Constant-flow Insufflation Prevents Arterial Oxygen Desaturation during Endotracheal Suctioning[1,2]

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SUMMARY In mechanically ventilated patients, disconnection from the ventilator and endotracheal suctioning can induce major arterial oxygen desaturation resulting from apnea, changes in inspired oxygen fraction, and decrease in lung volume. The aim of this study was to test the efficacy of a simple method of delivering oxygen and maintaining lung volume during this process. Our study was conducted in two parts. In the first part, constant-flow insufflation of oxygen (CFI) was used in seven patients ventilated for acute respiratory failure (Pa_{O_2}/FI_{O_2} = 347 ± 33 mm Hg) as a means of maintaining arterial oxygenation during apnea and disconnection from the ventilator. CFI was administered via a modified endotracheal tube in which small capillaries allowed delivery of a high-velocity jet flow near the tracheal end of the tube during disconnection from the ventilator. In comparison to apnea alone, CFI prevented a fall in arterial oxygen tension (16 ± 7 mm Hg during CFI versus 117 ± 27 during apnea, after 90 s of disconnection in the two situations, $p < 0.001$), whereas it did not reduce the development of hypercapnia. The efficacy of CFI resulted both from the injection of oxygen into the trachea and from the maintenance of positive alveolar pressure induced by air entrainment (mean 10.4 ± 1.1 cm H_2O), preventing a fall in lung volume usually occurring after disconnection (+338 ± 88 ml during CFI versus −344 ± 64 ml during apnea, $p < 0.01$). In the second part of the study CFI was used to prevent arterial oxygen desaturation induced by endotracheal suctioning. In seven other patients who were sedated but not paralyzed (Pa_{O_2}/FI_{O_2} = 199 ± 34 mm Hg), endotracheal suctioning was performed with or without administration of CFI. In five of the seven patients oxygen desaturation was fully prevented when CFI was used, but it was observed in all patients and reached −15.6 ± 2.6% during standard suctioning. In the two remaining patients, desaturation was much lower and recovery time was much shorter when CFI was used. Measurements of transpulmonary pressure and lung compliance during these periods suggested that CFI was able to prevent a decrease in lung volume induced by suctioning. Assessment of lung volume by CT scanning in five patients demonstrated that CFI prevented the 27% fall in lung volume induced by endotracheal suctioning. We propose to use this simple method as a means to avoid or minimize arterial oxygen desaturation during disconnection from the ventilator or during endotracheal suctioning in severely hypoxemic patients ventilated for acute respiratory failure. AM REV RESPIR DIS 1991; 144:395-400

Introduction

Disconnection from the ventilator is often required in critically ill mechanically ventilated patients. Since the normal coughing mechanisms are disrupted, frequent airway suctioning of secretions is necessary. Endotracheal suctioning promotes arterial oxygen desaturation, which may produce such adverse effects as cardiac arrhythmia, cardiovascular collapse, and even sudden death (1). Moreover, in patients ventilated with positive end-expiratory pressure (PEEP), disconnection from the ventilator induces a sudden decrease in lung volume that may worsen the harmful effect of apnea on gas exchange (2).

Constant-flow ventilation has been proposed in experimental studies in dogs, pigs, and cats (3–6) as a means of eliminating carbon dioxide and supplying oxygen. This ventilation was administered through catheters placed in the main stem bronchi (3) or via a Carlen's double-lumen tube (6). In anesthetized human subjects, two endobronchial catheters terminating in the main bronchi were at first used to apply constant-flow ventilation (5). In the present study, we postulated that such an insufflation may be useful in patients with acute respiratory failure to maintain satisfactory gas exchange during periods of disconnection from the ventilator required for endotracheal suctioning. We proposed applying constant-flow oxygen insufflation (CFI) with a modified endotracheal disposable tube. Small capillaries molded by extrusion in the wall of the tube allowed delivery of high-velocity microjets near the tracheal end of the tube, maintaining a constant positive pressure resulting from the air entrainment mechanism (7). We first examined the effect of CFI in apneic patients via such a standard-sized tube normally positioned in the trachea, and in the second part, we applied this technique during endotracheal suctioning.

Methods

The protocol was approved by the Research and Ethics Committee of the Henri Mondor Hospital (Paris XII University), and informed consent was obtained from the patients or next of kin in each case. This study was conducted in two parts.

Part 1

The first part of this study focused on the effects of CFI in apneic paralyzed patients.

Patients. Seven mechanically ventilated patients with stable hemodynamic status were studied. They had various acute or chronic lung disorders. Their mean age ± SEM was 65 ± 6 yr, and their other main characteristics are listed in table 1 (Patients 1 to 7). All patients were under controlled mechanical ventilation (CMV) with a Siemens Servo® Ventilator 900C (Solna, Sweden). They were under sedation (flunitrazepam and morphine) and paralyzed with pancuronium during the study.

All patients were intubated with a disposable standard-sized endotracheal tube (Patent Boussignac-Labrune, Synthelabo, Le Plessir-Robinson, France) with an internal diameter of 8.0 mm allowing delivery of oxygen by constant-flow insufflation. Five capillaries

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TABLE 1

MAIN CHARACTERISTICS OF THE PATIENTS

Patient	Age (yr)	Sex	FI_{O_2}	Pa_{O_2}/FI_{O_2} (mm Hg)	Diagnosis
Part 1					
1	34	M	0.40	340	Multiple trauma
2	76	M	0.60	182	Acute pancreatitis, ARDS
3	54	F	0.40	292	Asthma, pneumonia
4	72	M	0.30	380	Meningitis, encephalitis
5	87	M	0.45	380	Tuberculosis sequellae and acute bronchitis
6	63	F	0.30	447	Head injury
7	67	M	0.35	410	Cardiogenic shock
Part 2					
8	65	F	0.50	144	Coma, aspiration pneumonia
9	57	M	0.50	128	Pneumonia
10	48	M	0.40	247	Meningitis
11	48	M	0.50	258	Meningitis, encephalitis
12	65	M	0.45	182	Cardiac surgery, pneumonia
13	66	M	0.80	88	Sepsis, ARDS
14	72	M	0.30	346	Cardiac surgery

Definition of abbreviations: FI_{O_2} = fraction of inspired oxygen used for ventilation of the patient; ARDS = adult respiratory distress syndrome.

(diameter less than 0.7 mm) were extruded in the wall of the tube without changing the size of its lumen, thus forming apertures for the microjets. The inlet of these capillaries was located at the proximal end of the tube, and the outlet, 1 cm before the distal end. A constant 12-L/min flow of humidified oxygen was administered during CFI. Preliminary experimental studies in a lung model showed that this flow generates a positive pressure of about 10 cm H_2O.

Measurements. The oxygenation status of the patients was monitored with an ear oximeter (BIOX® II; Ohmeda, Louisville, CO). A radial arterial line was inserted and blood gases were measured with an ABL 30 (Radiometer, Copenhagen, Denmark). Changes in lung volume (Δvol) were studied with a differential linear transformer, composed of a sensor (Schrewittz LN Industries, Gaillard, France) mounted on a flexible but nonextensible belt and positioned around the patient at nipple level, as previously described (8). As the respiratory system of a paralyzed ventilated patient can be considered a system with a single degree of freedom, changes in lung volume were computed from a single signal, the rib cage displacement. Δvol was calculated as the difference between the volume measured during mechanical ventilation at the end of expiration and the volume measured at the end of the disconnection period. The calibration procedure was conducted during mechanical ventilation by comparing Δvol with the integrated signal obtained from a heated calibrated Fleisch No. 1 pneumotachygraph (Lausanne, Switzerland) connected to a differential pressure transducer (Validyne MP45 ± 2.5 cm H_2O; Northridge, CA) and inserted between the endotracheal tube and the ventilator tubings.

Tracheal pressure (Ptrach) was monitored with a multiperforated catheter (ID 1.65 mm) inserted into the trachea, whose tip was located 35 mm below the distal end of the endotracheal tube; at this distance the pressure plateau generated by the jet is reached and no direct effect of the jet on the pressure measured can occur (7). The catheter was connected to a differential pressure transducer (Validyne MP45 ± 50 cm H_2O). Esophageal pressure (Pes) was obtained using the balloon catheter technique (8) and was measured with a differential pressure transducer (SENSYM® LDX 06001 ± 70 cm H_2O; Sensym, Santa Clara, CA). Esophageal pressure was used to estimate pleural pressure.

The compliance of the respiratory system (Crs) was computed from the ratio VT/(Ppause − PEEPtot), where VT is the tidal volume; Ppause is the Ptrach value obtained at the end of a 0.3-s end-inspiratory pause; and PEEPtot is the total Ptrach obtained during occlusion of the expiratory line at the end of exhalation, performed during controlled mechanical ventilation using a special function of the Servo 900C ventilator. The value PEEPtot therefore took into account both the external positive end-expiratory pressure applied to the patient and the intrinsic PEEP due to the mechanical characteristics of the respiratory system of the patients (9, 10).

Protocol. The following maneuvers were performed in a random order in all seven patients once anesthesia and paralysis were considered sufficient: (*1*) 10 min of CMV with a level of 1.0 for FI_{O_2} (inspired fraction of oxygen) followed by disconnection from the ventilator for 90 s; (*2*) 10 min of CMV with an FI_{O_2} level of 1.0 followed by disconnection from the ventilator and addition of CFI for 90 s (O_2 = 12 L/min).

The following additional maneuvers were randomly performed in five of the seven patients: 10 min of CMV with an FI_{O_2} level of 1.0 followed by disconnection from the ventilator and the provision of a supplementary bulk supply of O_2 (at 12 L/min for 90 s) via a large cannula (CH 16) placed 2 cm down the external tip of the endotracheal tube, a maneuver designed to study the effect on gas exchange of apneic oxygenation; and 10 min of CMV at the usual FI_{O_2} level for patient ventilation, followed by disconnection from the ventilator and application of CFI for 90 s (O_2 = 12 L/min). Blood gas samples were obtained at T_0 before disconnection and 45 and 90 s after disconnection (T_{45} and T_{90}).

Part 2

The second part of this study looked at the usefulness of CFI to prevent arterial oxygen desaturation induced by endotracheal suctioning.

Patients. Seven patients ventilated for various disorders were selected for this study. Their main characteristics are listed in table 1 (Patients 8 to 14). Four patients had severe lung injury with a Pa_{O_2}/FI_{O_2} ratio less than 200 mm Hg. They all were intubated with an 8.0-mm endotracheal tube allowing delivery of oxygen by constant-flow insufflation. Patients were often sedated but never paralyzed. At least five of them had spontaneous breathing activity during disconnection.

Measurements. Oxygen saturation (Biox® II; Ohmeda, Louisville, CO) was continuously monitored before, during, and after endotracheal suctioning and recorded on a strip-chart recorder (TA 550; Gould, Cleveland, OH). It was monitored after reconnection to the ventilator until saturation returned to its baseline value. Arterial blood gases were obtained before and after endotracheal suctioning. Tracheal and esophageal pressure were recorded as described, and transpulmonary pressure was obtained by the electronic difference of these two pressures. Dynamic lung compliance was calculated before and after suctioning as the ratio of tidal volume to the change in transpulmonary pressure during mechanical ventilation.

Protocol. Measurements were obtained before, during, and after two suctioning procedures. One was performed during 60 s, while the patient was disconnected from the ventilator without prior hyperoxygenation (standard). The suction catheter (CH 16) was inserted into the airways until resistance was met and then pulled back 2 to 3 cm. Negative suctioning pressure was then started, and the catheter was rotated and gradually removed. Negative wall pressure amounted to −80 cm H_2O. Suction was interrupted when the catheter reached the external outlet of the tube. The maneuver was repeated until the end of the 60-s period. The other suctioning procedure was performed in an identical manner with the addition of CFI of oxygen at 12 L/min. The two periods were selected in a random order and were separated by at least 30 min.

CT scan study. In six further patients, changes in lung volume induced by endotracheal suctioning were assessed by computed tomographic (CT) scanning of the chest. The mean age of these patients was 67 ± 5 yr. They were ventilated for 13 ± 2 days, and the mean FI_{O_2} was 37 ± 2%. Three CT scan cuts were performed (apex, carina, and basis) and repeated four times in a randomized order: (*1*) during mechanical ventilation, at

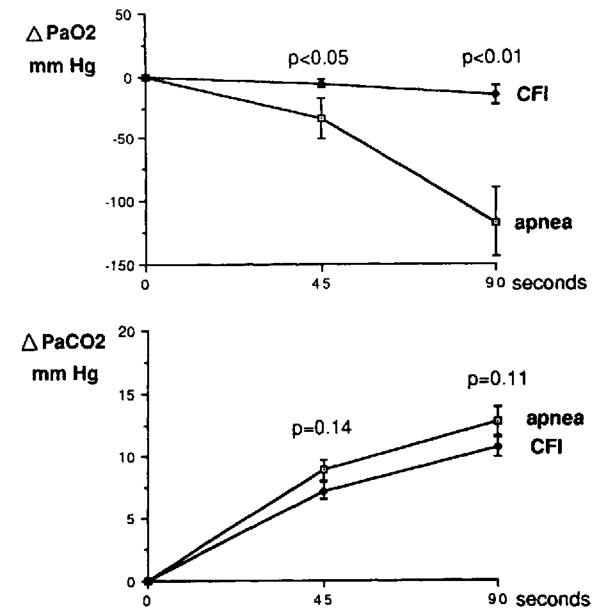

Fig. 1. Mean values (± SEM) for the drop in Pa_{O_2} (ΔPa_{O_2}, *top*) and the rise in Pa_{CO_2} (ΔPa_{CO_2}, *bottom*) relative to the baseline value at a F_{IO_2} level of 1.0, 45, and 90 s after disconnection from the ventilator, either during apnea or during constant-flow insufflation (CFI).

end expiration after clamping of the endotracheal tube; (*2*) after 30 s of disconnection alone; (*3*) after 30 s of endotracheal suctioning; (*4*) after 30 s of endotracheal suctioning and CFI. Between each series of images, patients were reconnected to the ventilator for at least 10 min. Patients were sedated and paralyzed for the study. Two parameters were measured on the CT cuts. First, the surface area of each cut was computed by planimetry. For each condition, the lung volume between two cuts was estimated as the product of the mean surface areas and the distance between the cuts. Total "estimated lung volume" (VL) was the sum of the volumes between each cut. Second, the mean density of the tomographic cuts was calculated in each condition.

Results are expressed in terms of mean ± SEM. The Mann-Whitney U test for comparison of two samples was used for statistical analysis. Comparison of several conditions was made by analysis of variance (ANOVA), and two-by-two comparison was made using Tukey's test.

Results

Part 1

Baseline Pa_{O_2} during controlled mechanical ventilation with an F_{IO_2} of 1.0 was identical before simple disconnection (360 ± 38 mm Hg) and before disconnection plus CFI (349 ± 34 mm Hg). When the patients were disconnected from the ventilator, they exhibited a mean change in Pa_{O_2} of −35 ± 16 mm Hg (range −7 to −129 mm Hg) at T_{45} without CFI. When CFI was applied, Pa_{O_2} decreased only by −6 ± 4 mm Hg (range 10 to −23 mm Hg) at T_{45} ($p < 0.05$). At T_{90}, the change in Pa_{O_2} was much greater: −117 ± 27 mm Hg (range −42 to −217 mm Hg) without CFI, but only −16 ± 7 mm Hg (range 13 to −41 mm Hg) during CFI ($p < 0.001$) (figure 1). These highly significant differences between Pa_{O_2} in the two periods were not found for Pa_{CO_2}, which described a similar rise in the two situations (10.7 ± 0.7 mm Hg during CFI versus 12.7 ± 1.1 without CFI, $p = 0.11$).

With CFI, Ptrach remained constant at 10.4 ± 1.1 cm H_2O during disconnection from the ventilator, so that the changes in lung volume during this period were different with and without CFI. Without it, all patients displayed a fall in lung volume (mean 344 ± 64 ml) corresponding to a mean drop in Pes of −1.9 ± 0.6 cm H_2O. Conversely, during CFI, lung volume was maintained or increased (mean 338 ± 88 ml) corresponding to a mean increase of 1.8 ± 0.4 cm H_2O in Pes. Individual values for Δvol during disconnection are given in table 2.

In the five patients in whom we compared the respective effects of oxygenation by apneic diffusion (bulk flow) and CFI, Pa_{O_2} was lower during bulk flow than during CFI, as illustrated in figure 2. Ptrach remained at zero throughout bulk flow oxygenation (as observed in all seven patients when CFI was absent). Accordingly, lung volume was not different during bulk flow oxygenation and without either bulk flow or CFI.

These five patients were also disconnected after being ventilated at their maintenance F_{IO_2} level (0.30 to 0.45), and CFI was administered during the 90 s of disconnection (O_2 = 12 L/min). Before disconnection (T_0), the mean baseline value of Pa_{O_2} was 102 ± 8 mm Hg. Despite the disconnection, Pa_{O_2} did not change substantially and even increased in some patients (figure 3).

Part 2

Individual recordings of the changes in arterial oxygen saturation induced by endotracheal suctioning are shown in figure 4. During standard suctioning desaturation tended to be more severe in patients with the lowest compliance ($r = -0.65$, $p = 0.08$). During suctioning with CFI arterial oxygen desaturation was never observed in five patients. Desaturation was noted in Patients 9 and 14 during CFI but was of smaller magnitude than during standard suctioning. In addition, return to baseline value was obtained more rapidly during CFI than during standard suctioning for these two patients (135 and 40 s after CFI versus 430 and 230 s after the beginning of disconnection for Patients 9 and 14, respectively, with a mean of 193 ± 47 s for the seven patients during standard suctioning). No difference was observed for the rise in Pa_{CO_2} which increased from 35 ± 6 to 40 ± 6 cm Hg during standard suctioning and from 36 ± 6 to 41 ± 6 mm

TABLE 2

CHANGES IN LUNG VOLUME DURING DISCONNECTION

Patient	PEEPext (*cm H_2O*)	PEEPtot (*cm H_2O*)	Crs (*ml/cm H_2O*)	Δvol (ml) Apnea	Δvol (ml) CFI	Ptrach (CFI) (*cm H_2O*)
1	0	4	37	−240	250	12
2	10	11	42	−680	−60	10
3	0	8	46	−430	250	12.5
4	0	3	89	−250	350	7
5	0	2	90	−350	650	10
6	0	2	65	−160	350	7
7	0	6	53	−300	580	16

Definition of abbreviations: PEEPext = external positive end-expiratory pressure; PEEPtot = total positive end-expiratory pressure; Crs = total effective respiratory system compliance; Δvol = modifications of lung volume measured at the end of the disconnection period either during apnea or during continuous flow insufflation (CFI); Ptrach (CFI) = value of Ptrach during CFI.

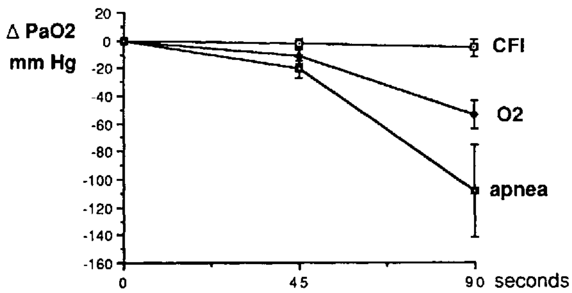

Fig. 2. Mean values (± SEM) for the drop in Pa_{O_2} (ΔPa_{O_2}) observed during apnea, during administration of O_2 (12 L/min) at the external end of the tube (O_2), and during constant flow insufflation (CFI), 45 and 90 s after disconnection.

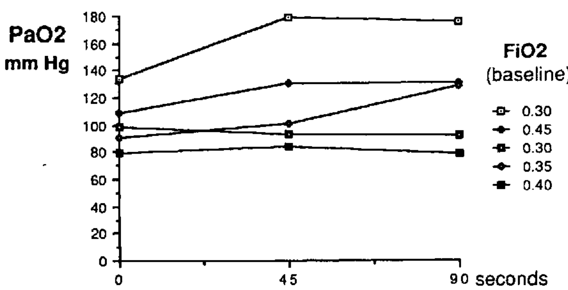

Fig. 3. Individual values of Pa_{O_2} after disconnection from mechanical ventilation at maintenance F_{IO_2} level (0.30 to 0.45) in five patients 45 and 90 s after disconnection during constant-flow insufflation (CFI).

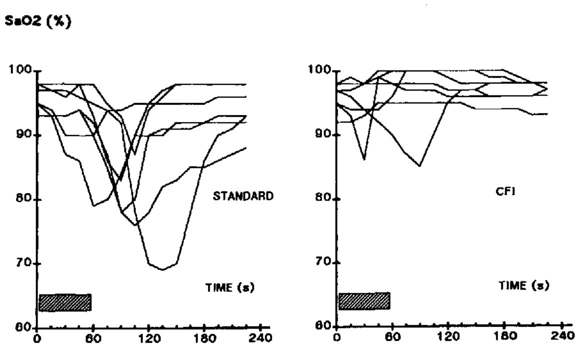

Fig. 4. Individual recordings of arterial oxygen saturation measured with a pulse oxymeter during standard suctioning (*left*) or during suctioning with CFI (*right*). The seven patients experienced desaturation during standard suctioning, but only two of them experienced mild desaturation during a shorter period of time with CFI. Hatched areas = suctioning.

TABLE 3

CT SCAN ASSESSMENT OF CHANGES IN LUNG VOLUME INDUCED BY SUCTIONING*

	End-expiration	Disconnection	Suctioning	Suctioning and CFI
Lung volume, ml	1,430 ± 88	1,243 ± 79 NS	1,043 ± 86 $p < 0.05$	1,339 ± 89 NS
Mean density, Hu†	−748 ± 13	−725 ± 12 NS	−691 ± 12 $p < 0.05$	−739 ± 13 NS

* Statistical values are given by comparison with end-expiration.
† Hunsfield unity.

Hg during CFI. During endotracheal suctioning, changes in transpulmonary pressure (PtP) were the following: Ptp decreased from 1.7 ± 0.8 to −11.0 ± 1.1 cm H_2O during standard suctioning ($p < 0.05$); during CFI, Ptp initially rose from 2.7 ± 0.7 to 7.1 ± 1.0 cm H_2O when CFI was applied immediately before suctioning and fell to only −0.4 ± 1.7 cm H_2O during suctioning (p = NS). Finally, compliance significantly fell during standard suctioning (57.7 ± 4.1 versus 49.5 ± 3.8 ml/cm H_2O, $p < 0.05$), but it was unchanged after CFI suctioning (53.1 ± 4.5 versus 56.5 ± 5.3 ml/cm H_2O, p = NS).

CT scan study. The computations of lung volume and mean density assessed by CT scanning before disconnection and after disconnection alone, disconnection and suctioning, or disconnection, suctioning, and CFI are given in table 3. Striking differences appeared concerning lung volume and mean density. During disconnection alone, the fall in lung volume was small (−12 ± 2%), but during disconnection and suctioning lung volume described a major fall (−27 ± 6%) accompanied by a shift in mean density to higher values and the appearance of atelectasis. In contrast, CFI during suctioning prevented any significant change in lung volume or mean density.

Discussion

The main finding of this study is that in intubated patients disconnected from the ventilator, constant-flow insufflation allows adequate arterial oxygenation to be maintained during disconnection and endotracheal suctioning, as a result of the combined effects of tracheal O_2 injection and constant positive alveolar pressure, which prevents a fall in lung volume.

Disconnection from the ventilator and endotracheal suctioning may induce severe arterial oxygen desaturation. In patients with major lung disease, hypoxemia rapidly worsens and may reach life-threatening levels (1, 12–28). Previous studies focused on methods of limiting arterial desaturation during endotracheal suctioning (12–28). They methods proposed to minimize desaturation include preoxygenation with an increased level of F_{IO_2}, administration of extra breaths before and/or after suctioning, limitation of the duration of suctioning, and on-ventilator suctioning. Preoxygenation by means of manual inflation with a self-inflating bag filled with a continuous flow of 100% oxygen is a standard method but requires several maneuvers before suctioning and also requires additional equipment (14, 17, 18, 22, 25). Alternatively, delivery of extra breaths by the ventilator before suctioning is inefficient for minimizing desaturation when used without altering the F_{IO_2} (17). Postsuctioning hyperoxygenation can be performed as a means of shortening the recovery time of arterial oxygen saturation but does not reduce the maximal desaturation (22).

Since disconnection from the ventilator plays a major role in desaturation, several authors have proposed the use of a special adaptor allowing on-ventilator suctioning (15, 16, 18–20, 22, 23, 28). These adaptors are designed to permit the introduction of a suction catheter during mechanical ventilation without disconnecting the patient and with minimal or no air leaks. A potential risk of this method is the creation of a large negative airway pressure in a closed circuit leading to a decrease in lung volume if suction flow rates exceed ventilation minute volume or to rapid autocycling of the ventilator in an assisted mode (19).

Therefore, the use of such adaptors is probably not recommendable with controlled or assisted ventilation set at a low flow rate (19). Last, oxygen insufflation during endotracheal suctioning has been proposed in several studies with interesting but sometimes opposite conclusions (17, 20, 21, 24). The method of insufflation required the use of a modified suction catheter, allowing intermittent or continuous delivery of oxygen at the tip of the catheter. In the present study no comparison was made with methods that proved earlier to be effective. However, constant-flow insufflation appeared to be an acceptable method for routine clinical usage, capable on the one hand of maintaining adequate arterial oxygenation for 90 s of apnea and avoiding arterial desaturation during endotracheal suctioning on the other hand.

This study confirms that gas exchange can occur during continuous flow ventilation in humans. Successful constant-flow ventilation in apneic dogs was initially described by Meltzer and Auer in 1909 (29). Recently, Lehnert and coworkers studied arterial blood gas tensions in anesthetized paralyzed dogs in which constant gas flow was delivered via two catheters placed in the main stem bronchi (3). With this setup, normal blood gases were obtained with constant flow rates ranging from 8 to 28 L/min for periods as long as 2 h. Similar beneficial results were obtained by other authors in normal dogs (3, 5) and cats (5) and in a dog ventilatory failure model (30). In pigs, however, the efficacy of constant-flow ventilation in maintaining blood gas tensions was markedly poor (4), indicating that interspecies differences exist concerning the efficacy of this mode of ventilation. In five anesthetized human subjects, Perl and coworkers (5) found that during continuous flow ventilation, the mean rate of increase in Pa_{CO_2} was significantly lower than the rate obtained during apneic oxygenation. Here, we found a nonsignificant difference in the rate of rise in Pa_{CO_2} between apnea and continuous flow insufflation (8.5 versus 7.1 mm Hg/min). The first explanation of the poor CO_2 elimination we observed might be that the site of O_2 injection into the lungs, 30 to 40 mm above the carina inside the endotracheal tube, was too proximal (31, 32). Another explanation of our poor results for CO_2 elimination could be the relatively small O_2 flow used in this study since a relationship between Pa_{CO_2} and flow has been previously described (3, 33, 34).

From our data, the mechanisms responsible for maintaining adequate arterial oxygenation during CFI were both apneic oxygenation and the positive alveolar pressure induced by jets. When gas is injected into the tube, air entrainment is combined with a pressure increase that both greatly depend on (*1*) the velocity of the gas injected, (*2*) the wall friction, and (*3*) the angle of injection (7). Positive end-expiratory pressure increases functional residual capacity and decreases intrapulmonary shunt, and the positive pressure created by constant-flow insufflation probably enhanced arterial oxygenation by maintaining or increasing functional residual capacity. Indeed, when oxygen was administered at a low velocity via a large cannula during apnea and thus without positive pressure, maintenance of the arterial oxygen level (which was due only to apneic oxygenation) was not as good as during CFI.

To assess the changes in lung volume induced by endotracheal suctioning, we performed thoracic cuts obtained by CT scanning before and after suctioning. We observed that the alterations in lung volume were of major magnitude and were prevented by the application of constant-flow insufflation with no regional disparities. Although we did not correlate them at the same time, the parallel changes in oxygen saturation and in lung volume strongly suggest that fall in lung volume is a major determinant to explain the fall of arterial oxygen saturation.

A possible risk during experiments with continuous flow ventilation is that the bronchial epithelium might be damaged by the direct impingement of the jets on the airway wall. In fact this risk is unlikely because the outlet of the capillaries was situated 1 cm above the distal end of the tube so that the velocity of the ejected gas was considerably reduced by the time it reached the tracheal epithelium (7). The pressure generated during CFI can be easily predicted from the size of the tube and the flow rate of injected gas (7), and we thus chose to generate a relatively low level of positive pressure to avoid barotrauma. Of concern is the potential risk of hyperinflation if the oxygen was left on when the patient was returned to the ventilator. In this case, the end-expiratory positive pressure generated would not exceed the pressure during disconnection, but each tidal inflation would be increased by an amount equal to the product of oxygen flow rate times inspiratory time. Thus, using relatively low flow rates, as in our study, prevents severe hyperinflation. However, a security system using foam cuffs should be proposed before the use of this endotracheal tube can be recommended.

In summary, the present constant-flow insufflation method efficiently maintained arterial oxygenation during apnea and, moreover, minimized or fully prevented desaturation during endotracheal suctioning in patients mechanically ventilated for acute respiratory failure. These results were made possible partly by the use of a new endotracheal tube that permitted tracheal delivery of oxygen and maintenance of a positive alveolar pressure.

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