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Effectiveness and side effects of closed and open suctioning: an experimental evaluation

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Abstract *Objective:* To compare the effectiveness of closed system suctioning (CSS) and open system suctioning (OSS) and the side effects on gas exchange and haemodynamics, during pressure-controlled ventilation (PCV) or continuous positive airway pressure (CPAP). *Design:* Bench test and porcine lung injury model. *Participants:* Twelve bronchoalveolar saline-lavaged pigs. *Setting:* Research laboratory in a university hospital. *Interventions:* In a mechanical lung, the efficacy of OSS and CSS with 12 and 14 Fr catheters were compared during volume-control ventilation, PCV, CPAP 0 or 10 cmH_2O by weighing the suction system before and after aspirating gel in a transparent trachea. Side effects were evaluated in the animals with the same ventilator settings during suctioning of 5, 10 or 20 s duration. *Measurements and results:* Suctioning with 12 and 14 Fr catheters was significantly more efficient with OSS (1.9±0.1, 2.8±0.9 g) and with CSS during CPAP 0 cmH_2O (1.8±0.2, 4.2±0.5 g) as compared to CSS during PCV (0.2±0.2, 0.8±0.3 g) or CPAP 10 cmH_2O (0.0±0.1, 0.7±0.4 g), $p<0.01$ (means ± SD). OSS and CSS at CPAP 0 cmH_2O resulted in a marked decrease in SpO_2, mixed venous oxygen saturation and tracheal pressure, $p<0.001$, but the side effects were considerably fewer during CSS with PCV and CPAP 10 cmH_2O, $p<0.05$. *Conclusions:* Irrespective of catheter size, OSS and CSS during CPAP 0 cmH_2O were markedly more effective than CSS during PCV and CPAP 10 cmH_2O but had worse side effects. However, the side effects lasted less than 5 min in this animal model. Suctioning should be performed effectively when absolutely indicated and the side effects handled adequately.

Keywords Suctioning · Closed system suctioning · Airway pressure · Gas exchange · Acute respiratory distress syndrome (ARDS) · Mechanical ventilation

Introduction

Closed system suctioning (CSS) was originally introduced for hygienic reasons [1, 2, 3] and as a method of avoiding desaturation during suctioning [4, 5, 6, 7, 8, 9, 10]. Since the introduction of the open lung concept, prevention of lung derecruitment in acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) patients during endotracheal suctioning has been focused on [11, 12]. CSS minimises the loss of end-expiratory lung volume during suctioning [13, 14, 15, 16], but there are limited data on its effectiveness and a clinical impression that it is not as effective as open suctioning (OSS) [17, 18, 19].

Regulatory authorities have received several reports of complications of CSS, in which pressures of –500 cmH_2O were registered. A combination of large suction catheters and insufficient triggering of the ventilator could lead to extreme negative pressures during CSS [20, 21]. High intrinsic positive end-expiratory pressure (PEEP) may occur during insertion of the suction catheter if unsuitable ventilator settings are used [21]. Thus, manufacturers were compelled to issue guidelines limiting the catheter to 12 Fr in a 7 mm endotracheal tube and 14 Fr for 8 mm. Reduced vacuum levels and suctioning times were proposed. These new guidelines may have influenced suctioning efficacy.

Research has focused on evaluating and minimising the side effects of suctioning. The primary goal of suctioning is to remove secretions, but little is known about the effectiveness of different techniques, the influence of catheter size and ventilatory modes [17, 18, 22]. The primary objective of this study was to examine the efficacy of closed and open suctioning during controlled conditions in a bench test. The side effects of suctioning on respiration and circulation were assessed in a porcine lung injury model.

Material and methods

Suctioning efficacy

A Biotek ventilator tester, model VT-1 (Bio-Tek Instruments, Vermont, USA) was used as a lung model. Compliance was set at 50 ml/cmH_2O. The lung model was fitted with a plastic "trachea", inner diameter (ID) 18 mm, which was intubated with a cuffed endotracheal tube (Portex Blue Line, SIMS Portex, UK) with 7 or 8 mm ID. A 12 or 14 Fr Trach Care closed suctioning system (CSS) catheter with an outer diameter (OD) of 4.0 or 4.6 mm and a standard ejector vacuum device with an interposed suction bottle, volume 1.0 l (2.5 l in animal experiments), connected to a Servo 900C ventilator were used. Vacuum level was set at −150 mmHg or −300 mmHg. Before intubation, 15 ml of a soap gel, density 1.0 kg m^{-3}, (Hudosil, Stockholms Analytiska Lab, Sweden) was applied in the "trachea", 2 cm below the endotracheal tube tip with the trachea completely clogged with gel. Open suctioning (OSS) was performed by disconnecting the CSS from the Y-piece. Suctioning was applied for 10 s in accordance with clinical guidelines [23, 24, 25, 26].

Protocol

Before suctioning, the catheter was inserted 2 cm below the tip of the tube. Suction was applied for 10 s without moving the catheter. The amount of gel recovered by suctioning was quantified by weighing the suctioning systems on a precision scale (Sauter RC 1631, August Sauter, Germany). CSS was performed during volume-controlled ventilation (VCV), pressure-controlled ventilation (PCV) and continuous positive airway pressure (CPAP) mode (0 or 10 cmH_20). Ventilator settings during PCV and VCV mode were: MV 9.0 l, PEEP 5, RR 20, I:E 1:3, trigger –2 cmH_2O. The suctioning system and ventilator settings chosen were performed randomly and each intervention repeated six times.

Suctioning side effects

Twelve anaesthetised Landrace pigs, of either gender, weighing 31±3 kg (mean ± SD) were studied in accordance with the NIH guidelines [27] and the protocol approved by Gothenburg University ethics committee. The effects of OSS and CSS with ongoing PCV were compared in the first series of animals (*n*=6). Due to results from the bench test, a second series of animals was used to evaluate the side effects of OSS and CSS (*n*=6) during CPAP mode of 0 or 10 cmH_2O.

Anaesthesia

The animals were fasted overnight with free access to water. The induction of anaesthesia was performed with ketamine (Ketalar, Parke-Davis, USA) 15 mg kg^{-1} and midazolam (Dormicum, Roche, Switzerland) 0.2 mg kg^{-1} intramuscularly. In the first series, this was followed by an intravenous (i.v.) bolus injection of α-chloralose (Merck, Germany) 100 mg kg^{-1} and fentanyl (Fentanyl, Dumex-Alpharma, Sweden) 2 μg kg^{-1} before intubation, and anaesthesia was maintained with an infusion of α-chloralose 25–50 mg kg^{-1} h^{-1} and fentanyl 3 μg kg^{-1} h^{-1}. In the second series, the induction of anaesthesia was as above, followed by i.v. sodium pentobarbital (Pentobarbitalnatrium, Apoteket, Sweden) 5–6 mg kg^{-1} before intubation and maintained with an infusion of sodium pentobarbital 7.5–10 mg kg^{-1} h^{-1} and fentanyl 5–7 μg kg^{-1} h^{-1}. (Due to a change of routines in the animal research laboratory). The pigs were intubated with an endotracheal tube, 7 mm ID. Mechanical ventilation was started with a Servo 900 C ventilator (Siemens, Sweden) with the animals placed supine. Ringer's solution with glucose 2.5%, 10–15 ml kg^{-1} h^{-1} was given intravenously to maintain central venous pressure at 7–10 mmHg. Rectal temperature was kept normal by heating pads.

Measurements

A pulmonary artery catheter (7.5 Fr Swan-Ganz thermodilution catheter, CCO/SvO_2, Edward Lifesciences, CA, USA) was inserted via the internal jugular vein for mixed venous oxygen saturation (SvO_2) and pulmonary arterial pressure (MPAP). A pulse-oximetry probe was placed on the tail. In the carotid artery, mean arterial pressure (MAP) and heart rate (HR) were measured. Tidal volume (V_T) and respiratory compliance (C_{rs}) were monitored with a D-lite flow and airway pressure sensor (Datex-Ohmeda, Instrumentarium, Finland) connected at the Y-piece [27, 28]. Intratracheal pressure (P_{trach}) was measured with a 1.6/1.1 mm OD/ID, fluid-filled catheter inserted into the endotracheal tube and connected to a pressure-monitoring set (PVB Medizintechnik, Germany) [29, 30]. The catheter was positioned 2 cm below the tip of the endotracheal tube. End-tidal carbon dioxide concentration ($ETCO_2$) was monitored with an infra-red side-stream capnograph and breath-by-breath airway oxygen concentration was monitored with a paramagnetic analyser. Transducers were connected to an AS/3 monitor (Datex-Ohmeda, Finland) and calibrated according to the manufacturer's recommendations. Physiological data were collected with a sample frequency of 0.1 Hz. Oxygen tension (PaO_2) was calculated from pulse-oximetry (SpO_2) values using a standard oxyhaemoglobin dissociation curve [31].

Lung injury model

After preparation, repeated bronchoalveolar lavage was performed with 12±2 l isotonic saline at body temperature, 30 ml kg^{-1} in each wash. During the lavage procedure, the animals were ventilated with PCV, minute ventilation (MV) 7–8, inspired oxygen fraction (FIO_2) of 1.0 and PEEP 5–15 cmH_2O to prevent desaturation [32]. After lavage, they were allowed to stabilise, ventilated with PCV, MV 7.7±1.2 l, PEEP 9±3 cmH_2O, RR 20 and I:E 1:2. The experimental procedure was started when oxygen saturation (SpO_2) was stable above 90% with a FIO_2 of 0.4±0.1 and steady-state $ETCO_2$. The baseline-estimated PaO_2/FIO_2 ratio was 197±55 mmHg with PEEP around 10 cmH_2O, fulfilling the oxygenation criteria for ALI [12].

Protocol

The first group of animals (n=6) were subjected to four interventions in random order: (1) OSS with 12 Fr catheter (2) OSS with 14 Fr catheter (3) CSS with 12 Fr catheter and (4) CSS with 14 Fr catheter during PCV. For each of the four modes, suctioning was applied for 5, 10 and 20 s consecutively. Measurements were made at baseline, during the first minute after the start, at the point when the most extreme (worst) value was registered and at 5 min. Between manoeuvres the animals were allowed to stabilise and a new baseline was registered when SpO_2 and $ETCO_2$ reached steady state, which took 4–10 min. CSS was performed during PCV 26–28 cmH_2O, PEEP 9±3 cmH_2O, I:E 1:2, RR 20 and trigger level –2 cmH_2O.

The second group of animals (n=6) were subjected to three interventions in random order: (1) OSS with 12 Fr catheter (2) CSS with 12 Fr catheter during CPAP 0 cmH_2O (3) CSS with 12 Fr catheter during CPAP 10 cmH_2O. Suctioning and measurement procedures were performed as above.

Statistical analysis

For comparison of the effects in the bench test, Kruskal-Wallis tests were used. Mann-Whitney U-tests were used for pair-wise comparisons between interventions.

The two groups of animals were analysed separately. Within each group the effects of OSS versus CSS were compared between interventions using a two-way ANOVA for repeated measures [33]. In the case of a significant ANOVA finding, dependent variables (baseline vs 1 min values) were compared using single degree of freedom contrast analysis. Probability values less than 0.05, after Bonferroni correction, were considered significant. The values in text, tables and figures are given as means ± SD, if not stated otherwise.

Results

Suctioning efficacy

Open system suctioning was significantly more efficient than CSS with both 12 and 14 Fr catheters during VCV, PCV or CPAP 10 cmH_2O ($p<0.01$). In contrast, CSS during CPAP 0 cmH_2O was as effective as OSS with both 12 and 14 Fr catheters. Increasing the vacuum level from –150 to –300 mmHg during CSS and CPAP 10 cmH_2O did not improve the removal of secretions. Removal was significantly greater with the 14 Fr catheter compared to the 12 Fr catheter during CSS with CPAP 0 ($p<0.01$), CPAP 10 ($p<0.01$), PCV ($p<0.05$) and VCV ($p<0.01$) (Fig. 1). Auto-triggering of the ventilator was seen during all CSS procedures. During CSS with positive pressure ventilation (including CPAP 10 cmH_2O) in the transparent "trachea", the triggered inspiratory gas inflow pushed secretions away from the catheter tip.

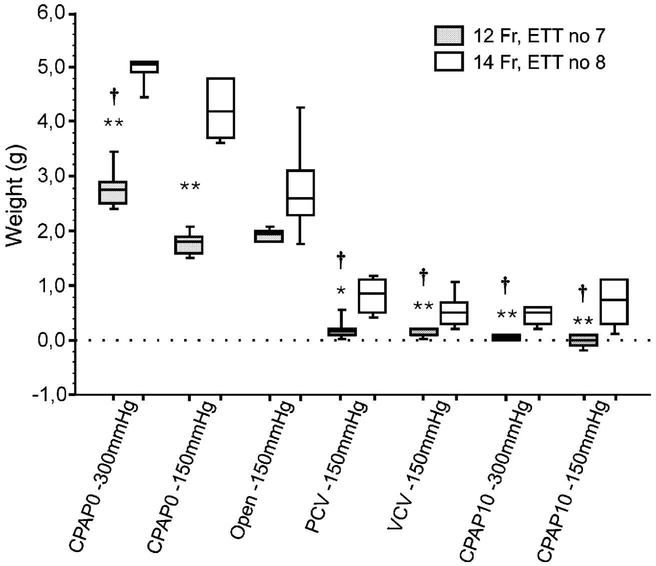

Fig. 1 Box plot showing median, 25th to 75th percentile and 10th–90th percentile of the suctioning system's weight difference before and after suctioning 10 s with 12 and 14 Fr catheters. 12 versus 14 Fr catheters *$p<0.05$, **$p<0.01$, ***$p<0.001$; open versus closed system $^{\dagger}p<0.01$

Table 1 Open suctioning versus closed suctioning during pressure-controlled ventilation (*PCV*) with 12 Fr catheters. Gas exchange, haemodynamics and ventilatory parameters registered during suctioning 10 s (n=6). One-minute value is the most extreme value observed during the first minute after start of suctioning (10 s)

	Open system			Closed system/PCV		
	Baseline	0–1 min worst value	5 min	Baseline	0–1 min worst value	5 min
SpO_2 (%)	93±3	59±10^{a}	92±6	93±1	86±5^{b}	94±1
SvO_2 (%)	55±6	40±11^{a}	54±7	54±8	50±9^{c}	57±7
P_{trach} (cmH_2O)	24±4	–5±5^{a}	24±4	24±2	4±6^{a,d}	24±2
Crs (ml/cmH_2O)	18±2	13±2^{a}	18±2	19±2	17±4^{e}	19±3
V_T (ml)	412±40	322±45^{a}	403±37	442±52	402±68	428±66
MAP (mmHg)	90±8	82±11	87±10	83±11	85±19	84±10
MPAP (mmHg)	27±5	32±9	28±5	27±7	25±6	25±4
HR (beats/min)	91±15	100±20	91±15	100±17	98±17	97±18

SpO_2 oxygen saturation, *SvO_2* mixed venous oxygen saturation, *P_{trach}* tracheal peak pressure, *Crs* respiratory system compliance, *V_T* tidal volume, *MAP* mean arterial pressure, *MPAP* mean pulmonary arterial pressure and *HR* heart rate
Baseline versus 1 min: $^{a}p<0.001$; $^{e}p<0.05$
Open versus closed: $^{b}p<0.001$; $^{c}p<0.05$; $^{d}p<0.01$

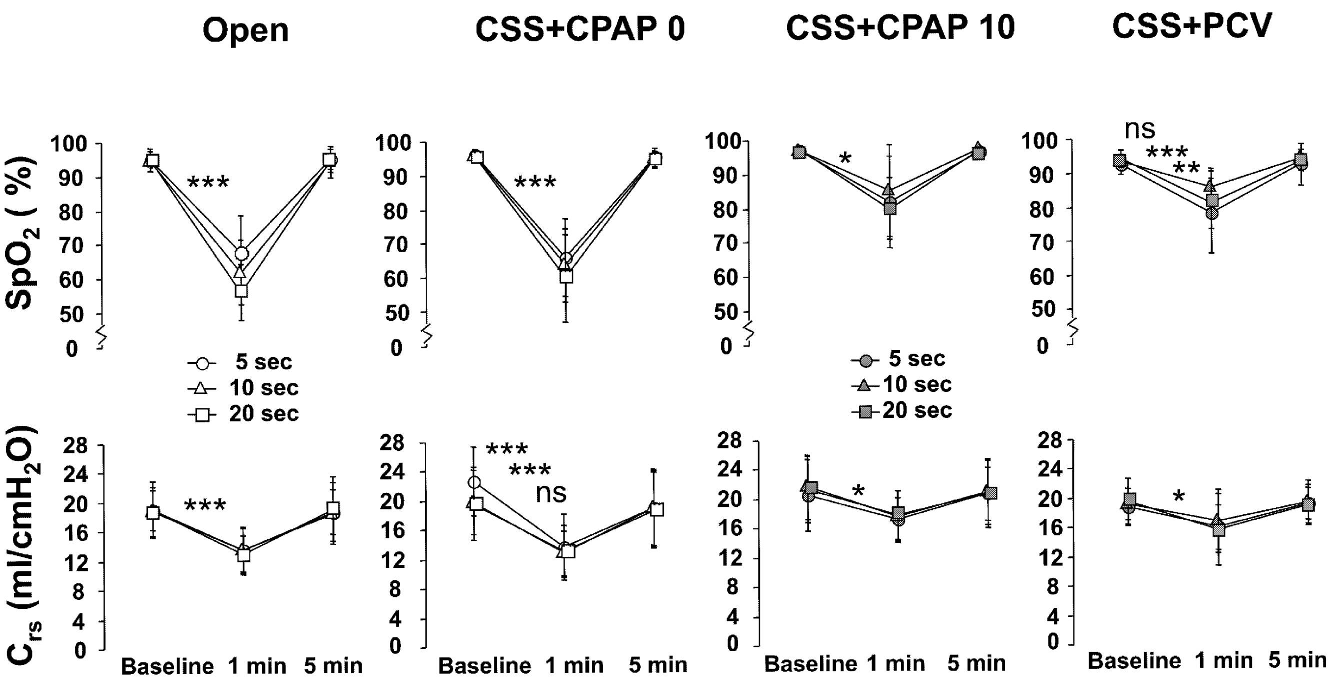

Fig. 2 Effects on oxygen saturation (*SpO_2*) and compliance (*Crs*) during and after suctioning 5, 10 and 20 s with 12 Fr catheters. Open suctioning (*n*=12) and closed suctioning during continuous positive airway pressure (*CPAP*) 0 cmH_2O, 10 cmH_2O and pressure-controlled ventilation (*PCV*), left to right (*n*=6). Baseline versus 1 min value $*p<0.05$, $**p<0.01$, $***p<0.001$, *ns* non-significant

Table 2 Open suctioning versus closed suctioning with 14 Fr catheters during pressure-controlled ventilation (*PCV*) Gas exchange, haemodynamics and ventilatory parameters registered during suctioning 10 s. (*n*=6). One-minute value is the most extreme value observed during the first minute after start of suctioning (10 s)

	Open system			Closed system/PCV		
	Baseline	0–1 min worst value	5 min	Baseline	0–1 min worst value	5 min
SpO_2 (%)	93±2	59 ± 8^{a}	93±2	94±1	$77\pm8^{a,b}$	95±3
SvO_2 (%)	53±8	33 ± 14^{a}	53±7	57±10	$47\ \pm11^{a,d}$	57±8
P_{trach} (cmH_2O)	25±4	-8 ± 2^{a}	24±4	24±3	$-1\pm5^{a,c}$	24±4
Crs (ml/cmH_2O)	17±3	13 ± 3^{a}	17±2	19±2	16 ± 3^{a}	19±2
V_T (ml)	408±45	302 ± 69^{a}	420±52	435±53	373 ± 104^{e}	440±51
MAP (mmHg)	89±11	82±18	92±15	83±5	78±6	83±6
MPAP (mmHg)	29±5	34 ± 9^{e}	30±4	25±5	28±7	25±5
HR (beats/min)	86±11	93±16	86±10	96±18	99±20	96±17

SpO_2 oxygen saturation, *SvO_2* mixed venous oxygen saturation, *P_{trach}* tracheal peak pressure, *Crs* respiratory system compliance, *V_T* tidal volume, *MAP* mean arterial pressure*,* *MPAP* mean pulmonary arterial pressure and *HR* heart rate
Baseline versus 1 min: $^{a}p<0.001$; $^{e}p<0.05$
Open versus closed: $^{b}p<0.001$; $^{c}p<0.05$; $^{d}p<0.01$

Side effects of suctioning

Open system suctioning for 5, 10 or 20 s with 12 Fr catheters resulted in SpO_2 of 66±7, 59±10 and 54±7%, respectively, worst values during the first minute after the start of suctioning. The corresponding values for CSS during PCV were 78±12, 86±6 and 81±7%. OSS for 10 s using 12 and 14 Fr catheters resulted in SpO_2 of 59±10 and 59±8%, and CSS for 10 s during PCV resulted in SpO_2 of 86±6 and 77±8% (worst values). SvO_2, P_{trach}, C_{rs}, V_T, HR, MAP and MPAP differed marginally with the various durations of suctioning and catheter sizes (Fig. 2, Tables 1 and 2).

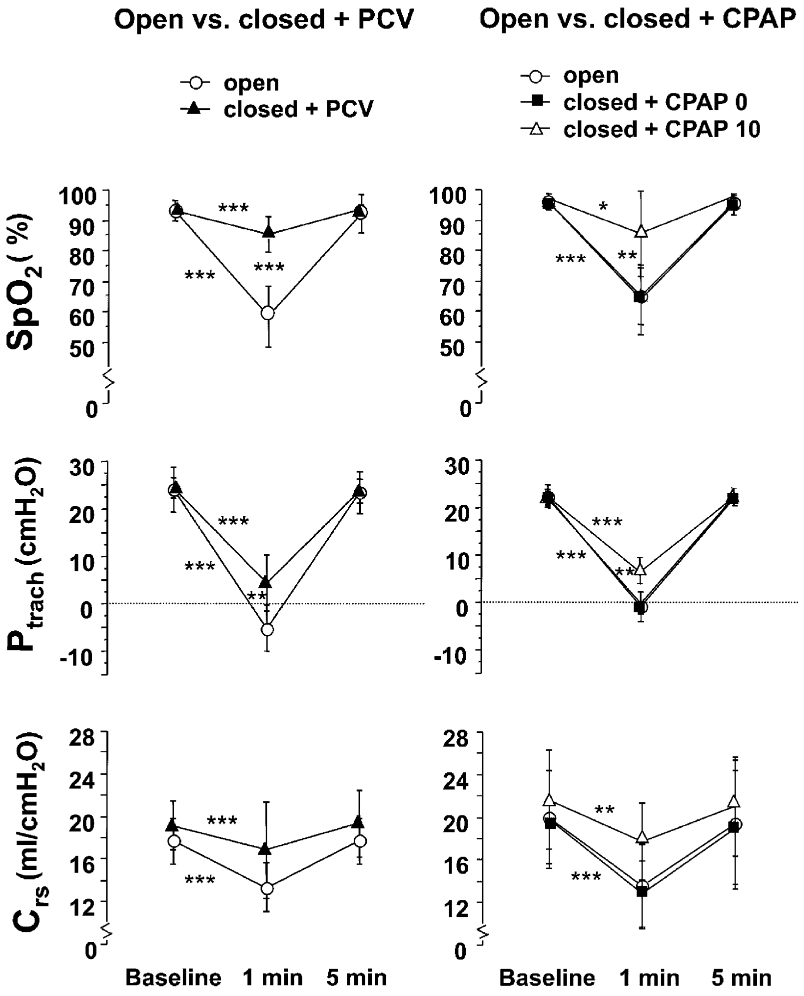

Fig. 3 Effects on oxygen saturation (*SpO_2*), peak tracheal pressure (*P_{trach}*) and compliance (*Crs*) during and after suctioning 10 s with 12 Fr catheters. In the *left column* closed system suctioning (*CSS*) during pressure-controlled ventilation (*PCV*) compared to open suctioning, (*n*=6). To the *right* CSS during continuous positive airway pressure (*CPAP*) of 0 or 10 cmH$_2$O compared to open suctioning (*n*=6). Baseline versus 1 min value and open versus closed system, $^*p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$

Table 3 Open suctioning versus closed suctioning during continuous positive airway pressure (*CPAP*) with 12 Fr catheters. Gas exchange, haemodynamics and ventilatory parameters registered during suctioning 10 s (*n*=6). One-minute value is the most extreme value observed during the first minute after start of suctioning (10 s)

	Open system			Closed system/CPAP 0			Closed system/CPAP 10		
	Baseline	0–1 min worst value	5 min	Baseline	0–1 min worst value	5 min	Baseline	0–1 min worst value	5 min
SpO_2 (%)	96±1	65±9^{a}	96±3	96±2	64±11^{a}	95±3	97±1	85±14^{d,e}	98±1
SvO_2 (%)	63±6	49±9^{a}	61±7	56±8	42±8^{a}	55±7	63±8	58±10^{c,e}	64±7
P_{trach} (cmH$_2$O)	22±2	−1±3^{a}	22±1	22±2	0±2^{a}	22±2	22±1	6±3^{a,d}	22±2
Crs (ml/cmH$_2$O)	20±4	14±4^{a}	19±6	20±4	13±3^{a}	19±5	22±4	18±3^{f}	21±5
V_T (ml)	323±70	225±75^{a}	306±72	320±70	203±90^{a}	310±76	333±57	292±54^{c,e}	338±70
MAP (mmHg)	87±12	69±13	86±14	89±12	69±18	86±15	89±10	80±14	87±13
MPAP (mmHg)	26±3	26±5	29±8	27±4	26±4	29±5	26±4	25±5	25±4
HR (beats/min)	88±9	89±6	89±9	86±5	83±11	86±6	86±9	85±10	86±10

SpO_2 oxygen saturation, *SvO_2* mixed venous oxygen saturation, *P_{trach}* tracheal peak pressure, *Crs* respiratory system compliance, *V_T* tidal volume, *MAP* mean arterial pressure, *MPAP* mean pulmonary arterial pressure and *HR* heart rate
Baseline versus 1 min: $^{a}p<0.001$; $^{e}p<0.05$; $^{f}p<0.01$
Open versus closed: $^{b}p<0.001$; $^{c}p<0.05$; $^{d}p<0.01$

Within 1 min of the start of the 10-s suctioning period with OSS and 12 or 14 Fr catheters, there were marked decreases in SpO_2, SvO_2, C_{rs}, V_T and P_{trach} ($p<0.001$). P_{trach} reached sub-atmospheric levels. CSS in PCV mode or CPAP 10 cmH_2O with 12 Fr catheters also decreased SpO_2, SvO_2 and P_{trach}, but to a lesser extent ($p<0.05$). However, during CSS with CPAP 0 cmH_2O, SpO_2, SvO_2, C_{rs}, V_T and P_{trach} all reached levels similar to those during OSS. Irrespective of open or closed suctioning, all variables returned to baseline within 5 min (Fig. 3, Tables 1, 2 and 3).

Discussion

Using a porcine lung injury model, we have shown that OSS and CSS during 0 cmH_2O CPAP significantly decreased arterial and mixed venous oxygen saturation irrespective of the suction catheter size. Tracheal pressure became sub-atmospheric and static respiratory compliance and tidal volumes were markedly reduced. In contrast, CSS during PCV and CPAP 10 cmH_2O caused only minor ventilatory and circulatory side effects.

In a bench test we found that the suction interventions which caused only minor side effects in the animal model (CSS with PCV and 10 cmH_2O CPAP) were significantly less effective in removing secretions than OSS and CSS at CPAP 0 cmH_2O.

Suctioning efficacy of open and closed suctioning techniques

Open system suctioning causes desaturation, lung collapse and bacterial contamination. CSS causes less desaturation and lung collapse as ventilation can continue during suctioning [5, 7, 8, 9, 10, 13, 14, 15, 16, 20]. However, the effectiveness of CSS has been questioned [17], which has led to the use of larger catheters, greater vacuum levels and longer suction procedures. A study [18] comparing CSS to OSS in ventilated ICU patients (14 Fr catheter) found no difference in efficacy. The mass of aspirate was measured by weighing. In vivo, condensed water accumulates quickly in the breathing system, the connected closed suctioning catheter and its protective sleeve. Much of the increase measured in weight could thus be due to water [34]. The present study circumvented these problems by determining the efficacy in vitro, which allows the deposition of a standardised volume of "secretions" at a fixed position in the trachea and observation of the suctioning catheter tip as well as movement of the "secretions" during suctioning. The moisture artefact is avoided.

Combes et al. [19] showed that the same amount of secretions were aspirated in both OSS and CSS. However, the amount of aspirate was only estimated according to a four-point scale and the quantity of secretions available for suctioning was unknown. Maggiore and co-workers have evaluated the effect of different suctioning techniques on lung volume and gas exchange [16]. They found that OSS was more harmful in terms of lung derecruitment in ALI/ARDS patients, but did not assess the effectiveness of suctioning. We have shown that techniques that cause decreases in P_{trach}, C_{rs} and V_T in vivo (OSS and CSS during CPAP 0 cmH_2O) remove more secretions in vitro than CSS. During OSS, resistance to the suction flow from room air towards the suction catheter tip in the tube is greater than that from the lungs towards the suction catheter tip because the cross-sectional area of the trachea is about 250 mm^2 and the area between the inner surface of a 7 mm ID endotracheal tube and a 12 Fr (4 mm OD) suction catheter is 35–13 mm^2=22 mm^2. Gas is thus aspirated from the lung rather than from room air. During CSS with normal trigger sensitivity, sub-atmospheric lung pressures are avoided, and thus CSS has fewer side effects. The ventilator is triggered at the start of suctioning, which helps overcome the resistance of the endotracheal tube with the suction catheter inside and also feeds the suction catheter with gas, minimising suction from the airway below the suction catheter tip.

However, during CSS with positive pressure ventilation (including CPAP 10 cmH_2O) in the transparent "trachea", the triggered inspiratory gas inflow can be seen to push secretions away from the catheter tip. Conversely, during OSS, gas aspirated from the lung will facilitate the movement of secretions towards the suction catheter. Finally, the rapid change in lung volume following disconnection of the ventilator for OSS may initiate a cough, moving secretions towards the suction catheter. During CSS, more ventilator gas is aspirated and thus there is less likelihood of movement of the secretions from the lungs.

Different results were obtained for CPAP 0 and 10 cmH_2O. With the ventilator set at CPAP 0 cmH_2O the flow needed to keep the ventilator pressure at zero is small. However, with CPAP 10 the inspiratory valve delivers enough flow to keep the pressure at 10 cmH_2O and, during suctioning, the flow needed to maintain CPAP is much greater. This higher flow feeds the suction catheter with gas and blows tracheal secretions distally out of reach of the suction catheter so that the suction is relatively ineffective. There may be variations in ventilator behaviour in this respect. A modern ventilator with a faster response and more adequate flow adjustment should deliver gas as fast in CPAP 0 as in CPAP 10 cmH_2O, possibly decreasing both side effects and suctioning efficacy. This needs further studies.

Side effects of suctioning

Our lung injury model is a simple surfactant-deficiency model. The level of lung injury was estimated by conversion of SpO_2 values to PaO_2 values, fulfilling ALI criteria. The minor respiratory effects of CSS during PCV and VCV have been reported previously [13, 16, 20]. Our findings agree with these reports and also with that of Brochard et al., where constant flow oxygen was insufflated through small channels in an endotracheal tube during open suctioning [35], preventing the fall in arterial oxygen saturation. The effect was explained by the insufflation leading to a tracheal (and alveolar) pressure of around 10 cmH_2O, which probably prevented lung collapse. We achieved the same results by setting the ventilator at CPAP 10 cmH_2O during CSS. However, using CPAP 0 cmH_2O provides none of these advantages, as the only gas available for suctioning is the gas in the lungs.

It may seem surprising that varying suction duration, (5, 10 and 20 s) and suction catheter size produced little difference in side effects. This might be explained by the surfactant-depleted lungs of the pigs being prone to rapid collapse.

Study limitations

In the bench test we cannot study any effects of diaphragmatic movements when the ventilator is disconnected from the patient. This can only be studied in patients and the effect will vary with sedation level and end-expiratory lung volume. In the animal side effect part of our study we have used a relatively small number of animals and a simple lung injury model which is not totally comparable with ALI/ARDS patients. This could be an explanation for the little difference found in side effects among the various suction durations and catheter sizes.

We did not sample arterial blood gases at baseline, but used SpO_2 values at baseline as an estimation of oxygen saturation instead.

Clinical considerations

By combining in vitro and in vivo methods, we standardised the comparison of open and closed systems and their side effects. Although the results of our study must be interpreted with caution, it seems that tracheal secretions cannot be effectively removed without inducing lung collapse and deterioration of gas exchange, i.e. by OSS or CSS during CPAP 0 cmH_2O. The surfactant-deficiency model of lung injury may cause the lungs to collapse extremely rapidly during suctioning but also to expand easily again without a special recruitment manoeuvre. Such collapse in ALI/ARDS patients is a severe disadvantage. It is therefore very important to suction only when necessary and to use effective methods for suctioning. Furthermore, ALI/ARDS patients' lungs may be more difficult to expand and suctioning should, perhaps, be followed by a recruitment manoeuvre to re-inflate the lungs [36].

At present we lack sufficient outcome studies of suctioning to know whether CSS is superior to OSS [37, 38]. There are also no clear data available on how aggressive suctioning policies need to be in order to manage ventilator patients [22, 26]. In the presence of a clear indication for suctioning, such as bubbling secretions in the trachea, OSS may be the method of choice. CSS, originally advocated for hygienic reasons, is possibly less effective and may have to be repeated more frequently.

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