# Effects of Zero PEEP and < 1.0 $F_{IO_2}$ on $S_{pO_2}$ and $P_{ETCO_2}$ During Open Endotracheal Suctioning

Jacqueline Rodrigues de Freitas Vianna, Valéria Amorim Pires Di Lorenzo, Miléa Mara Lourenço da S Simões, Jorge Luís Guerra, and Maurício Jamami

**BACKGROUND: Hyperoxygenation and hyperinflation, preferably with a mechanical ventilator, is the most commonly used technique to prevent the adverse effects of open endotracheal suctioning on arterial oxygenation and pulmonary volume. However, limited data are available on the effects of oxygen concentrations < 100% and PEEP with zero end-expiratory pressure (0 PEEP) to improve oxygenation and to maintain adequate ventilation during open endotracheal suctioning. The aim of this study was to analyze the behavior of $S_{pO_2}$ and end-tidal $CO_2$ pressure ($P_{ETCO_2}$) in open endotracheal suctioning using the 0 PEEP technique with baseline $F_{IO_2}$ (0 PEEP baseline $F_{IO_2}$) and 0 PEEP + hyperoxygenation of 20% above the baseline value (0 PEEP $F_{IO_2}$ + 0.20) in critically ill subjects receiving mechanical ventilation. METHODS: This was a prospective, randomized, single-blind crossover study, for which 48 subjects with various clinical and surgical conditions were selected; of these, 38 subjects completed the study. The subjects were randomized for 2 interventions: 0 PEEP baseline $F_{IO_2}$ and 0 PEEP $F_{IO_2}$ + 0.20 during the open endotracheal suctioning procedure. Oxygenation was assessed via oxygen saturation as measured with pulse oximetry ($S_{pO_2}$), and changes in lung were monitored via $P_{ETCO_2}$ using volumetric capnography. RESULTS: In the intragroup analysis with 0 PEEP baseline $F_{IO_2}$, there was no significant increase after open endotracheal suctioning in either $S_{pO_2}$ ($P$ = .63) or $P_{ETCO_2}$ ($P$ = .11). With 0 PEEP $F_{IO_2}$ + 0.20, there was a significant increase in $S_{pO_2}$ ($P$ < .001), with no significant changes in $P_{ETCO_2}$ ($P$ = .55). In the intergroup comparisons, there was a significant increase compared to the basal values only with the 0 PEEP + 0.20 method at 1 min after hyperoxygenation ($P$ < .001), post-immediately ($P$ < .001), at 1 min after ($P$ < .001), and at 2 min after open endotracheal suctioning ($P$ < .001). CONCLUSIONS: The appropriate indication of the hyperinflation strategy via mechanical ventilation using 0 PEEP with or without hyperoxygenation proved to be efficient to maintain $S_{pO_2}$ and $P_{ETCO_2}$ levels. These results suggest that the technique can minimize the loss of lung volume due to open endotracheal suctioning. (ClinicalTrials.gov registration NCT02440919).** *Key words: suction; mechanical ventilation; pulmonary ventilation; physical therapy modalities; oxygen; capnography.* [Respir Care 2020;65(12):1805–1814. © 2020 Daedalus Enterprises]

## Introduction

Critically ill patients with artificial airways have shown changes in mucociliary clearance with the accumulation of secretions due to sedation, depression of the cough reflex, high concentrations of oxygen, inadequate cuff pressure, inflammation, and mucosal trauma.[1-4] Airway aspiration is often necessary to maintain alveolar permeability and to prevent respiratory tract infection.[5] According to the guidelines of the American Association for Respiratory Care (AARC),[6] this procedure may result in numerous side effects, such as risks and complications for developing

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hypoxia/hypoxemia due to reduced level of tissue oxygenation ($P_{aO_2}$), decreased arterial oxygen saturation ($S_{aO_2}$), and peripheral oxygen saturation ($S_{pO_2}$);[7-11] tissue trauma to

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the tracheal or bronchial mucosa with hemorrhagic secretion;[7] increased microbial colonization of lower airways;[9] decrease in dynamic compliance[10-12] and functional residual capacity;[13] atelectasis;[1,9] bronchoconstriction;[14] changes in cerebral blood flow and increased intracranial pressure; vasovagal reactions; changes in blood pressure and heart rate;[7-16] cardiac arrhythmias;[15] low tidal volume;[10,17-19] and elevated carbon dioxide levels in the blood ($P_{aCO_2}$).[11,17]

Use of a closed suction system is suggested for adults with high $F_{IO_2}$ or PEEP at risk of lung de-recruitment and for neonates.[6] Advantages of a closed suction system compared with an open system include continuous mechanical ventilation, reduced hemodynamic impairment, shorter hospital stay, and reduced costs for patients and the health care system. Therefore, this method can replace open suction methods in the care of critically ill patients.[20]

The recommendations to minimize or prevent a decrease in $S_{aO_2}$ include appropriate catheter size, depth and time of suctioning, pressure setting, as well as routinely avoiding saline instillation and manual hyperinflation.[8,17,18,20-23]

Hyperoxygenation is a method used to increase $F_{IO_2}$ above basal levels, and 100% hyperoxygenation has been the most widely used method.[6,16] Manual hyperinflation and ventilator hyperinflation are 2 physiotherapy procedures used to remove secretions. Manual hyperinflation with manual chest compression, also known as bag squeezing, was first described in 1968 by Clement and Hübsch.[24] This physiotherapeutic technique aims to improve oxygenation, clear bronchial secretions, and achieve alveolar re-expansion. Ventilator hyperinflation was originally described by Berney and Denehy[25] in 2002 as an alternative to manual lung hyperinflation, and it has been adopted to achieve the same purposes.

Based on the goal to increase expiratory air flow to remove secretions, studies have shown that pulmonary secretion removal depends not only on high expiratory flows, but also on the presence of an expiratory flow bias, ie, on the peak expiratory flow being higher than the peak inspiratory flow generated in the airways.[26] Furthermore, Volpe et al[27] reported that the most significant threshold for expiratory flow bias to move secretion toward the glottis, for human conditions, is the difference between peak expiratory flow and peak inspiratory flow being $> 33$ L/min.

The effects of 0 PEEP on lung compliance,[4,28,30] gas exchange,[4,28-30] tidal volume,[30] and hemodynamic repercussions[4,28,29] have also been analyzed. This technique consists of imposing a gradual PEEP increase to 15 cm $H_2O$ followed by an abrupt PEEP reduction to 0 PEEP in

**QUICK LOOK**

**Current knowledge**

Open endotracheal suctioning is associated with hypoxemia and a loss of lung volume. Complications of endotracheal suctioning can be minimized by using appropriate diameter suction catheters, limiting suction pressure and performing shallow suctioning.

**What this paper contributes to our knowledge**

The 0 PEEP technique with or without hyperoxygenation maintained adequate $S_{pO_2}$ and $P_{ETCO_2}$ levels during open endotracheal suctioning. However, 0 PEEP with hyperoxygenation + 0.20 above baseline $F_{IO_2}$ should be considered in subjects previously diagnosed with hypoxemia since it avoided the loss of $S_{pO_2} < 94\%$, even in subjects with $S_{pO_2} \leq 88\%$.

association with a manual bilateral thoracic compression to potentiate the increase of expiratory air flow, limiting the peak pressure to 40 cm $H_2O$.[4,28-30] The ventilator hyperinflation with increased volume or with 0 PEEP was similar to manual hyperinflation in terms of the bronchial secretion removal, oxygenation, and with insignificant hemodynamic repercussions.[4,28,29,31] The 0 PEEP technique appears to be safe, without alterations of hemodynamic variables, even in post-cardiac surgery patients.[4] However, there have been few studies investigating using the 0 PEEP method to prevent hypoxemia or evaluating its impact on ventilation, whether associated with pre-oxygenation or not. Study designs involving ventilator hyperinflation are quite different, and the routine use of ventilator hyperinflation as well as the need for 100% hyperoxygenation are still debatable clinical issues.

Previous studies have reported that $F_{IO_2} = 1.0$ should be the method of choice to prevent lower levels of $P_{aO_2}$ or $S_{pO_2}$, especially during open endotracheal suctioning, as recommended by the latest guidelines of the AARC.[16,32,33] However, other studies suggest the evaluation of the need for hyperoxygenation with $F_{IO_2} = 1.0$, considering that the delivery of low or no oxygen was able to prevent hypoxemia during open endotracheal suctioning.[11,34-39] Although $O_2$ was delivered for a short period of time, it is known that exposure to $F_{IO_2} = 1.0$ in humans produces toxic effects that can occur by reabsorption atelectasis, hyperoxic hypercapnia, bronchial and epithelial damage, decreased effectiveness of the ciliary epithelium, and bactericidal bronchial function.[40] Respiratory markers of oxidative stress were observed in healthy volunteers,[41] while hyperoxygenation with 28% above baseline was delivered for 30 min.[41] Oxidative damage was also detected in the lungs of rats exposed to 100% hyperoxygenation for 10 min.[42]

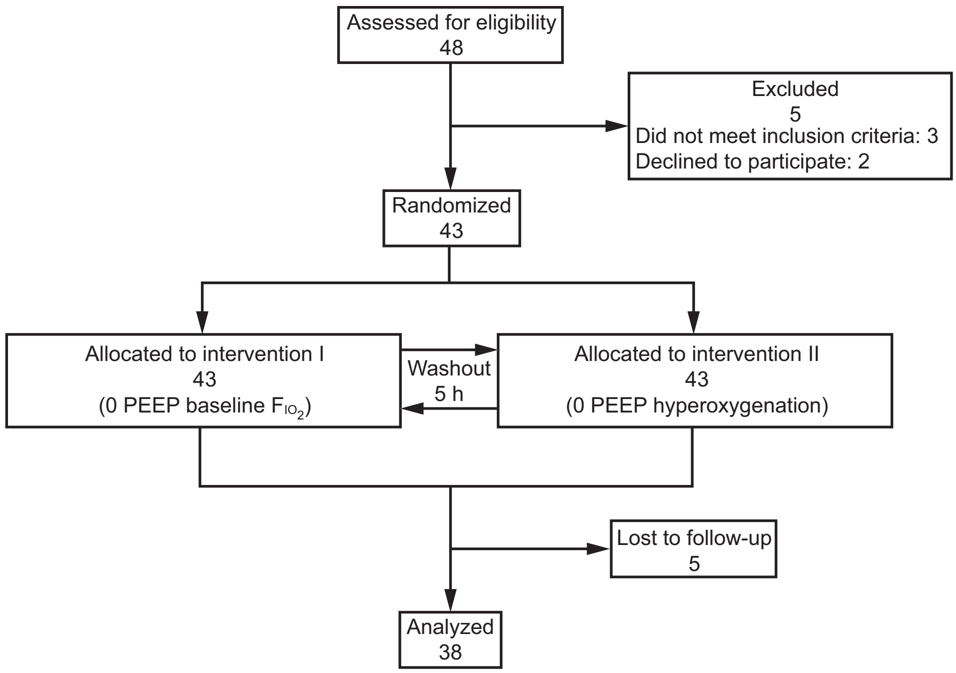


Fig. 1. Flow chart.

Hyperoxygenation combined with hyperinflation has been the most commonly used technique for the prevention of the adverse effects caused by open endotracheal suctioning and is well documented in the literature.[32] However little is known about the effects of < 100% oxygen delivery combined with the 0 PEEP technique on increasing oxygenation and maintaining adequate ventilation during open endotracheal suction. Therefore, we hypothesized that 0 PEEP baseline $F_{IO_2}$ or 0 PEEP $F_{IO_2}$ + 0.20 may maintain adequate $S_{pO_2}$ and $P_{ETCO_2}$ in open endotracheal suctioning without $F_{IO_2} = 1.0$ and the loss of lung volume. The aim of this study was to investigate the behavior of $S_{pO_2}$ and $P_{ETCO_2}$ in open endotracheal suctioning using 0 PEEP baseline $F_{IO_2}$ and 0 PEEP $F_{IO_2}$ + 0.20 in critically ill subjects on mechanical ventilatory support.

## Methods

### Study Location and Subject Population

The study was approved by the Human Research Ethics Committee of our institution and by the National Unified Research Registry involving human beings (Brazil Platform - CEP/Conep System- CAAE: 11354813.1.0000.5504). Written informed consent was obtained from the legal representatives of the subjects. The study was conducted in the tertiary adult ICU at Santa Casa de Misericórdia, Batatais, São Paulo, Brazil. All consecutive subjects requiring mechanical ventilation and ≥ 18 y of age were included during the period from June 2013 to May 2015. A total of 48 subjects of both sexes with several clinical and surgical conditions were selected. Of these, 10 subjects were excluded, leaving 38 subjects who completed the study. Figure 1 provides a flow chart of the study.

### Inclusion and Exclusion Criteria

Inclusion criteria were as follows: subjects undergoing orotracheal intubation and on mechanical ventilation for > 12 h, hemodynamically stable, and requiring endotracheal suctioning according to the American Association for Respiratory Care criteria.[6] Exclusion criteria were as follows: individuals using high doses of vasopressor amines or showing severe cardiac arrhythmias; with hemoglobin < 7 g/dL; impossibility of appropriate $S_{pO_2}$ monitoring; baseline $F_{IO_2}$ ≥ 0.60; requirement of PEEP of > 10 cm $H_2O$; ARDS; rib fractures; presence of a chest drain; severe bronchospasm; intracranial hypertension (ie, intracranial pressure > 10 mm Hg); hemorrhagic disorders; marked degree of gastroesophageal reflux; bullous lung disease; unilateral lung disease; use of tracheostomy; closed suction system; peak pressure > 35 cm $H_2O$; hemodynamic instability with mean arterial pressure < 60 mm Hg; central venous pressure < 6 mm Hg; and no indication for endotracheal suctioning.

### Study Design and Data Collection

This was a prospective, randomized, single-blind, crossover study with randomization by drawing lots using

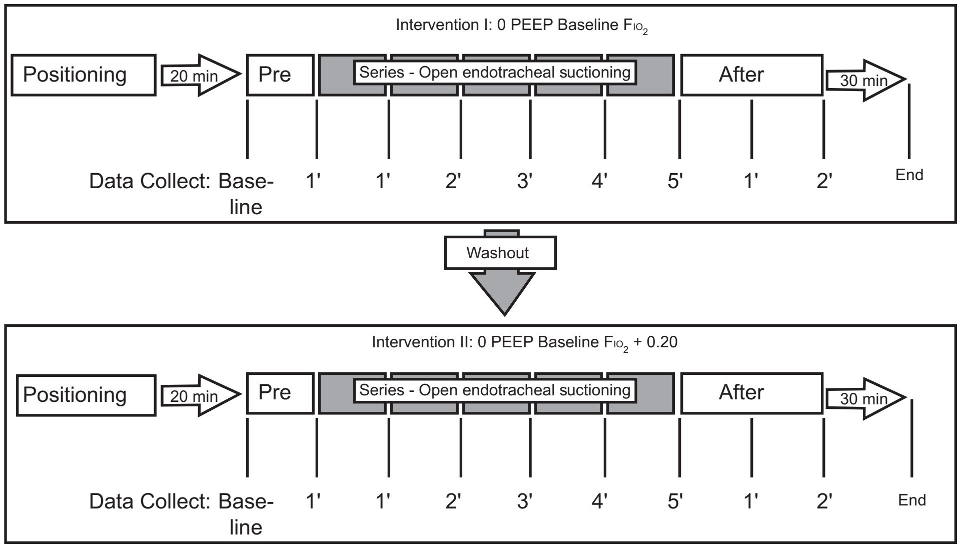


Fig. 2. Data collection of experimental protocols. Baseline $F_{IO_2}$ (current $F_{IO_2}$ without hyperoxygenation); $F_{IO_2}$ + 0.20 (hyperoxygenation with offer of $F_{IO_2}$ 20% above baseline); Positioning (supine position for 20 min with the headrest at 40°); Pre (data collected at Baseline after positioning); Series: open endotracheal suctioning, data collected at 1 min after offer or not of oxygenation (Intervention I: 0 PEEP Baseline $F_{IO_2}$; Intervention II: 0 PEEP $F_{IO_2}$ + 0.20) and at 1 min before and after each catheter insertion, on the 5 open endotracheal suctioning procedures; After: data collected at 1 min, 2 min, and 30 min after open endotracheal suctioning.

opaque envelopes containing sequential interventions: Intervention I was 0 PEEP with $F_{IO_2}$ (0 PEEP baseline $F_{IO_2}$), and Intervention II was 0 PEEP with 20% hyperoxygenation above baseline $F_{IO_2}$ (0 PEEP $F_{IO_2}$ + 0.20) during the open endotracheal suctioning procedure.

This study used the open suction system because it reflects the reality of Brazilian ICUs. The AARC guidelines were followed, not including adults with high $F_{IO_2}$ and high PEEP levels with risk for lung de-recruitment.

To eliminate the carryover effects of the previous treatments, a washout period[43] of 5 h was allowed between interventions (Fig. 1). After the washout period, the subject was placed in a supine position for 20 min with the headrest at 40°. The endotracheal tube cuff was insufflated with 24 cm $H_2O$ with a cuff pressure monitor (AMBU, Madrid, Spain). The following variables were then determined: tube size, level of consciousness, level of sedation with the vasoactive drug, indications for the open endotracheal suctioning procedure, ventilatory mode, ventilatory parameters, hemoglobin and hematocrit in the baseline condition before open endotracheal suctioning in both interventions. The interventions were performed by the senior author and a physiotherapist. Complications during or after the procedure, such as vomiting, trauma, or bronchospasms, were recorded.

$S_{pO_2}$ was measured via pulse oximetry (Dixtal, Córdoba, Argentina) or ear lobe pulse oximetry (Dixtal); the multiparameter monitor DX-2021 or DX-2023 (Dixtal) was also used as an index of hypoxia. $P_{ETCO_2}$ was measured via volumetric capnography with the Dixtal 3012 mechanical ventilator with a monitor and Capnostat 5 (Respironics, Murrysville, Pennsylvania) and a sensor equipped with a mainstream flow sensor. Heart rate, breathing frequency, systolic arterial pressure, diastolic arterial pressure, and mean arterial pressure were obtained with the multiparameter monitor DX-2021 or DX-2023 (Capnostat 5, Respironics). $S_{pO_2}$ and $P_{ETCO_2}$ were measured at baseline (ie, immediately before each of the cleaning maneuvers) and then immediately after and again 30 min after the cleaning episodes were performed. $S_{pO_2}$ was also measured during each of the cleaning episodes during both interventions at 1 min before oxygenation, 1 min after each of the 5 procedures for open endotracheal suctioning, and 1 min after oxygenation. At the end of data collection, subjects received the physiotherapy, medical, and nursing care routinely performed in the ICU (Fig. 2).

## Procedures

All subjects were ventilated using the following ventilatory modes: volume control ventilation, assist/control; pressure control ventilation, assist/control; volume control synchronized intermittent mandatory ventilation; and spontaneous breath with volume guarantee pressure-support ventilation. After all inclusion criteria were checked, the subjects were randomly allocated to one of the 2 sequences. The subjects were placed in the supine position with elevation of the head of the bed at 40° for 20 min before the baseline measurements and the open endotracheal suctioning procedure.

The open endotracheal suction procedure was performed using an atoxic, sterile, siliconized polyvinyl chloride, 12 French catheter with a lateral and bottom orifice, and a suction control valve (Embramed, São Paulo, Brazil) for endotracheal tubes with an internal diameter of 7.0–8.5 mm.[44] The catheter was introduced until resistance was met, and it was then withdrawn 2–3 cm with a negative pressure of ~150 mm Hg[45,46] applied for 15 s with circular movements; there was a 60-s interval between each of the 5 insertions, according to the recommendations of the latest endotracheal suctioning directives of the American Association for Respiratory Care.[6]

Hyperoxygenation was performed using a Dixtal 3012 ventilator. In 0 PEEP hyperoxygenation, $F_{IO_2}$ + 0.20 was increased to a value 20% above the baseline value of the subject for 1 min before each of the 5 procedures and for 1 min after the open endotracheal suctioning procedure.

At the start of each maneuver, PEEP was increased to 15 cm $H_2O$ for 60 s at the end of the inspiratory phase, with the pressure peak limited to 40 cm $H_2O$.[25] PEEP was then abruptly reduced to 0 cm $H_2O$; this cycle is known as 0 PEEP.[28-30] The tidal volume was previously adjusted to 6 mL/kg with an inspiratory time of 0.8–1.2 s and a breathing frequency of 8 breaths/min, followed by an abrupt PEEP reduction to 0 cm $H_2O$ (0 PEEP) in the expiratory phase, returning the PEEP value to the inspiratory phase. The maneuver was repeated after 2 ventilatory cycles at baseline PEEP. In each step, the maneuver was performed 3 times[28-30,47,48] before each of the 5 open endotracheal suctioning procedures, for a total of 15 cycles per step, totaling 15 min.

### Statistical Analysis

The sample size calculation was performed using GPower 3.1 with the dependent variables ($S_{pO_2}$ and $P_{ETCO_2}$) of a pilot study with 16 subjects carried out by the authors, where $\alpha$ = 5% (2-tailed) and 80% power, estimating a sample of 41 subjects. Data were analyzed using GraphPad Prism 5.01 (GraphPad Software, San Diego, California). Initially, 1-way repeated measures analysis of variance was used to test the possibility of grouping all subjects within different ventilation modes. According to the Shapiro-Wilk test for sample data with non-normal distribution, we used the paired Wilcoxon test for between and within comparisons. The Friedman test post hoc Dunn test was used for the 4 measures obtained during the 5 open endotracheal suctioning procedures. A significance level was set at 5% for all tests. Data are expressed as absolute frequency (*n*), percentage (%), or median (range).

## Results

Thirty-eight subjects with mean age of 65.82 ± 12.26 y participated in the study. The initial sample characteristics are displayed in Table 1. The indication for mechanical ventilation was predominantly respiratory, mainly due to COPD and acute respiratory failure caused by pneumonia.

Table 1. Subject Characteristics and Baseline Conditions

| Variable | *n* (%) |
|---|---|
| Sex | |
| Female | 12 (31.6) |
| Male | 26 (68.4) |
| Causes of intubation | |
| Respiratory | 24 (63) |
| Cardiac | 11 (29) |
| Surgical (abdominal and orthopedic) | 3 (8) |
| Ventilation mode | |
| Volume control ventilation, assist/control | 10 (26.3) |
| Pressure control ventilation, assist/control | 5 (13.2) |
| Volume control synchronized intermittent mandatory ventilation | 8 (21.1) |
| Pressure control synchronized intermittent mandatory ventilation | 8 (21.1) |
| Volume-guaranteed pressure support | 7 (18.4) |

*N* = 38 subjects.

The Acute Physiologic and Chronic Health Evaluation II (APACHE II) prognostic index was applied upon admission to the hospital and 48 h after admission to estimate the severity of the disease and predict hospital mortality. The mean APACHE II scores were 22.2 ± 8.64 and 22.3 ± 8.28. The risk of death was 40% for nonoperative subjects and 30% for postoperative subjects. The mortality rate was 55.3% ($n$ = 21), with a high rate of ICU discharge of 44.7% ($n$ = 17). The mean duration of mechanical ventilation was 14.29 ± 12.81 d, and the mean length of stay in the ICU was 14.72 ± 9.08 d.

The endotracheal tubes had a mean internal diameter size of 7.99 ± 0.36 mm (range 7.0–8.5 mm). Most tubes (66%) used were 8.5 mm in diameter. There was no statistically significant difference between $F_{IO_2}$, PEEP, mean airway pressure, and hemoglobin and hematocrit values in baseline conditions ($P > .05$) (Table 2).

### Oxygenation Behavior Measured With $S_{pO_2}$

There was a significant increase in $S_{pO_2}$ within groups immediately after the open endotracheal suctioning with the 0 PEEP $F_{IO_2}$ + 0.20 method, with $S_{pO_2}$ returning to baseline values after 30 min in both interventions; however, the $S_{pO_2}$ values were higher with the 0 PEEP $F_{IO_2}$ + 0.20 method compared to the 0 PEEP baseline $F_{IO_2}$ method (Table 3). In the continuous analyses within groups, there was a significant increase compared to the basal values only in the 0 PEEP $F_{IO_2}$ + 0.20 method at 1 min after hyperoxygenation ($P < .001$), post-

Table 2. Comparison of Subjects' Basal Conditions

| | Intervention I | Intervention II | $P$* |
|---|---|---|---|
| Hemoglobin, g/dL | 10.9 (7.2–15.4) | 11.5 (7.0–15.2) | .26 |
| Hematocrit, % | 34.7 (23.5–53.5) | 35.9 (21.0–53.7) | .84 |

Data are presented as median (range). $N = 38$ subjects. Intervention I: 0 PEEP, baseline $F_{IO_2}$; Intervention II: 0 PEEP, hyperoxygenation.
* Paired Wilcoxon test used for statistical comparison.

immediately ($P < .001$), at 1 min after ($P < .001$), and at 2 min after open endotracheal suctioning ($P < .001$) (Fig. 3).

In both interventions, the 4 values were maintained during the 5 suction procedures ($P = .65$ and $P = .93$). A significant difference was found between the groups after hyperoxygenation ($P = .003$) and at all time points measured ($P < .001$). No significant difference was observed in baseline values and at 30 min after the procedure (Fig. 3).

It is noteworthy that, in the 0 PEEP baseline $F_{IO_2}$ intervention, 6 subjects (15.8%) had hypoxemia ($S_{pO_2} <$ 90%), 2 subjects had $S_{pO_2} \leq 90\%$ during and after 2 min, and 3 (7.8%) subjects had $S_{pO_2} \leq 90\%$ after 30 min of open endotracheal suctioning. In the 0 PEEP $F_{IO_2}$ + 0.20 method, 4 subjects had baseline hypoxemia (10.5%) ($S_{pO_2} < 90\%$) and 1 subject (7.8%) exhibited $S_{pO_2} = 90\%$ after 30 min following open endotracheal suctioning.

### Ventilation Behavior Evaluated With $P_{ETCO_2}$

In the intragroup analysis, no significant changes were observed in $P_{ETCO_2}$ at any time point in either intervention ie. ($P = .11$, $P = .46$, $P = .29$, and $P = .32$); the same was noted in the between-group analysis ie. ($P = .10$, $P = .50$ and $P = .98$) (Table 3, Fig. 4). Emphasis should be given to the baseline homogeneity of the interventions. In 0 PEEP baseline $F_{IO_2}$, 27 subjects (71%) were isocapnic ($P_{ETCO_2} \leq$ 45 mm Hg) and 11 (29%) were hypercapnic ($P_{ETCO_2} >$ 45 mm Hg); in 0 PEEP $F_{IO_2}$ + 0.20, 26 subjects were isocapnic (68%) and 12 were hypercapnic (32%).

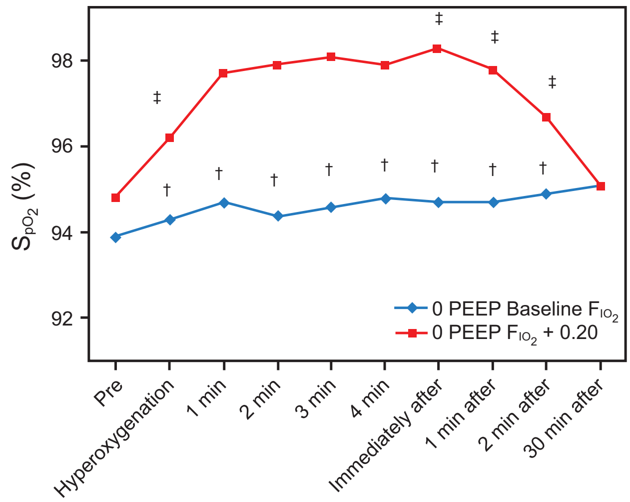


Fig. 3. Changes in $S_{pO_2}$ before and after open endotracheal suctioning at different time points with 0 PEEP $F_{IO_2}$ + 0.20 and 0 PEEP baseline $F_{IO_2}$. †Comparison between the groups. ‡Comparison within the groups pre- and immediately after.

## Discussion

In this study, we analyzed the behavior of $S_{pO_2}$ and $P_{ETCO_2}$ in open endotracheal suctioning using the 0 PEEP technique with $F_{IO_2}$ at baseline and 0 PEEP + hyperoxygenation of 20% above the baseline value in critically ill subjects receiving mechanical ventilation. The results indicated that the 0 PEEP technique with or without hyperoxygenation during the open endotracheal suctioning pro-cedure was effective in maintaining adequate oxygenation, with a median $S_{pO_2}$ of 95%, as well as adequate ventilation, with a median $P_{ETCO_2}$ of 39.5 mm Hg. The PEEP to 0 PEEP $F_{IO_2}$ + 0.20 technique maintained adequate $S_{pO_2}$ even in subjects previously diagnosed with hypoxemia ($S_{pO_2} \leq 88\%$).

Table 3. Changes in $S_{pO_2}$ and $P_{ETCO_2}$ During the Open Endotracheal Suctioning Procedure

| Tempo | | $S_{pO_2}$, % | | | $P_{ETCO_2}$, mm Hg | | |
|---|---|---|---|---|---|---|---|
| | | Intervention I | Intervention II | $P$* | Intervention I | Intervention II | $P$* |
| Pre | | 0.94 (0.88–0.99) | 0.95 (0.87–1.0) | .19 | 39.5 (15–72) | 40.5 (16–68) | .10 |
| Immediately after | | 0.95 (0.87–1.0) | 0.99 (0.93–1.0) | < .001 | 37 (11–75) | 39.5 (16–71) | .050 |
| Pre × Immediately after | $P$† | .63 | < .001 | | .11 | .29 | |
| 30 min after | | 0.96 (0.89–1.0) | 0.95 (0.90–0.99) | .77 | 39 (12–63) | 40 (17–66) | .98 |
| Pre × 30 min after | $P$‡ | .055 | .89 | | .46 | .32 | |

Data are presented as median (range). Intervention I: 0 PEEP, baseline $F_{IO_2}$; Intervention II: 0 PEEP, hyperoxygenation.
* Paired Wilcoxon test used for between comparison.
† Paired Student $t$ test for within comparison (Pre × Immediately after).
‡ Paired Student $t$ test for within comparison (Pre × 30 min after).

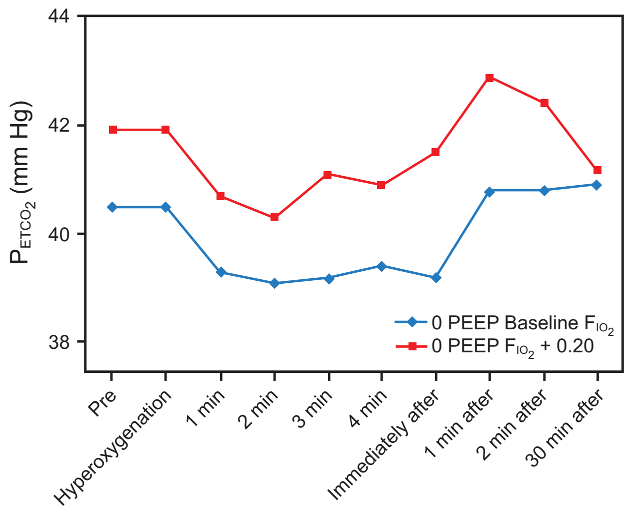


Fig. 4. Changes in $P_{ETCO_2}$ before and after open endotracheal suctioning at different time points with 0 PEEP $F_{IO_2}$ + 0.20 and 0 PEEP baseline $F_{IO_2}$.

$S_{pO_2}$ is one of the most important advances in respiratory monitoring. It is commonly used to assess oxygenation of ICU subjects during open endotracheal suctioning, mainly due to its the degree of accuracy and the ease of operation of most pulse oximetry instruments.[10,50,51] The $S_{pO_2}$ value usually reflects $S_{aO_2}$, especially when > 90%, with normal values of $S_{pO_2}$ and $S_{aO_2}$ ranging from 3% to 5%, respectively.[50,52]

Helayel et al[53] reported that $S_{pO_2}$ values ≥ 99% ruled out the possibility of $S_{aO_2}$ < 90% in critically ill or surgical patients. Jubran et al[52] considered that limits between 92% and 94% should be targets to avoid $S_{aO_2}$ < 90%, which corresponds to mild hypoxemia.[51,54] However, Seguin et al[55] detected the absence of hypoxemia only with $S_{pO_2}$ values ≥ 96% in critically ill subjects receiving mechanical ventilation, ie, the value that would determine $S_{pO_2}$ ≥ 90%. According to Torsani et al,[56] 88–92% $S_{pO_2}$ is typically accepted as ideal in clinical practice for critically ill subjects. Nonetheless, Jubran[51] reported that $S_{pO_2}$ > 92% would be a satisfactory level of oxygenation for mechanically ventilated subjects. Ghayumi et al[57] recently reported that $S_{pO_2}$ ≥ 94% can be used as a reliable and accurate substitute for arterial blood gas for the assessment of hypoxemia and that arterial blood gas analysis should be limited to subjects with $S_{pO_2}$ < 94%.

In this study, when considering the moments before and immediately after open endotracheal suctioning, the median $S_{pO_2}$ in 0 PEEP baseline $F_{IO_2}$ was 94–95%; with the 0 PEEP + hyperoxygenation of 20% method, it was 95–99%, maintaining oxygenation with or without hyperoxygenation. It should be noted that the 0 PEEP baseline $F_{IO_2}$ method was effective in preventing levels of $S_{pO_2}$ ≥ 97%.

However, in the 0 PEEP baseline $F_{IO_2}$ method, 4 subjects (10%) presented with baseline $S_{pO_2}$ = 88% before open endotracheal suctioning, and 3 subjects maintained $S_{pO_2}$ ≤ 90% during the procedure. In the 0 PEEP hyperoxygenation method, 3 subjects (8%) exhibited baseline $S_{pO_2}$ ≤ 88%. $S_{pO_2}$ ≥ 94% was maintained in all subjects during the procedure.

Clinical trials have indicated that there are no beneficial effects of hyperoxia on critically ill subjects.[40] Prescription of $F_{IO_2}$ levels higher than are necessary to achieve arterial oxygenation goals may further increase the risk of oxygen toxicity.[51] The use of $F_{IO_2}$ = 1.0 has potential toxic effects due to the release of large amounts of proinflammatory cytokines and significant microvascular and muscular changes, inducing severe lung injury.[2,40,42,58-60]

We investigated the delivery of 20% above baseline $F_{IO_2}$, similar to a previous reported by Rogge et al[34] in 11 subjects with COPD, who compared the delivery of 20% above baseline $F_{IO_2}$ to the delivery of $F_{IO_2}$ = 1.0 both combined with manual lung hyperinflation, observing whether the $O_2$ levels were properly maintained in both oxygen therapies.

Souza et al[37] reported the effectiveness of $F_{IO_2}$ + 0.20 delivery by comparing baseline $F_{IO_2}$ versus hyperoxygenation with $F_{IO_2}$ + 0.20 above baseline, combined with conventional lung physiotherapy and bag squeezing technique in 30 critically ill subjects. Demir and Dramali[35] also reported that $S_{pO_2}$ and $P_{aO_2}$ without hyperoxygenation was not significantly reduced in intubated subjects undergoing mechanical ventilation with closed endotracheal suctioning.

In the present study, the 0 PEEP technique with baseline $F_{IO_2}$ and the 0 PEEP $F_{IO_2}$ + 0.20 technique in open endotracheal suctioning maintained adequate levels of $S_{pO_2}$ in critically ill subjects receiving mechanical ventilation.

Capnography is an effective noninvasive method in diagnosing early respiratory depression and airway disorders. It also indirectly measures metabolism and circulation, estimating $P_{aCO_2}$ with some accuracy, whereas the observed gradient is minimal, with a significant difference of 2–5 mm Hg when comparing $P_{aCO_2}$ and $P_{ETCO_2}$. A normal average $P_{aCO_2}$ value of 40 mm Hg has a capnometry reading of 35–38 mm Hg $P_{ETCO_2}$.[61-66]

Savian et al[31] observed an increase in $CO_2$ production with the application of manual lung hyperinflation in subjects under the volume control synchronized intermittent mandatory ventilation mode. Ahmed et al[67] also reported that ventilator hyperinflation provided better dynamic compliance compared to manual hyperinflation.

Our study indicated that both interventions (ie, 0 PEEP baseline $F_{IO_2}$ and 0 PEEP $F_{IO_2}$ + 0.20) maintained adequate levels of $P_{ETCO_2}$ in critically ill subjects undergoing mechanical ventilation in the moments before and after open endotracheal suctioning, suggesting that the 0 PEEP technique can minimize the loss of lung volume due to pulmonary de-recruitment with an open endotracheal suctioning system.

Berney and Denehy[25] and Savian et al[31] described that both hyperinflation methods (ie, manual hyperinflation and ventilator hyperinflation) proved to be effective in removing secretions and improving static lung compliance, hemodynamics, and oxygenation. We used the 0 PEEP technique, which was applied in only 3 studies without hyperoxygenation, following the same patterns; ie, imposing a gradual PEEP increase to 15 cm $H_2O$, with peak pressure limited to 40 cm $H_2O$ for 5 ventilatory cycles, followed by an abrupt PEEP reduction. The variations found were the different evaluation time periods (5 min, 10 min, or 3 sets of 5 ventilation cycles) with or without manual chest compression.

Rodrigues[28] reported that the 0 PEEP technique in combination with manual chest compression was a safe technique in removing bronchial secretions in myocardial revascularization subjects during the immediate postoperative period. The 0 PEEP technique also allowed greater control in respiratory mechanics, monitoring pressures and flows delivered to the lungs. Santos et al[30], using the same study design[28] to compare the 0 PEEP technique combined with manual chest compressions in 12 subjects undergoing mechanical ventilation, reported a significant increase in the respiratory system compliance in both techniques, with no significant differences between them as well as favorable behavior of $S_{pO_2}$ in the manual chest compressions group. In a similar study with 20 subjects, Lobo et al[29] compared the 0 PEEP technique combined with manual vibrocompression with no hyperoxygenation versus a bag-squeezing technique, using 5 L/m of oxygen ($F_{IO_2} = \sim 0.40$). The authors considered the 0 PEEP technique feasible in critically ill subjects because its use did not cause any significant hemodynamic repercussions. In 2011, Herbst-Rodrigues et al[4] analyzed 15 subjects submitted to a coronary artery bypass graft surgery and did not find alterations in the hemodynamic variables (ie, $S_{pO_2}$ and $P_{ETCO_2}$), confirming the safety of the 0 PEEP technique combined with manual chest compressions when it is not used as an alternative technique for the removal of bronchial secretions.

In the present study, the removal of bronchial secretions was not analyzed. We used the method of previous studies, without association with manual chest compression and with pressurization time and using 60 s in each series, and we noted similar results in terms for the alterations in $S_{pO_2}$ and $P_{ETCO_2}$. The 0 PEEP technique in the expiratory flow bias concept is effective for mucus mobilization in the central direction, maintaining the levels of $S_{pO_2}$ and $P_{ETCO_2}$.

It is noteworthy that the standardized 0 PEEP technique appears to be a safe method in cardiovascular subjects, given that no hemodynamic alterations were observed in those subjects in previous studies.[4,28] The 0 PEEP application time should not exceed 15 min, because there could be repercussions for heart rate.[49] This technique should not be used with subjects with COPD because potential detrimental effects of manual hyperinflation have been reported, including increased intrinsic PEEP and its consequences.[68] Further research focusing on the effects of the 0 PEEP method on subjects with COPD is required for a better understanding of the potential benefits of this technique.

Open endotracheal suctioning may cause a significant but transient loss of lung volume.[69] The prevention of lung volume loss is of paramount important because the high shear forces between the open and closed lung units, combined with lung de-recruitment, can be harmful to the lungs.[70] Therefore, future studies should focus on the fact that lung volume loss should be avoided not only during but also after open endotracheal suctioning using lung recruitment strategies.

This study has limitations that are inherent to its design, although no significant differences were noted in baseline interventions and in the type of sample. A study population with more homogeneous clinical features is likely to provide a better understanding of the results. Additional investigations are needed to compare different ventilatory modes and strategies for the protection of pulmonary volume during and after open circuit suctioning, as well as the impact of the relationship between the diameter of the suction catheter and the endotracheal tube volume losses during open endotracheal suctioning.

## Conclusions

The results indicated that an appropriate indication of the hyperinflation strategy by mechanical ventilation using the 0 PEEP technique with or without hyperoxygenation was efficient to maintain $S_{pO_2}$ and $P_{ETCO_2}$ levels in critically ill subjects, suggesting that the technique minimized lung volume loss due to the open endotracheal suctioning system. However, we recommend the use of the 0 PEEP technique + 20% above the baseline in subjects previously diagnosed with hypoxemia because the 0 PEEP with hyperoxygenation + 0.20 above baseline $F_{IO_2}$ method avoided the loss of $S_{pO_2} < 94\%$, even in subjects with $S_{pO_2} \leq 88\%$.

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