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A M E R I C A N C O L L E G E O F  
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# Side Effects of Endotracheal Suction in Pressure- and Volume-Controlled Ventilation\*

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**Study objectives:** To investigate the effects of endotracheal suction in volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) with an open suction system (OSS) or a closed suction system (CSS).

**Design:** Randomized comparison.

**Setting:** Animal research laboratory.

**Patients:** Twelve healthy anesthetized pigs.

**Interventions:** The effects of endotracheal suction during VCV and PCV with tidal volume ( $V_T$ ) of 14 mL/kg were compared. A 60-mm inner-diameter endotracheal tube was used. Ten-second suction was performed using OSS and CSS with 12F and 14F catheters connected to  $-14$  kPa vacuum.

**Measurements and results:** Thirty minutes after suction in PCV,  $V_T$  was still decreased by 27% ( $p < 0.001$ ), compliance (Crs) by 28% ( $p < 0.001$ ), and  $P_{aO_2}$  by 26% ( $p < 0.001$ );  $P_{aCO_2}$  was increased by 42% ( $p < 0.0001$ ) and venous admixture by 158% ( $p = 0.003$ ). Suction in VCV affected only Crs (decreased by 23%,  $p < 0.001$ ) and plateau pressure (increased by 24%,  $p < 0.001$ ). The initial impairment of gas exchange following suction in VCV was no longer statistically significant after 30 min.

**Conclusions:** In conclusion, endotracheal suction causes lung collapse leading to impaired gas exchange, an effect that is more severe and persistent in PCV than in VCV.

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**Key words:** gas exchange; lung; mechanical ventilation; pigs; suction; trachea; venous admixture

**Abbreviations:** ANOVA = analysis of variance; Crs = compliance; CSS = closed suction system; CVP = central venous pressure; HR = heart rate; MAP = mean systemic arterial pressure; MPAP = mean pulmonary arterial pressure; OSS = open suction system;  $P_{aw}$  = airway pressure; PCV = pressure-controlled ventilation; PEEP = positive end-expiratory pressure;  $P_{plat}$  = plateau pressure; VCV = volume-controlled ventilation;  $V_T$  = tidal volume

Patients dependent on mechanical ventilation often need to have mucus suctioned from their airways. Because endotracheal suction may create negative pressures in the trachea, there is a risk of partial lung collapse, which can lead to desaturation.

To minimize the risk of complications during endotracheal suctioning, various ventilator settings have been proposed to prevent desaturation and loss of lung volume.<sup>1-3</sup>

Different endotracheal suction systems are used, ie, open and closed systems. When an open suction system (OSS) is used, the endotracheal tube is disconnected at the Y-piece and the suction catheter is inserted into the endotracheal tube before suction. The disconnection allows airway pressure ( $P_{aw}$ ) to fall to atmospheric pressure before the suction starts. When a closed suction system (CSS) is used, the system is connected into the tubing and the suction catheter is introduced into the trachea without the endotracheal tube being disconnected.<sup>4,5</sup> One advantage of CSS is that it reduces the risk of infection from contamination.<sup>6</sup> Another indication is for patients with high positive end-expiratory pressure

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(PEEP) settings.<sup>7</sup> The use of CSS has also been shown to prevent arterial and systemic venous oxygen desaturation and lung collapse during volume-controlled ventilation (VCV).<sup>8</sup>

Negative effects after endotracheal suction during VCV have been described, but we have found no study that compares the effects of suctioning during VCV and pressure-controlled ventilation (PCV). Our hypothesis is that endotracheal suction might have different side effects depending on ventilator mode and suction method; therefore, we compared the effect of endotracheal suction on hemodynamics and gas exchange in PCV and VCV with different suction systems and catheter sizes.

## MATERIALS AND METHODS

Twelve healthy anesthetized pigs of mixed breed (Hampshire, Yorkshire, and Swedish native breed) with a body weight ranging from 25 to 35 kg were investigated. The experimental protocol was examined and approved by the local Ethics Committee for Animal Experiments, Uppsala, Sweden. The study was performed in accordance with the recommendations of the Swedish National Board for Laboratory Animals.

### Anesthesia

Before transport to the laboratory, the pigs were premedicated with 40 mg of azaperon administered by IM injection. Anesthesia was induced with 0.5 mg of atropine and a mixture of 100 mg of tiletamin and 100 mg of zolazepam dissolved in 5 mL of medetomidin (1 mg/mL), 1 mL per 20 kg of body weight IM. The animals were placed in supine position on a heating pad and intubated with a cuffed endotracheal tube, 6.0-mm inner diameter. A bolus injection of 0.2 mg of fentanyl was administered IV. Anesthesia was maintained by infusion of 5 mL/kg/h of a solution containing 4 g of ketamin, 1 mg of fentanyl, and 48 mg of pancuron in 1,000 mL of Rehydrex with glucose.

All pigs received mechanical ventilation (Evita 4; Dräger Medical; Lübeck, Germany) in either volume-controlled (intermittent positive pressure ventilation) or a pressure-controlled (bilevel pressure ventilation) modes. Ventilator settings were fraction of inspired oxygen of 0.3 and PEEP of 3 cm H<sub>2</sub>O. Tidal volume (V<sub>T</sub>) was either set to 14 mL/kg or inspiration pressure level was set to achieve V<sub>T</sub> of 14 mL/kg. Respiratory rate was adjusted to achieve a stable end-tidal CO<sub>2</sub> of 5.5 kPa. Auto flow was off and trigger set to minimum. Inspiration/expiration ratio was 1:1 in PCV and 1:2 in VCV.

### Suction

In order to standardize lung volume history, a recruitment maneuver was performed: Paw was increased for 10 s to 15 cm H<sub>2</sub>O above plateau pressure (P<sub>plat</sub>) in VCV or above inspiration pressure level in PCV. The next endotracheal suction started when all variables had returned to baseline values. During the suction procedure, the catheter was inserted into the endotracheal tube and suction with a -14-kPa vacuum was performed for 10 s. Immediately after suction, the catheter was removed. Supplementary oxygenation was not used before or after endotracheal suction. Measurements were made at baseline, and 1 min, 10 min, and 30 min after suction. Suction systems (CSS

[Trach Care; Ballard Medical Products; Draper, UT] and OSS [UNO; Maersk Medical A/S; Lyngø, Denmark]) with 12F (outer diameter 4.0 mm) and 14 F (outer diameter 4.7 mm) catheters were used.

### Measurements and Monitoring

A catheter was inserted in the carotid artery for pressure measurements and blood sampling. A Swan-Ganz thermodilution catheter was introduced in the external jugular vein and advanced to the pulmonary artery for measurement of pressure and cardiac output, and for blood sampling. A central venous catheter was inserted in the same vein as the Swan-Ganz catheter to measure pressure. Measurements included arterial and venous blood gases (ABL 5; Radiometer; Copenhagen, Denmark) [tonometric correction for pig blood was made], heart rate (HR), mean systemic arterial pressure (MAP), mean pulmonary arterial pressure (MPAP), central venous pressure (CVP), and cardiac output measured by thermodilution technique and oxygen saturation.

A flow sensor (D-lite; Datex-Ohmeda; Helsinki, Finland) was connected at the Y-piece for dynamic gas monitoring. Fraction of inspired oxygen, fraction of expired oxygen, respiratory rate, V<sub>T</sub>, end-tidal carbon dioxide, compliance (C<sub>rs</sub>), Paw, and P<sub>plat</sub> were registered. All measurements were recorded with a critical care monitor (CS/3 CCM; Datex-Ohmeda).<sup>9</sup> The monitor was connected to a computer, and data were collected continuously. Venous admixture was calculated from the blood gas values according to the method described by Berggren.<sup>10</sup>

### Protocols

The effects of endotracheal suction during two ventilation modes, VCV and PCV, were compared. Both ventilation modes were applied in random order in all pigs. An OSS 14 catheter was used (n = 8). The effects of endotracheal suction with different catheters, 12F and 14F, using OSS and CSS were compared during PCV (n = 4).

### Statistical Analysis

Analysis of variance (ANOVA) and repeated-measurement ANOVA was used to compare data between and within the VCV and PCV groups, and within the OSS and CSS groups, at different study times. The Tukey honest significant difference test was used for *post hoc* comparisons, and probability values were calculated. Mann-Whitney was used to compare data between 12F and 14 F OSS and CSS groups, at different study times. For all statistical calculations, the Statistica/v 5.0 software package (StatSoft; Tulsa, OK) was used. Results are given as mean ± SD; p < 0.05 was regarded as significant.

## RESULTS

### Effect of Suction During PCV and VCV Using a 14F OSS

In PCV 1 min after suction, MPAP (p = 0.009) and venous admixture (p < 0.001) were increased, and PaO<sub>2</sub> (p < 0.001), V<sub>T</sub> (p < 0.001), and C<sub>rs</sub> (p < 0.001) were decreased. After 30 min, these changes were still significant; in addition, PaCO<sub>2</sub> had increased (p < 0.001). In VCV 1 min after suction, MPAP (p = 0.004), venous admixture (p = 0.001),

and Pplat ( $p < 0.001$ ) were increased, and PaO<sub>2</sub> ( $p < 0.001$ ) and Crs ( $p < 0.001$ ) were decreased. Thirty minutes after suction, these variables had returned to baseline values except for Crs and Pplat (Table 1). When PCV and VCV were compared, it was found that 30 min after suction, MPAP was higher ( $p = 0.001$ ), PaO<sub>2</sub> was lower ( $p = 0.009$ ), PaCO<sub>2</sub> was higher ( $p = 0.001$ ), and venous admixture was higher ( $p = 0.008$ ) in PCV.

#### Effect of Suction With OSS or CSS in PCV

There was no significant difference between 12F OSS and 12F CSS in any variable, measured 1 min, 10 min, and 30 min after suction (Table 2). Nor could any significant differences be found between 14F OSS and 14F CSS (Tables 1, 2).

The results of suction with catheter size 14F OSS (Table 1) and size 12F OSS (Table 2) show a significant difference when 14F was used in terms of higher MPAP ( $p = 0.004$ ), lower PaO<sub>2</sub> ( $p = 0.02$ ), higher PaCO<sub>2</sub> ( $p = 0.04$ ), higher venous admixture ( $p = 0.001$ ), and lower VT ( $p < 0.001$ ) after 30 min. Comparison of the effects of CSS with 12F and 14F catheters showed that after 30 min, PaO<sub>2</sub> was lower ( $p = 0.001$ ), PaCO<sub>2</sub> was higher ( $p = 0.001$ ), venous admixture was higher ( $p = 0.04$ ), and VT was lower ( $p < 0.03$ ) when catheter size 14F was used (Table 2).

## DISCUSSION

We have shown that gas exchange and lung mechanics were more negatively affected by endotracheal suction in PCV than in VCV. Most of the negative effects of suction remained after 30 min in PCV, but this was not the case when VCV was used.

One possible explanation is that in VCV, where the volume of each breath is the same, there is a small recruitment with each successive breath. However, in VCV, the changes in both Crs and Pplat remained 30 min after suction; this may indicate partial lung collapse. Given that VT was not changed, pulmonary collapse might lead to overdistension of those parts of the lung that remained open. During artificial ventilation, it is important to prevent lung collapse and thus minimize the risk of ventilator-induced lung injury. Daily suction procedures—sometimes even hourly suction procedures—are required to clear the endotracheal tube of mucus. Therefore, it is important to understand what side effects suction can have, in order to select the best suction method for each patient.

A previous study<sup>11</sup> found complications such as desaturation, hemorrhagic secretions, hemodynamic changes, and HR modifications in 57% of 79 patients who had undergone endotracheal suctioning. The most important risk factor found was high levels of PEEP. In addition, CSS has been found to prevent lung collapse during VCV in patients with acute lung injury.<sup>8</sup> In that study,<sup>8</sup> CSS was done with a 12F catheter in a 7.5- to 8-mm inner-diameter endotracheal tube with a negative vacuum pressure of 100 mm Hg.<sup>8</sup>

In our study, we went on to examine the effects of different suctioning systems in PCV. The negative pressure created during suction can contribute to lung collapse and gas exchange impairment that remains long after completed suction. When CSS is used, the ventilator can deliver breaths even though the suction catheter has been inserted into the endotracheal tube, provided that the catheter is narrow enough to allow the ventilator to continue ventilation and maintain PEEP. Maintained PEEP

**Table 1—Side Effects of Endotracheal Suction During PCV and VCV With a 14F OSS Catheter\***

Variables (n = 8)	PCV				VCV			
	Baseline	1 min	10 min	30 min	Baseline	1 min	10 min	30 min
MPAP, mm Hg	19 ± 1	22 ± 3†	24 ± 4†	24 ± 4†‡	20 ± 1	22 ± 2†	21 ± 2	21 ± 2
PaO <sub>2</sub> , kPa	20 ± 1	12 ± 4†	15 ± 4†	15 ± 4†‡	19 ± 1	15 ± 3†	18 ± 2	19 ± 2
PaCO <sub>2</sub> , kPa	4.8 ± 0.1	5.5 ± 0.6	6.4 ± 1.2†	6.9 ± 1.3†‡	5.1 ± 0.2	5.1 ± 0.3	5.2 ± 0.3	5.0 ± 0.3
Venous admixture, %	5 ± 2	14 ± 8†	12 ± 7†	13 ± 9†‡	5 ± 3	9 ± 5†	7 ± 2	6 ± 2
Crs, mL/cm H <sub>2</sub> O	33 ± 3	24 ± 7†	24 ± 6†	24 ± 6†	33 ± 5	26 ± 5†	26 ± 5†	26 ± 5†
VT, mL	395 ± 28	291 ± 81†	291 ± 75†	290 ± 73†	389 ± 26	388 ± 24	391 ± 26	390 ± 29
Pplat, cm H <sub>2</sub> O	17 ± 1	17 ± 1	17 ± 1	17 ± 1	15 ± 2	19 ± 3†	19 ± 2†	19 ± 2†
MAP, mm Hg	90 ± 13	93 ± 12	94 ± 11	93 ± 8	83 ± 14	85 ± 12	84 ± 14	84 ± 14
Cardiac output	3.1 ± 1.1	2.9 ± 1.1	3.1 ± 1.2	3.2 ± 1.3	3.3 ± 1.2	3.3 ± 1.2	3.4 ± 1.2	3.2 ± 1.1
HR, beats/min	97 ± 17	95 ± 14	95 ± 16	96 ± 17	99 ± 23	99 ± 24	96 ± 19	97 ± 19
CVP	9 ± 2	10 ± 2	10 ± 2	9 ± 2	10 ± 2	10 ± 2	10 ± 2	10 ± 2

\*Data are presented as mean ± SD.

†Different from baseline, repeated-measurement ANOVA ( $p < 0.05$ ).

‡Different from VCV, ANOVA ( $p < 0.05$ ).

**Table 2—Comparisons of OSS and CSS With Catheter Size 12F and 14F in PCV\***

Variables (n = 4)	OSS 12F		CSS 12F		CSS 14F	
	Baseline	30 min	Baseline	30 min	Baseline	30 min
MPAP, mm Hg	18 ± 2	18 ± 2	19 ± 4	20 ± 3	19 ± 1	24 ± 4†
PaO <sub>2</sub> , kPa	19 ± 2	18 ± 2	19 ± 2	18 ± 1	19 ± 1	14 ± 7†‡
PaCO <sub>2</sub> , kPa	4.8 ± 0.5	4.9 ± 0.6	4.9 ± 0.4	5.2 ± 0.8	4.9 ± 0.1	7.3 ± 1.7†‡
Venous admixture, %	4 ± 2	6 ± 1	5 ± 1	5 ± 1	5 ± 2	17 ± 14†‡
Crs, mL/cm H <sub>2</sub> O	33 ± 6	30 ± 7	32 ± 8	29 ± 8	33 ± 4	23 ± 5†
VT, mL	418 ± 48	394 ± 49	410 ± 47	380 ± 53	406 ± 32	290 ± 84†‡
MAP, mm Hg	82 ± 7	80 ± 6	78 ± 8	80 ± 15	93 ± 22	96 ± 12
Cardiac output	3.0 ± 0.7	2.9 ± 0.6	3.0 ± 0.5	3.0 ± 0.6	3.1 ± 1.5	3.3 ± 1.6
HR, beats/min	91 ± 17	88 ± 17	93 ± 12	91 ± 13	86 ± 19	91 ± 23
CVP	8 ± 1	9 ± 2	8 ± 1	8 ± 1	9 ± 2	9 ± 2

\*Data are presented as mean ± SD.

†Different from baseline, repeated-measurement ANOVA ( $p < 0.05$ ).

‡Different from 12F CSS, Mann-Whitney ( $p < 0.05$ ).

could explain why less desaturation was found in patients with PEEP settings  $> 8$  cm H<sub>2</sub>O when CSS was used.<sup>7</sup>

The selection of catheter size is important in order to avoid obstruction of the endotracheal tube that would limit gas flow. The results of OSS with 12F and 14F catheters show significant differences in terms of MPAP, PaO<sub>2</sub>, PaCO<sub>2</sub>, venous admixture, and VT. Likewise, CSS with 12F and 14F catheters gives significantly different results in terms of PaO<sub>2</sub>, PaCO<sub>2</sub>, venous admixture, and VT. These results highlight the importance of correct catheter size.

In order to limit the negative effects of both OSS and CSS, it is recommended to keep suction pressure at the lowest possible level ( $\leq 150$  mm Hg or 20 kPa) and suction duration no longer than 15 s.<sup>4</sup> When these recommendations were followed, we found no side effects of suction with a 12F catheter, whether using OSS or CSS, in PCV. This confirms the clinical value of the recommendations, but if there had been mucus in the tube the results might be similar to the results obtained after use of a 14F catheter.

In previous studies, only minor hemodynamic changes were observed when CSS was used. The patients were sedated and paralyzed.<sup>8</sup> The present study was done in healthy pigs that were deeply anesthetized to keep the experimental model unaffected by stress; under these conditions, no changes in HR and MAP were observed. The PEEP level was also kept low (3 cm H<sub>2</sub>O). The hemodynamic changes might be more prominent if other conditions and ventilator settings were used.

In conclusion, our study provides further evidence that endotracheal suction can cause lung collapse, especially in PCV. However, if smaller catheters are used, the risk of collapse might be lower. In contrast, when VCV is used, some of the collapsed lung areas

can be partially reopened. We suggest that side effects of suction should be monitored routinely, not only by observing saturation but also by following values such as Crs, VT, and Pplat. We suggest that further studies should focus on suction efficacy and pressure measurement during endotracheal suction.

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