

Open and Closed-circuit Endotracheal Suctioning in Acute Lung Injury

Efficiency and Effects on Gas Exchange

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Background: **Closed-circuit endotracheal suctioning (CES) is advocated for preventing hypoxemia caused by the loss of lung volume resulting from open endotracheal suctioning (OES). However, the efficiency of CES and OES on tracheal secretion removal has never been compared in patients with acute lung injury. The authors designed a two-part study aimed at comparing gas exchange and efficiency between OES and CES performed at two levels of negative pressure.**

Methods: **Among 18 patients with acute lung injury, 9 underwent CES and OES at 3-h intervals in a random order using a negative pressure of −200 mmHg. Nine other patients underwent CES twice using two levels of negative pressure (−200 and −400 mmHg) applied in a random order. After each CES, a recruitment maneuver was performed using 20 consecutive hyperinflations. Tracheal aspirates were weighed after each suctioning procedure. Arterial blood gases were continuously recorded using an intravascular sensor.**

Results: **Open endotracheal suctioning induced a significant 18% decrease in arterial oxygen tension (Pa_{O_2}) (range, +13 to −71%) and an 8% increase in arterial carbon dioxide tension (Pa_{CO_2}) (range, −2 to +16%) that persisted 15 min after the end of the procedure. CES using −200 cm H_2O did not change Pa_{O_2}, but tracheal aspirate mass was lower compared with OES (0.6 ± 1.0 *vs.* 3.2 ± 5.1 g; *P* = 0.03). Increasing negative pressure to −400 cm H_2O during CES did not change Pa_{O_2} but increased the tracheal aspirate mass (1.7 ± 1.6 *vs.* 1.0 ± 1.3 g; *P* = 0.02).**

Conclusions: **Closed-circuit endotracheal suctioning followed by a recruitment maneuver prevents hypoxemia resulting from OES but decreases secretion removal. Increasing suctioning pressure enhances suctioning efficiency without impairing gas exchange.**

ENDOTRACHEAL suctioning–induced hypoxemia was reported in mechanically ventilated patients more than 30 yr ago.[1–4] In presence of acute lung injury (ALI), the massive loss of lung volume induced by the disconnection of the patient from the ventilator is the predominant mechanism of hypoxemia.[5,6] Furthermore, the high negative suctioning pressure required for removing bronchial secretions contributes to the loss of lung volume.[7]

Closed-circuit endotracheal suctioning (CES) was initially developed for preventing arterial desaturation complicating ventilator disconnection.[8,9] Although significantly reduced in comparison to open endotracheal suctioning (OES),[10] the loss of lung volume resulting from CES remains dependent on the negative pressure applied during the procedure.[7,11] However, recent experimental studies as well as clinical experience suggest that CES is less efficient than OES for removing tracheobronchial secretions.[12,13] As a consequence, generating enough negative pressure during CES seems mandatory to produce adequate secretion removal.[14] To limit the duration of arterial oxygenation impairment caused by the loss of lung volume resulting from the negative pressure generated during CES, a recruitment maneuver performed immediately at the end of the procedure has been proven to be beneficial.[5]

The aims of the study performed in patients with ALI were (1) to compare the effects of CES and OES on gas exchange and secretion removal and (2) to compare the effects on gas exchange and secretion removal of two different negative pressures applied during CES. Gas exchange was continuously monitored using an optical fiber intraarterial catheter.

Materials and Methods

Patients

The study protocol was reviewed and approved by the Ethical Committee of the Société de Réanimation de Langue Française (Paris, France). Eighteen mechanically ventilated patients with ALI were included. ALI was defined according to the criteria proposed by the American-European Consensus Conference.[15] Inclusion criteria were (1) arterial oxygen tension (Pa_{O_2}) less than 300 mmHg at a fraction of inspired oxygen (FI_{O_2}) of 1.0 and positive end-expiratory pressure of 5 cm H_2O or greater; and (2) absence of left ventricular failure defined as pulmonary capillary wedge pressure greater than 18 mmHg and/or a left ventricular ejection fraction less than 50% as estimated by transesophageal echocardiography. Patients with severe head trauma were excluded. All patients already had a femoral arterial catheter, allow-

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ing the insertion of the intravascular Paratrend 7 multiparameter sensor for continuous monitoring of blood gases (Diametrics Medical, Buckinghamshire, United Kingdom).

Ventilatory Management

Patients were orotracheally intubated (internal diameter 7.5 mm for a single patient and 8 mm for the others; Mallincrodt, Hazelwood, MO) and mechanically ventilated using a volume-controlled mode (Horus ventilator; Antony, France). Trigger sensitivity was set at −1 cm H_2O, inspiratory:expiratory ratio at 1:2 and tidal volume at 6 ml/kg of ideal body weight. Pressure–volume curves were obtained at zero end-expiratory pressure using the constant low-flow method.[16,17] The following parameters were determined from the pressure–volume curve[18]: (1) the inflation compliance, computed as the slope of the pressure–volume curve above the lower inflection point in its most linear segment; (2) the starting compliance, computed as the ratio between the first 100 ml inflation and the corresponding airway pressure; and (3) the lower inflection point, computed as the airway pressure corresponding to the intersection between the starting compliance and the inflation compliance. Positive end-expiratory pressure was set above the lower inflection point when present and at 10 cm H_2O when absent, and F_{IO_2} was maintained at 1.0 throughout the study.

Protocol of Endotracheal Suctioning

Endotracheal suctioning is systematically performed every 3 h in our intensive care unit and more frequently when needed. In the current study and for each patient, two techniques of endotracheal suctioning were performed in a random order at 3-h intervals as described below. F_{IO_2} was increased at 1.0 at 15 min before endotracheal suctioning and returned to control 30 min after. Endotracheal suctioning was performed using two different-sized catheters (Vygon, Ecouen, France): 16 French (external diameter 5.0 mm) for 8-mm endotracheal tubes and 14 French (external diameter 4.5 mm) for 7.5-mm endotracheal tubes. Suctioning catheter was connected to a reservoir (Asept In. Med, Quint-Fonsegrives, France), which was weighed on an electronic balance (Teraillon, Chatou, France) before and after the procedure, the difference of the weight indicating the mass of tracheal aspirate. The study was divided into two parts.

In the first part of the study, OES and CES were performed in nine patients. During OES, the patient was disconnected from the ventilator. The suctioning catheter was then inserted into the endotracheal tube, advanced until resistance was met, and withdrawn 2–3 cm. A negative pressure of −200 cm H_2O was applied for 20 s, during which the catheter was gently rotated and withdrawn. The patient was then reconnected to the ventilator. During CES, the patient remained connected to the ventilator, and the suctioning catheter was inserted in the endotracheal tube *via* the swivel adapter. The same endotracheal suctioning procedure as during OES was applied for 20 s using a negative pressure of −200 cm H_2O. At the end of suctioning, the adapter was closed, and a recruitment maneuver consisting of 20 tidal volumes set at twice the baseline value was performed without changing the respiratory rate. The upper limit of pressure alarm was set at 70 cm H_2O during the procedure.

In the second part of the study, CES followed by a recruitment maneuver was performed in nine patients as described above at two levels of suctioning pressure: −200 and −400 cm H_2O.

Continuous Measurement of Gas Exchange

Continuous blood gas monitoring was obtained by an intravascular multiparameter sensor inserted *via* the femoral artery catheter and connected to a TrendCare blood gas monitoring system (Diametrics Medical, St. Paul, MN). Such system allowed one measurement of pH, Pa_{O_2}, and arterial carbon dioxide tension (Pa_{CO_2}) every second.[19–22] Blood gases were continuously displayed on the screen of the monitor and recorded on a personal computer through the RS-32 serial port.

Data recording was started 15 min before and stopped 15 min after endotracheal suctioning at an F_{IO_2} of 1.0. Baseline Pa_{O_2} and Pa_{CO_2} were defined as the mean value of the 4-min measurements preceding endotracheal suctioning. To compare gas exchange during each procedure in the two parts of the study, three timings were chosen after the recording of baseline values: 60 s (T1), 180 s (T2), and 10 min after endotracheal suctioning (T3). For each patient and each procedure, minimal Pa_{O_2} and maximal Pa_{CO_2} values observed during the 15 min after endotracheal suctioning are reported. The maximum mean variation as well as the maximum individual variation of Pa_{O_2} and Pa_{CO_2} compared with baseline values (difference between minimum or maximum value and baseline value for Pa_{O_2} and Pa_{CO_2}) were calculated and expressed as percentage of variation.

Statistical Analysis

Data are expressed as mean ± SD or median (minimum–maximum) according to data distribution. Comparisons of Pa_{O_2} and Pa_{CO_2} before and after endotracheal suctioning at different timings and between the two procedures were made using a two-way analysis of variance for one within (baseline, T1, T2, and T3) and one grouping factor (OES *vs.* CES in the first part of the study and −200 *vs.* −400 cm H_2O in the second part of the study). The issue as to whether endotracheal suctioning–induced changes in Pa_{O_2} and Pa_{CO_2} were different according to the procedure was tested by looking at the

Table 1. Respiratory and Ventilatory Characteristics of 18 Patients at Inclusion*

Patient No.	VT, ml	RR, breaths/min	Ppeak, cm H_2O	Pplat, cm H_2O	PEEP, cm H_2O	P/F, mmHg	CLin, ml/cm H_2O	Pinf, cm H_2O	LISS
Part 1									
1	440	17	31	23	15	137	64	6	2.3
2	500	20	30	26	8	70	—	—	2.5
3	450	26	50	36	16	182	—	—	3
4	500	22	21	20	6	230	58	3	1.5
5	360	18	33	28	6	242	20	12	2.5
6	500	24	33	24	13	150	64	6	3
7	500	20	35	24	6	212	30	3	2
8	470	18	28	22	10	121	67	5	2
9	400	20	34	22	10	180	65	Absent	2
Mean ± SD	458 ± 51	21 ± 3	33 ± 8	25 ± 5	10 ± 4	169 ± 55	53 ± 19	5 ± 4	2.3 ± 0.5
Part 2									
1	470	24	36	24	11	212	30	3	2
2	470	18	26	20	10	121	67	5	2
3	460	22	30	19	11	250	60	10	1.8
4	300	32	31	24	11	138	44	10	2.5
5	400	20	34	22	10	180	65	Absent	2
6	650	15	32	23	10	251	64	5	1.8
7	430	28	46	28	11	209	—	—	2
8	400	15	32	26	8	121	—	—	2.5
9	400	20	30	26	7	298	—	—	2
Mean ± SD	442 ± 94	22 ± 6	33 ± 6	24 ± 3	10 ± 2	185 ± 54	55 ± 15	6 ± 4	2.0 ± 0.3

* Part 1: open *versus* closed-circuit endotracheal suctioning followed by a recruitment maneuver (n = 9); part 2: closed-circuit endotracheal suctioning followed by a recruitment maneuver using two levels of negative pressure (n = 9).

CLin = compliance of the linear segment of the pressure–volume curve at zero end-expiratory pressure; LISS = lung injury severity score; PEEP = positive end-expiratory pressure; P/F = arterial oxygen tension (Pa_{O_2})/fraction of inspired oxygen (F_{IO_2}) ratio; Pinf = lower inflection point; Ppeak = peak airway pressure; Pplat = end-inspiratory plateau pressure; RR = respiratory rate; VT = tidal volume.

presence of a significant interaction. Comparisons between baseline, T1, T2, and T3 were performed by a paired Student *t* test with Bonferroni correction. A paired Wilcoxon rank sum test and a paired Student *t* test were used respectively for comparison of the mass of tracheal aspirate between OES and CES and between two levels of suctioning pressure applied during CES: −200 and −400 cm H_2O. The statistical significance level was fixed at 0.05.

Results

Patients

Eighteen patients with ALI (17 males and 1 female; mean age 56 ± 16 yr) were studied, 9 patients being included in each part of the study. The mean Simplified Acute Physiologic Score II was 37 ± 10 and the mean Sepsis Related Organ Failure Assessment was 9 ± 4 at the inclusion. Admission followed major surgery in 8 patients, multiple trauma in 5 patients, septic shock in 2 patients, and acute medical illness in 3 patients. ALI was caused by a primary injury to the lungs in 17 patients (bacterial pneumonia, aspiration pneumonia, pneumocystosis, and lung contusion) and a secondary injury to the lung in 1 patient (cardiopulmonary bypass). Respiratory and ventilator characteristics of the two groups are summarized in table 1.

Gas Exchange and Efficiency of Open versus *Closed-circuit Endotracheal Suctioning*

When considering all patients, OES induced a mean 18% decrease in Pa_{O_2} and a mean 8% increase in Pa_{CO_2} as compared with baseline values. Fifteen minutes after OES, Pa_{O_2} was still below and Pa_{CO_2} was still above baseline values. Blood gases remained unchanged during CES, whereas recruitment maneuvers after CES transiently and significantly increased Pa_{O_2}, which returned to baseline values 5 min after the recruitment maneuver (fig. 1). Table 2 shows that changes in Pa_{O_2} and Pa_{CO_2} were statistically different between OES and CES followed by a recruitment maneuver.

As shown in figure 2, Pa_{O_2} decreased in seven of nine patients after OES, with a maximum variation of 39% (median; range, −6 to −71%). The maximum reduction of Pa_{O_2} occurred 80 s (median; range, 41–300 s) after endotracheal suctioning. Pa_{O_2} was decreased in four of nine patients after CES, with a maximum variation of 11% (median; range, −5 to −26%), which was reversed by the recruitment maneuver. The maximum reduction of Pa_{O_2} occurred at 64 s (median; range, 57–71 s). Pa_{CO_2} was increased in eight patients after OES, with a maximum variation of 10% (median; range, 7–16%) (fig. 2).

As shown in figure 3, mean aspirate mass was significantly greater with OES than with CES using a suctioning pressure of −200 cm H_2O: 3.2 ± 5.1 g (range, 0–16 g) *versus* 0.6 ± 1.0 g (range, 0–3 g) ($P = 0.03$).

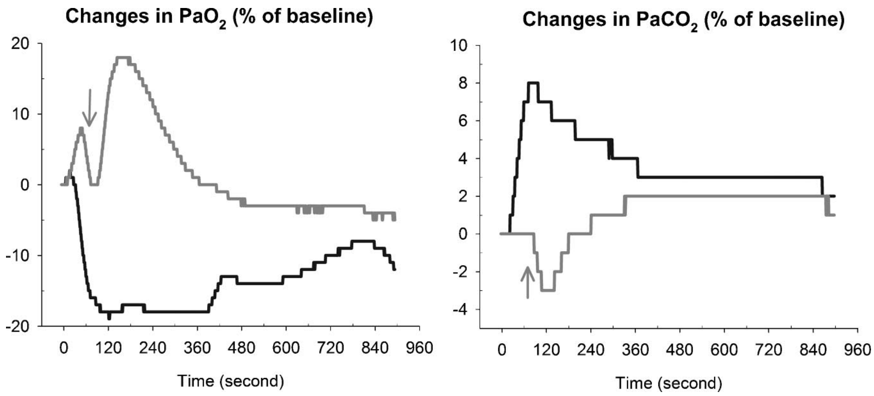

Fig. 1. Continuous recordings of changes in arterial oxygen tension (Pa_{O_2}; *left*) and arterial carbon dioxide tension (Pa_{CO_2}; *right*) from the beginning (time 0) to 15 min after endotracheal suctioning in nine patients undergoing at random open and closed-circuit endotracheal suctioning. Pa_{O_2} and Pa_{CO_2} were sampled every second in each individual patient, and the mean curves are represented. *Black lines* represent open suctioning, whereas *gray lines* represent closed-circuit suctioning followed by a recruitment maneuver. *Gray arrows* indicate the beginning of the recruitment maneuver.

Gas Exchange and Efficiency of Closed-circuit Endotracheal Suctioning Using −200 versus −400 cm H_2O

Figure 4 shows that profiles of gas exchange changes during CES with two levels of suctioning pressure (−200 and −400 cm H_2O) are quite similar. No significant changes in Pa_{O_2} and Pa_{CO_2} were observed at the different times of the CES and after the recruitment maneuver whatever the level of negative pressure (table 3). However, increasing the negative pressure from −200 to −400 cm H_2O resulted in a significant increase in tracheal aspirate mass: 1.0 ± 1.3 g (range, 0–3 g) *versus* 1.7 ± 1.6 g (range, 0–5 g) (P = 0.02; fig. 5).

Discussion

In patients with ALI, OES induces a significant and sustained decrease in Pa_{O_2} and increase in Pa_{CO_2}, with the maximum impairment in gas exchange occurring within 1 min after the end of the procedure. CES prevents hypoxemia observed during OES but seems less efficient in terms of secretion removal compared to OES. Increasing the suctioning pressure from −200 to −400 cm H_2O enhances the efficiency of CES without further impairing gas exchange.

Reasons for the Study Design

A few years ago, we performed an experimental study looking at the effect of open endotracheal suctioning on computed tomography lung aeration.[5] In anesthetized sheep receiving mechanical ventilation, OES induced segmental atelectasis and serious impairment of arterial oxygenation. Both effects were reversed by a postsuctioning recruitment maneuver consisting of 20 tidal volumes set at twice the baseline value. During the same period, two studies demonstrated that CES could partially prevent lung volume loss and arterial oxygenation impairment in patients with ALI receiving mechanical ventilation with positive end-expiratory pressure.[7,11]

Based on the existing literature, we designed in 2002 a written procedure aimed at optimizing endotracheal suctioning for patients with ALI admitted to our surgical intensive care unit. Four specific measures were adopted: (1) F_{IO_2} set at 1.0 at 10 min before endotracheal suctioning and maintained throughout the entire procedure; (2) CES; (3) suctioning pressure set at −200 cm H_2O; and (4) 20 tidal volumes set at twice the baseline value, delivered immediately after the suctioning procedure. This recruitment maneuver was decided because a previous study had demonstrated that CES using a negative pressure of −200 cm H_2O was associated with a 500-ml decrease in end-expiratory lung volume in patients with acute ALI.[7] After training of nursing and medical staff was completed, the procedure was implemented in the surgical intensive care unit. A few weeks later, the nurses asked for stopping the protocol, arguing that although the new procedure was not causing changes in pulse oximetry, it was not any more efficient for removing bronchial secretions. It was then decided to leave the procedure of endotracheal suctioning (open

Table 2. Comparison of Changes in Pa_{O_2} and Pa_{CO_2} Induced by Open and Closed-circuit Endotracheal Suctioning Followed by a Recruitment Maneuver

	ES	Baseline	T1	T2	T3	*P* Value	Interaction
Pa_{O_2}, mmHg	OES	221 ± 87	185 ± 65*	171 ± 68*	178 ± 64*	0.02	0.015
	CES_{RM}	225 ± 103	239 ± 106	258 ± 116†	218 ± 113	0.02	
Pa_{CO_2}, mmHg	OES	41 ± 7	44 ± 9‡	44 ± 7	43 ± 7	0.0006	0.002
	CES_{RM}	41 ± 7	42 ± 6	41 ± 6	42 ± 8	0.07	

Data are presented as mean ± SD.

* $P < 0.05$ *vs.* baseline. † $P < 0.05$ *vs.* baseline and T3. ‡ $P < 0.01$ *vs.* baseline and T3.

CES_{RM} = closed-circuit endotracheal suctioning followed by a recruitment maneuver; ES = endotracheal suctioning; Pa_{CO_2} = arterial carbon dioxide tension; Pa_{O_2} = arterial oxygen tension; OES = open endotracheal suctioning; T1 = 1 min after ES; T2 = 3 min after ES; T3 = 10 min after ES.

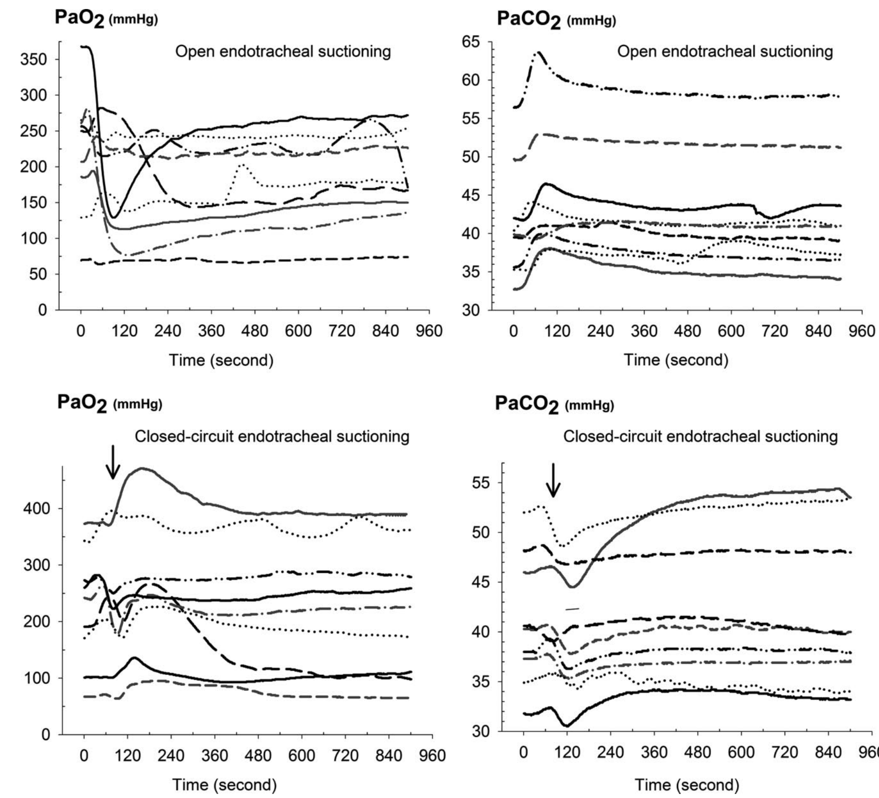

Fig. 2. Continuous changes of arterial oxygen tension (Pa_{O_2}; *left*) and arterial carbon dioxide tension (Pa_{CO_2}; *right*) from the beginning (time 0) to 15 min after endotracheal suctioning in nine patients undergoing at random open and closed-circuit endotracheal suctioning followed by a recruitment maneuver. Pa_{O_2} and Pa_{CO_2} were sampled every second. *Black arrows* indicate the beginning of the recruitment maneuver.

vs. closed) to the individual medical decision. Recruitment maneuvers were considered cumbersome by most of the housing-staff members and were simply not performed.

At that moment, we decided to set up the protocol of the current study with a double aim: quantifying secretion removal during OES and CES and testing two different suctioning pressures, −200 and −400 cm H_2O during CES. OES without postsuctioning recruitment maneuver served as the "control," because this procedure was commonly performed in the surgical intensive care unit after failure of the written protocol. In addition, it was considered to be of clinical interest to assess the duration of impairment of gas exchange after OES. CES was accompanied by a postsuctioning recruitment maneuver because we were willing to optimize endotracheal suctioning in the future by reconciling efficiency and limitation of side effects. Continuous blood gas monitoring gave us the unique opportunity to compare side effects caused by the suctioning procedure itself independently of the effects resulting from the recruitment maneuver.

Open and Closed-circuit Endotracheal Suctioning–induced Effects on Gas Exchange

In previous studies on endotracheal suctioning–induced arterial hypoxemia,[1,2,23] gas exchange was monitored using either pulse oximetry or blood gas analysis through intermittent arterial sampling.[4,6,11] Our study is the first human study to investigate on-line the conse-

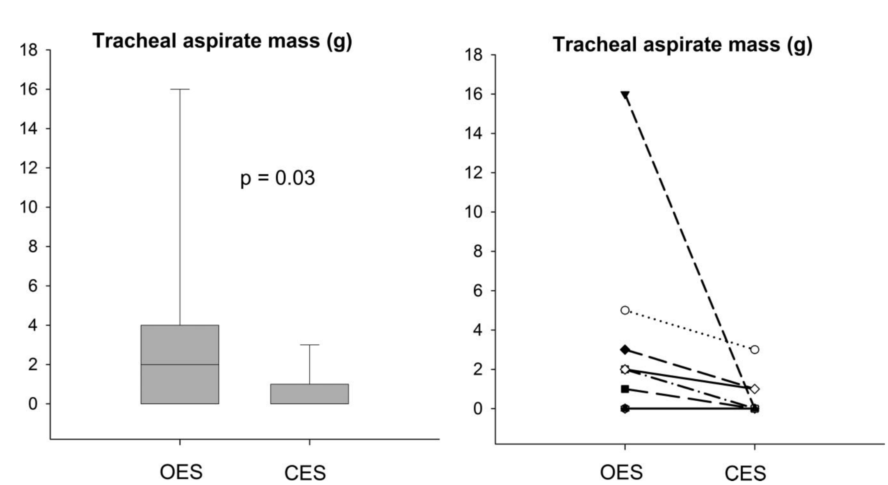

Fig. 3. Comparison of the mass of tracheal aspirate obtained with open (OES) and closed-circuit endotracheal suctioning (CES). Data expressed as median, 25th–75th percentiles, and 10th–90th percentiles are represented on the *left*, whereas individual values are represented on the *right*. The mass of tracheal aspirate is significantly greater after OES than after CES.

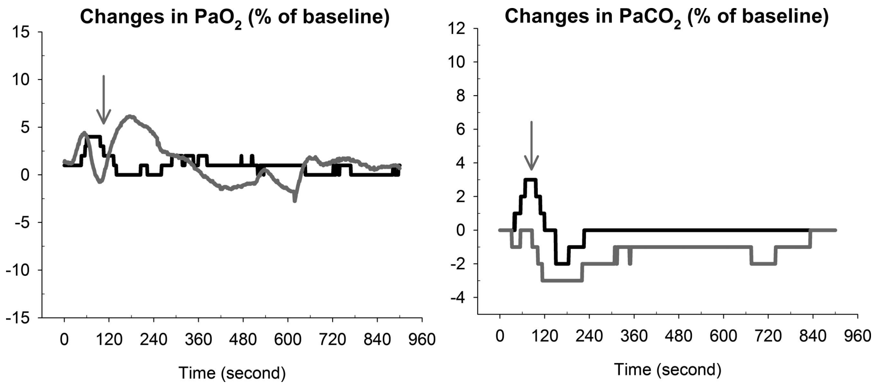

Fig. 4. Profiles of arterial oxygen tension (Pa_{O_2}; *left*) and arterial carbon dioxide tension (Pa_{CO_2}; *right*) changes from the beginning (time 0) to 15 min after closed-circuit endotracheal suctioning in nine patients with acute lung injury. Closed-circuit endotracheal suctioning followed by a recruitment maneuver (*arrow*) was performed at two levels of negative pressure: −200 cm H_2O (*gray lines*) and −400 cm H_2O (*black lines*). *Gray arrows* indicate the beginning of the recruitment maneuver. Pa_{O_2} and Pa_{CO_2} were measured every second. Data are expressed as percentage of changes from baseline values.

quences of endotracheal suctioning on gas exchange. The accuracy of the TrendCare, a continuous blood gas monitoring system, has been validated in different clinical situations, including intensive care.[19–22] Continuous blood gas monitoring offers the unique advantage of detecting hypoxemic episodes that may remain unrecognized using pulse oximetry[24] or intermittent blood gas measurement.[25]

Despite the presuctioning administration of pure oxygen, OES decreased Pa_{O_2} in seven of nine patients within 1 min after the beginning of the procedure. In two patients, a 60% decrease in Pa_{O_2} was observed, from 368 mmHg to 129 mmHg and from 265 to 77 mmHg, respectively. In most patients, Pa_{O_2} was still below baseline values 15 min after OES. These results indirectly confirm a recent study demonstrating that the loss of lung volume persists 20 min after the end of OES performed in patients with acute respiratory distress syndrome[26] and strongly suggest that the substantial loss of lung volume resulting from disconnection from the ventilator is impossible to offset without performing presuctioning and postsuctioning recruitment maneuvers.[5,7,26,27] It should be pointed out that in eight patients, OES induced a transitory but significant increase in Pa_{CO_2} within 2 min after the beginning of the procedure. This result likely explains why endotracheal suctioning is frequently associated with a significant increase in intracranial pressure in patients with severe head injury.[28]

Two methods of CES are proposed to prevent hypoxemia resulting from ventilator disconnection: quasi-closed endotracheal suctioning *via* a swivel adaptor positioned at the proximal tip of the endotracheal tube and total closed-circuit endotracheal suctioning using a sealed system incorporating a catheter continuously placed between the endotracheal tube and the Y-piece of the ventilator's circuit.[7] Because neither method requires disconnection of the patient from the ventilator, the loss of lung volume resulting from endotracheal suctioning is significantly lower compared with OES and depends mainly on the applied negative suctioning pressure.[7,10] Based on continuous blood gas monitoring, our results demonstrate that CES did not induce significant deleterious change in gas exchange during the procedure itself, as shown in figure 2.

In previous clinical studies, the negative suctioning pressures applied during CES were always lower than −200 cm H_2O.[7,10,11,26] It can be reasonably hypothesized that an additional loss of lung volume could result from the use of higher negative pressures with its negative consequences on gas exchange. In the current study, where two levels of suctioning pressure were compared (−200 and −400 cm H_2O) in each individual patient, no worsening of gas exchange was detected using continuous blood gas monitoring. This result supports previous studies suggesting that disconnection of the patient from the ventilator, rather than the suctioning procedure itself, is the main determinant of hypoxemia resulting from endotracheal suctioning in patients with ALI.[7,10]

Table 3. Comparison of Changes in Pa_{O_2} and Pa_{CO_2} between Two Levels of Suctioning Pressure (−200 *vs.* −400 cm H_2O) Using Closed-circuit Endotracheal Suctioning Followed by a Recruitment Maneuver

	ES	Baseline	T1	T2	T3	*P* Value	Interaction
Pa_{O_2}, mmHg	−200	245 ± 120	250 ± 126	292 ± 110	257 ± 113	0.09	0.91
	−400	257 ± 129	268 ± 136	279 ± 150	253 ± 124	0.09	
Pa_{CO_2}, mmHg	−200	43 ± 8	43 ± 8	42 ± 10	42 ± 8	0.12	0.86
	−400	42 ± 7	42 ± 7	41 ± 8	42 ± 7	0.12	

Data are presented as mean ± SD.

P values correspond to analysis of variance for repeated measure analysis and interaction.

ES = endotracheal suctioning; Pa_{CO_2} = arterial carbon dioxide tension; Pa_{O_2} = arterial oxygen tension; T1 = 1 min after ES; T2 = 3 min after ES; T3 = 10 min after ES.

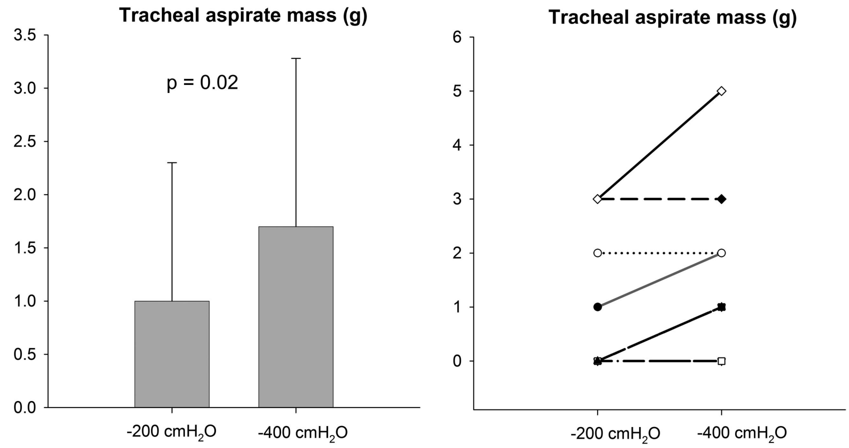

Fig. 5. Comparison of the mass of tracheal aspirate obtained at two levels of suctioning pressure (−200 *vs.* −400 cm H_2O) using closed-circuit endotracheal suctioning. Data expressed as mean ± SD are represented on the *left*, whereas individual values are represented on the *right*. The mass of tracheal aspirate is significantly greater with a suctioning pressure of −400 cm H_2O than with a suctioning pressure of −200 cm H_2O.

Comparative Efficiency of Open and Closed-circuit Endotracheal Suctioning on Tracheal Secretion Removal

Closed-circuit endotracheal suctioning prevents loss of lung volume and hypoxemia resulting from disconnection of the patient from the ventilator. However, its efficiency in terms of tracheal secretion removal remains uncertain. Blackwood and Webb[29] reported that nurses found the system "poorly effective" in 39% of the suctioning procedures performed. However, no quantitative measurements were performed in the study. Combes *et al.*,[30] comparing OES and CES in mechanically ventilated patients did not find any difference in the amount of tracheal aspirate. However, a negative pressure of −80 cm H_2O was used, and tracheal aspirates were only qualitatively evaluated.[30] Recently, in a porcine lung injury model, Lindgren *et al.*[12] showed that suctioning is more efficient with OES as compared with CES with a continuous positive airway pressure of 10 cm H_2O.

Our results, obtained in patients with ALI, confirm these animal findings and support the clinical feeling that OES is more efficient than CES for tracheal secretion removal. A number of mechanisms may contribute to this result. First, the actual applied negative pressure, which depends on the pressure gradient between the airway and the distal tip of the suctioning catheter, is different with each method: During OES, the airway pressure level is zero, whereas in CES it is positive, at least equal to the positive end-expiratory pressure. Second, during CES, the flow delivered by the ventilator to maintain positive pressure fills the suction catheter with gas and tends to blow bronchial secretions distally. Third, disconnection of the ventilator during OES induces a sudden decrease in expiratory lung volume resulting from alveolar derecruitment, and bronchial secretions may be entrained more proximally with the expiratory gas flow, thereby facilitating secretion removal.

Increasing negative pressure could be an alternative to enhance the efficiency of endotracheal suctioning.[14] Negative pressures greater than −400 cm H_2O, however, applied during CES, may be harmful if a thick catheter (external diameter ≥ 4 mm) is introduced in a narrow endotracheal tube (7 mm internal diameter), whose sectional area is further reduced by a layer of secretions. Low subatmospheric pressure can be generated in the lung with alveolar collapse, mucosal damage, and ventilator dysfunction.[31] In our study, the size of the suctioning catheter was adapted to the endotracheal tube: 14 French for the patient intubated with a 7.5-mm endotracheal tube and 16 French for the other patients, intubated with an 8-mm endotracheal tube. Interestingly, using a negative pressure of −400 cm H_2O increased the efficiency of secretion removal without impairing gas exchange and precipitating ventilator dysfunction. This result suggests that a negative pressure around −400 cm H_2O may be a good compromise between the main objective of endotracheal suctioning, which is to efficiently remove tracheal secretions, and the need for minimizing the side effects on gas exchange.[32]

However, such a pressure is greater than recommended (−200 cm H_2O).[33,34] In a bench test study on CES, a negative pressure of −500 cm H_2O applied during volume-controlled ventilation with inverse inspiratory: expiratory ratio induced two deleterious effects: a high intrinsic positive end-expiratory pressure after insertion of the catheter and a sudden decrease of end-expiratory pressure during suctioning.[31] In patients ventilated using an inspiratory:expiratory ratio of 1:1, however, the same vacuum pressure applied during CES induced similar pressure changes, but of a lesser intensity, 2.7 and −4.9 cm H_2O, respectively.[35] Tracheal mucosal damage is another potential complication of endotracheal suctioning. Animal models demonstrated that the severity of tracheobronchial damage depends on the vacuum pressure level applied.[36–38] Human data reporting the effects of negative pressure on bronchial trauma, however, are scarce, limited to the detection of blood in recovered secretions: Bronchial hemorrhage was observed in 3.3% of patients undergoing endotracheal suctioning with a negative pressure ranging between −200 and −400 cm

H_2O.[39] One should recall that, 10 yr ago, many nurses believed that CES was poorly effective,[13,29] leading the manufacturers to recommend higher vacuum levels and also thicker suction catheters. This, in turn, was followed by reports of ventilator malfunctions and severe lung collapse. A recent study, however, evaluating the impact of CES in 11 critical care ventilators did not provide evidence of any ventilator dysfunction when applying a vacuum pressure of −300 cm H_2O.[40] Because the current investigation was not powered to assess the safety of the different procedures, further clinical studies are needed to assess the effects of suctioning pressures ranging between −200 and −400 cm H_2O on possible complications.

Methodologic Limitations

In our study, recruitment maneuver was not performed after OES. As a consequence, this study does not provide any information about the ability of postsuctioning recruitment maneuver for reversing OES-induced deterioration of gas exchange. A recently published human study, however, gave a partial answer[26]: A postsuctioning recruitment maneuver made of two consecutive sustained inflations lasting 20 s with an interval of 1 min in between reverses OES-induced decrease in arterial oxygenation and end-expiratory lung volume. Therefore, it limits gas exchange deterioration to the period of endotracheal suctioning. Further study is required to demonstrate that a recruitment maneuver made of 20 large tidal volumes has the same beneficial effect.

Similarly, the study is not able to demonstrate that a recruitment maneuver is indispensable after CES. It can be argued that with CES preventing deterioration of gas exchange, a postsuctioning recruitment maneuver is not necessary. However, in our study, a mild decrease in Pa_{O_2} was observed in four of nine patients after CES, even if it was not significant. In one patient, a 26% decrease in Pa_{O_2} was observed, from 242 mmHg to 180 mmHg. Furthermore, a delayed decrease in arterial oxygenation cannot be excluded. This hypothesis is supported by previous studies reporting that negative end-expiratory pressure is generated in the patient's airway during the CES procedure,[31,35] resulting in a significant decrease in end-expiratory lung volume.[7] Whether a recruitment maneuver after CES is beneficial in patients with acute respiratory distress syndrome deserves further evaluation.

In conclusion, CES using a negative pressure of −200 cm H_2O prevents gas exchange deterioration but seems less efficient than open endotracheal suctioning for removal of secretions. Increasing negative pressure to −400 cm H_2O improves endotracheal suctioning efficiency without reintroducing deleterious effects on gas exchange. Further studies are required to assess whether recruitment maneuvers are necessary to avoid any deterioration of gas exchange and loss of lung volume after CES and to evaluate possible complications resulting from high negative suctioning pressure.

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