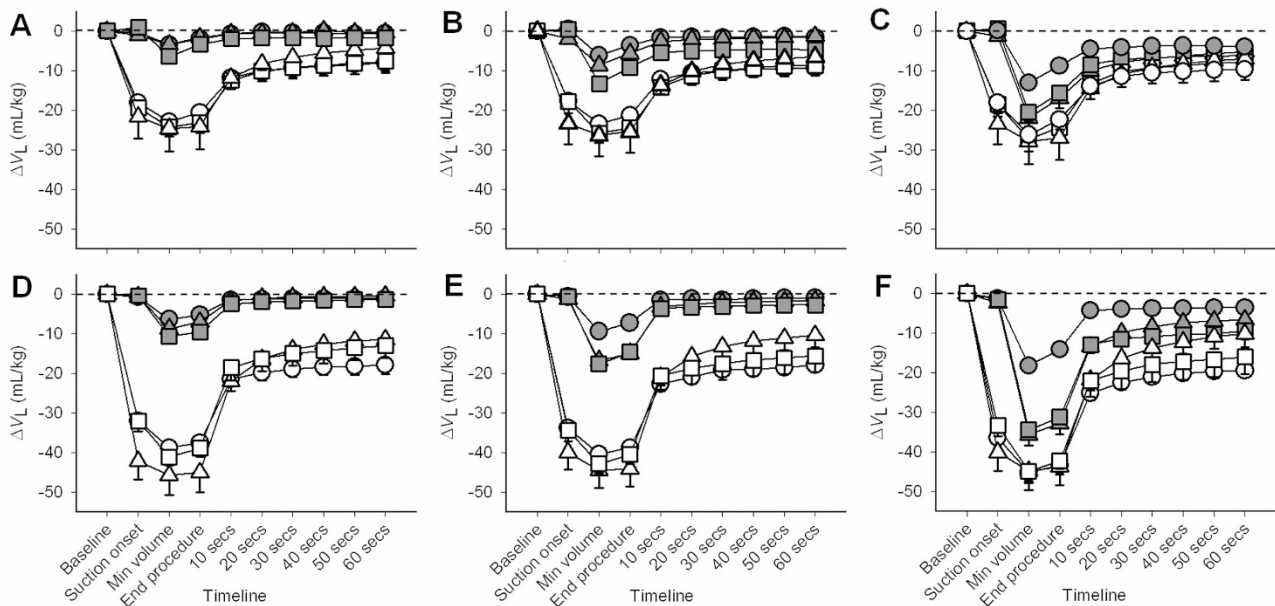


Figure 3. ΔV_L over time during TCPLV (panels A, B, and C) and HFOV (panels D, E, and F) with each individual combination of catheter size, suction method, and suction pressure ($n = 6$ per data point for open suction and 12 for closed suction). Panels A and D, 6 FG; Panels B and E, 7 FG; Panels C and F, 8 FG. Open suction is represented by open symbols, closed suction by gray symbols. Circles, 80 mm Hg; triangles, 140 mm Hg; squares, 200 mm Hg. All data represented as mean \pm SEM. TCPLV, time-cycled pressure-limited ventilation; HFOV, high-frequency oscillatory ventilation.

Table 1. Minimum lung volume and volume at 60 s after suction (ΔV_{L60}) with each combination of suction method, catheter size, and suction pressure

Catheter size	Suction pressure	TCPLV				HFOV			
		Minimum lung volume		ΔV_{L60}		Minimum lung volume		ΔV_{L60}	
		Open suction	Closed suction	Open suction	Closed suction	Open suction	Closed suction	Open suction	Closed suction
6 FG	80	-23.0 ± 6.4	-3.5 ± 2.9	-8.1 ± 6.0	-0.6 ± 1.1	-38.8 ± 5.3	-6.4 ± 3.7	-18.0 ± 5.3	-1.0 ± 1.8
	140*	-24.6 ± 14.2	-3.5 ± 1.4	-4.3 ± 1.9	-0.4 ± 1.5	-45.8 ± 12.0	-8.7 ± 3.0	-11.5 ± 3.2	-0.4 ± 1.0
	200	-24.3 ± 6.0	-6.4 ± 3.7	-7.7 ± 6.2	-1.7 ± 2.0	-41.1 ± 5.2	-10.7 ± 3.9	-10.7 ± 3.4	-1.3 ± 3.0
7 FG	80	-23.5 ± 6.4	-6.1 ± 2.4	-9.3 ± 4.8	-1.7 ± 2.1	-40.4 ± 4.8	-9.4 ± 3.0	-17.9 ± 3.4	-1.0 ± 1.5
	140*	-26.4 ± 13.0	-8.7 ± 2.8	-6.5 ± 3.2	-1.2 ± 1.4	-44.5 ± 10.9	-16.8 ± 3.9	-10.4 ± 7.5	-1.7 ± 1.8
	200	-25.8 ± 5.9	-13.3 ± 4.8	-8.6 ± 5.6	-4.8 ± 4.0	-42.9 ± 5.7	-17.6 ± 5.7	-15.6 ± 10.0	-2.7 ± 2.4
8 FG	80	-26.2 ± 7.1	-13.1 ± 3.7	-9.6 ± 6.7	-3.9 ± 3.6	-45.2 ± 6.5	-18.2 ± 4.5	-19.5 ± 4.0	-3.5 ± 3.2
	140*	-27.9 ± 13.9	-22.0 ± 11.2	-7.0 ± 3.9	-5.3 ± 4.0	-44.8 ± 11.7	-35.6 ± 9.8	-10.2 ± 8.2	-6.6 ± 3.2
	200	-27.4 ± 7.5	-20.5 ± 8.5	-7.8 ± 6.0	-6.2 ± 4.1	-44.9 ± 6.4	-34.4 ± 6.5	-16.0 ± 10.5	-9.4 ± 7.5

Volume expressed as change from baseline, in mL/kg. Mean \pm SD, $n = 6$ for open suction, $n = 12$ for closed suction.

* Separate group of animals.

in a greater loss of lung volume than closed suction and was associated with residual deficit 1 min after completion of the procedure. However, the difference between suction methods diminished as both catheter size and suction pressure increased and was not apparent when using an 8-FG catheter at suction pressures of 140 or 200 mm Hg, that is, under conditions likely to be used in clinical practice. In this sense, we contend that the use of closed suction in the clinical setting may not guarantee preservation of lung volume in infants and small children.

Larger catheters, that occlude more of the ETT lumen, have been shown *in vitro* to generate high negative airway pressures during both open and closed suction (15–17). In adults, it is recommended that the diameter of the suction catheter should be less than half that of the ETT (35). This ratio cannot be achieved with the smallest ETT sizes and is generally seen

as impractical with ETT sizes ≤ 4.0 mm; most authorities recommend either an 8- or a 10-FG be used with a 4.0-mm ETT (21,23,24,26,27,36). Our findings tend to support more recent recommendations for the use of smaller catheters whenever possible (22), at least with respect to closed suction. We found suction pressure had less influence on lung volume loss than catheter size. The range of pressures studied may have been too narrow to show greater differences. Importantly, we found an interaction between catheter size and suction pressure in determining volume loss with closed suction. It was notable that, when using the two smaller catheters at the highest pressure, volume loss was less than or similar to that generated by an 8-FG catheter at the lowest pressure. Guidelines generally seem to treat the two variables as independent entities, recommending severe restriction of suction pressure

Table 2. Logistic regression analysis of factors predicting restoration of end-expiratory lung volume to $\geq 90\%$ of baseline at 60s following the suction procedure

	Odds ratio	<i>p</i>	95% Confidence intervals	
Time-cycled pressure-limited ventilation				
Peak inspiratory pressure	1.24	0.001	1.09	1.42
Suction pressure	0.992	0.010	0.985	0.998
Closed suction	8.22	0.010	1.67	40.43
Interaction between closed suction and 7-FG catheter	0.267	0.003	0.111	0.643
Interaction between closed suction and 8-FG catheter	0.057	<0.001	0.013	0.250
High-frequency oscillatory ventilation				
Mean airway pressure	1.23	0.008	1.06	1.44
Closed suction	10.3	0.005	1.99	53.44
6-FG catheter	2.99	0.065	0.934	9.55
7-FG catheter	1.83	0.086	0.917	3.65

regardless of catheter size (25–27,36). Our findings support our previous contention that catheter size and suction pressure should be considered in relation to each other (15).

With open suction, lung volume changes were unaffected by catheter size or suction pressure. This finding is consistent with a study of oxygenation and hemodynamic changes with suction in ventilated children (4) but is somewhat surprising in light of *in vitro* studies (15,17). In contrast, in another pediatric study catheter size was implicated in reduction in dynamic compliance after suction (19). The suction pressure in this study was 360 mm Hg (48 kPa), higher than in our study or that of Singh *et al.* (4). In a nonrandomized study, right upper lobe collapse occurred in fewer children when suction pressure was limited to 120 mm Hg than when pressure was unregulated (18).

Lung rerecruitment following suction is as important a consideration as derecruitment during the procedure. Both open and closed techniques were associated with persistent volume deficit at 1-min postsuction, during both conventional and high-frequency ventilation. We did not investigate the effect of recruitment maneuvers in this study, but it was notable that higher ventilator pressures (PIP or P_{aw}) were associated with an increased likelihood of restoration of lung volume close to presuction levels. Further research is required to determine the most appropriate rerecruitment techniques, and the conditions under which they are required.

We found no difference in performance between the two closed suction methods. Similar findings were obtained in two studies in adult intensive care patients (6,7). A study in preterm infants found in-line suction resulted in less disruption to oxygenation and heart rate than suction using an adaptor (8); however, different protocols were used with each technique, which may have contributed to this finding. The cost of in-line suction systems is considerably higher than that of adaptors, which are used with ordinary disposable catheters. This cost is difficult to justify on current evidence.

However, the relative effects of the two techniques on other outcomes, such as infection, should be established before recommendations can be made.

ETT suction is performed to remove secretions, and effectiveness must be taken into consideration when choosing specific techniques. Animal and *in vitro* data suggest closed suction is less effective than open when used under similar conditions (20,37). Little is known of the effectiveness of various combinations of catheter size and suction pressure, and further research on this topic is warranted.

A strength of our study is that we standardized the volume state of the lung, rather than ventilating with standard pressures, the first study to our knowledge to do so. Despite the standardization of the model, lung volume loss varied considerably between animals, suggesting the involvement of factors additional to those we measured. Moreover, it cannot be assumed that similar results would be seen with absent or different lung pathology, or with a different ventilation strategy.

Our study had some limitations. First, all animals in our study were muscle relaxed, which is not routine in current neonatal ventilatory management. In a study of ventilated neonates, a minority of whom were muscle relaxed, we found lung volume was restored in a shorter timeframe than we have described here (14); however, no studies have directly compared lung volume changes in muscle relaxed and spontaneously breathing subjects. Second, data were obtained from only one pass of the suction catheter; in clinical practice a suction episode consists of 2–3 passes on average. The effect of repeated catheter passes on lung volume change remains to be determined. Third, we did not account for the effect of secretions, the volume of which was observed to vary during the experiment. Aspiration of mucus into the suction catheter is likely to limit the negative pressure generated in the airway and thus may reduce the overall volume loss. In the clinical setting, accumulated secretions can reduce the diameter of the ETT, and if not aspirated, will increase the pressure transmitted to the trachea, potentially increasing volume loss; however, this scenario was unlikely during our experiment because of the frequency with which suction was performed.

Finally, the limitations of RIP need to be considered. RIP measures change in total thoracic volume and cannot distinguish between gas and fluid changes. Changes in thoracic blood volume may have contributed to RIP changes during our experimental protocol. The summed RIP voltage output was calibrated to a known volume at the airway opening during TCPLV, a simple and practical method over short time periods (28,38). Whether the derived calibration factor, which assumes an equal weighting of each RIP signal, remains constant over prolonged periods in severe lung disease states has been questioned, especially during HFOV (31). Irrespective, the raw summed RIP voltage signal is a validated method of assessing global ΔV_L over time (29,39). RIP cannot determine where, within the lung, any volume change may occur. Electrical impedance tomography, which allows determination of regional ΔV_L , may be an alternative to RIP in the future (13,40,41).

In conclusion, this study in ventilated neonatal piglets found that lung volume changes during endotracheal suction can be

influenced by catheter size and suction pressure, as well as suction method. With catheter sizes and suction pressures commonly used in clinical practice, closed suction did not preserve lung volume.

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