The effects of recruitment maneuver during noninvasive ventilation after coronary bypass grafting: A randomized trial

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ABSTRACT

Objective: Pulmonary impairment is a common complication after coronary artery bypass graft procedure and may be prevented or treated by noninvasive ventilation. Recruitment maneuvers include sustained airway pressure with high levels of positive end-expiratory pressure in patients with hypoxemia, favoring homogeneous pulmonary ventilation and oxygenation. This study aimed to evaluate whether noninvasive ventilation with recruitment maneuver could safely improve oxygenation in patients with atelectasis and hypoxemia who underwent a coronary artery bypass grafting procedure.

Methods: Thirty-four patients admitted to our intensive care unit undergoing mechanical ventilation after surgery, with ratio of arterial oxygen partial pressure to fraction of inspired oxygen < 300 and radiologic atelectasis score ≥ 2 , were included. The control group consisted of 16 randomized patients and the recruitment group consisted of 18 patients. After extubation, noninvasive ventilation was applied for 30 minutes 3 times a day with positive end-expiratory pressure of 8 cm H₂O. The recruitment group received recruitment maneuver with positive end-expiratory pressure of 15 cm H₂O and 20 cm H₂O for 2 minutes each during noninvasive ventilation. We analyzed the arterial oxygen partial pressure in room air, radiologic atelectasis score, hemodynamic stability, and adverse events from extubation until discharge.

Results: Arterial oxygen partial pressure increased $12.6\% \pm 6.8\%$ in the control group and $23.3\% \pm 8.5\%$ in the recruitment group ($P < .001$). The radiologic atelectasis score was completely improved for 94.4% of the recruitment group with no adverse events, whereas 87.5% of the control group presented some atelectasis ($P < .001$).

Conclusions: Noninvasive ventilation with recruitment maneuvers is safe, improves oxygenation, and reduces atelectasis in patients undergoing coronary artery bypass. (J Thorac Cardiovasc Surg 2018;156:2170-7)

Individual evolution of Pao₂ in study patients after extubation in the ICU.

Central Message

We compared the efficacy and safety of NIV associated with recruitment maneuver versus usual NIV in patients undergoing coronary artery bypass grafting with hypoxemia and atelectasis.

Perspective

Recruitment maneuver during noninvasive ventilation was safe postoperatively in patients undergoing coronary artery bypass grafting with cardiopulmonary bypass and our findings demonstrate a significant improvement in oxygenation and in the atelectasis score during the ICU period and less oxygen supplementation at ICU discharge and during the ward period.

See Editorial Commentary page 2178.

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Cardiac surgery is frequently associated with pulmonary complications during the postoperative period, leading to a prolonged length of stay in the hospital and increased morbidity and mortality.^{1,2} Atelectasis and hypoxemia are common pulmonary complications and may be related to

Scanning this QR code will take you to a supplemental video for the article.

Abbreviations and Acronyms

CABG	= coronary artery bypass grafting
CPAP	= continuous positive airway pressure
Fio ₂	= fraction of inspired oxygen
CG	= control group
ICU	= intensive care unit
NIV	= noninvasive ventilation
Pao ₂	= partial pressure of arterial oxygen
PEEP	= positive end-expiratory pressure
RAS	= radiological atelectasis score
RG	= recruitment group
RM	= recruitment maneuver

previous pulmonary and cardiac function or the association of multiple intraoperative factors such as the effect of general anesthesia, a sternotomy incision, an inflammatory response to cardiopulmonary bypass, lung ischemia-reperfusion injury, disconnection from the circuit during a cardiopulmonary bypass, pleural cavity manipulation, and mechanical ventilation with a high fraction of inspired oxygen (Fio₂).²⁻⁵ Furthermore, inflammatory mediators produced during the intraoperative period are associated with increased microvascular permeability in the lung and, consequently, impaired gas exchange.⁵⁻⁷

Atelectasis occurs in excess of 50% of patients who undergo cardiac surgery, and the presence of collapsed lung regions has also been associated with an increased risk of respiratory infections.^{3,8,9} Although these complications may not be clinically significant in some cases, 40% of cardiac postoperative patients readmitted to intensive care unit (ICU) present respiratory failure.⁶

To prevent deleterious pulmonary repercussions following cardiac surgery, noninvasive ventilation (NIV) has been used in the postoperative period.¹⁰ Several studies have demonstrated the benefit of NIV in reducing pulmonary complications because it may restore lung volume, improve gas exchange, reduce respiratory workload, and reduce atelectasis, thus reducing reintubation rate and length of stay in the ICU, and in the hospital.^{9,11,12}

The recruitment maneuver (RM) consists of sustained increase in airway pressure aiming to minimize the deleterious effects of alveolar collapse.^{3,10,13} It attempts to ventilate the pulmonary parenchyma more homogeneously and enhance oxygenation because it increases the pulmonary area available for gas exchange and, consequently, improves arterial oxygenation.^{14,15} The application of positive end-expiratory pressure (PEEP) is widely practiced in ICU to prevent the collapse of ventilated alveoli and to maintain pulmonary expansion after RM.^{4,6}

This study evaluated whether the use of NIV with RM is effective in the improvement of oxygenation and atelectasis

compared with the sole use of NIV, and whether it can be safely applied to patients with atelectasis and hypoxemia after receiving coronary artery bypass grafting (CABG) with cardiopulmonary bypass. And secondarily, this study assessed the reintubation rate, mortality rate, the length of stay in the ICU and hospital.

METHODS**Study Design and Setting**

This was a single-center, controlled, and randomized clinical trial with parallel groups, performed at the Hospital do Coração, São Paulo, Brazil. The protocol study was approved by the ethics committee of the institution. The trial was registered as NCT02913391. Patients were invited to participate in the study before surgery, and written informed consent was obtained from the patients or their surrogates. Patients were then assessed for eligibility at ICU admission, after surgery. Patients who met the inclusion criteria and did not present any exclusion criteria were enrolled in the study and randomized by computer-based software (Figure E1).

Patients who met the inclusion criteria were patients older than age 18 years, admitted to the ICU under mechanical ventilation after an elective CABG with cardiopulmonary bypass, had a Glasgow Coma Scale > 11 after extubation, and a ratio of arterial oxygen partial pressure (Pao₂) to Fio₂ < 300 associated with a radiologic atelectasis score (RAS) ≥ 2. The initial blood gas sample for Pao₂/Fio₂ was collected before extubation during spontaneous ventilation. The routine chest radiograph taken on the same day (but before extubation) was considered for the calculation of RAS.

Patients who met the exclusion criteria used vasoconstrictor drugs in increasing doses throughout the last 2 hours or had a mean arterial blood pressure < 65 mm Hg; had presence of a tracheostomy, pre-existing lung disease with Global Initiative for Chronic Obstructive Lung Disease¹⁶ classification > 2, or pulmonary fibrosis; reoperation of this surgery; contraindication to the use of NIV; or refusal of the RM by the surgeon in charge.

Atelectasis was evaluated with the RAS—a score based on a chest radiograph made on the day that extubation was performed^{4,17}—according to the following classification:

- 0 = without atelectasis,
- 1 = line of atelectasis or discrete infiltration,
- 2 = partial atelectasis,
- 3 = lobar atelectasis, and
- 4 = bilateral lobar atelectasis.

Chest radiograph evaluations were performed by medical staff members who were not involved in the study and were thus blinded to the group allocation.

Randomization and Allocation

Patients eligible for the study were randomly assigned to the control group (CG) or recruitment group (RG) by simple randomization. Patients were not informed regarding the group to which they were allocated. Only the physiotherapy team, responsible for applying NIV therapy in the study, was aware of group allocation after randomization.

Interventions and Procedure

Patients from both groups received standard ICU care, with no difference between groups. The unit was a mixed ICU with a closed physician staff model and a nursing ratio of 1:1 or 1:2 that received postoperative patients and nonsurgical patients.

Both groups received physical therapy 3 or 4 times a day and incentive spirometry in all sessions after extubation. Mobilization was performed as soon as a patient was clinically stable, equally for both groups.

Orthostatism and gait were not performed, because in our unit patients do not leave the bed until drains are removed, which occurs at the day of ICU discharge.

The unit has a fast-track weaning program and decisions on extubation and ICU discharge are made by physicians. The ICU staff conducted mechanical ventilation and weaning processes for both groups until extubation. After extubation, both groups received a 30-minute NIV session 3 times a day until discharge from the ICU. NIV was applied outside of sleep and meal times and no aspiration events occurred.

NIV was applied with pressure support for volumes of 6 to 8 mL/kg and peripheral oxygen saturation was $\geq 95\%$ for both groups. In the CG, PEEP was maintained at 8 cm H₂O during the whole NIV session. The RG received RM during the NIV session with PEEP = 15 cm H₂O for 2 minutes, 20 cm H₂O for 2 minutes, and then returning to 8 cm H₂O for the remainder.

All patients were ventilated in SERVO-I (Maquet Critical Care AB, Solna, Sweden) and used the FitLife Total Face Mask (Philips Respironics, Murrysville, Pa) during NIV (Video 1).

Patients were monitored during the whole NIV session. The criteria to interrupt the RM were respiratory rate >35 breaths per minute, heart rate >120 bpm or <20 points from baseline, systolic blood pressure <90 mm Hg or >160 mm Hg, cardiac arrhythmia, or at the patient's request. When RM was interrupted, the medical staff would be called to check the patient in case any clinical instability occurred during or after the RM, such as barotrauma, respiratory instability, hemodynamic instability, or arrhythmia.

Before starting the physiotherapy session, patients could clear their doubts and were informed that they could interrupt the therapy at any time.

Outcomes

The main outcome of the study was a 10% improvement in Pao₂ and an improvement in RAS for the RG compared with the CG, between the extubation day and ICU discharge. We chose an improvement of 10% because we believed it would be clinically significant, and we reached this result in a pilot study that was conducted to calculate the sample size.

VIDEO 1. This is a simulation of the recruitment maneuver during noninvasive ventilation (NIV) in a healthy subject. For the recruitment group, positive end-expiratory pressure (PEEP) was increased from 8 cm H₂O to 15 cm H₂O and remained for 2 minutes. Patients were ventilated in Servo-I (Maquet Critical Care AB, Solna, Sweden). Pressure support level was set for tidal volume of 6 to 8 mL/kg and inspired oxygen fraction, for oxygen peripheral saturation $\geq 95\%$. After 2 minutes of PEEP = 15 cm H₂O, PEEP was increased to 20 cm H₂O. NIV was applied with the FitLife Total Face-mask (Philips Respironics, Murrysville, Pa). After 2 minutes of PEEP = 20 cm H₂O, PEEP was set back to 8 cm H₂O. Patient completed the 30 minutes in NIV. Video available at: [https://www.jtcvs.org/article/S0022-5223\(18\)31420-X/fulltext](https://www.jtcvs.org/article/S0022-5223(18)31420-X/fulltext).

The initial Pao₂ was collected on the day of extubation after removing the orotracheal tube, in room air for 2 minutes. Subsequently, arterial blood samples were collected every day and were used to regularly analyze Pao₂.

The secondary outcome of the study was RAS evaluated through daily chest radiographs by an ICU physician not related to the study. We used an ICU physician because it was feasible and more similar to the day-by-day routine of any ICU. The RAS improvement compared the chest radiograph from the day of ICU discharge to the day before extubation because the ICU conducts daily chest radiographs.

Safety was evaluated according to the rates of barotrauma, arrhythmia, and hemodynamic instability during or after RM with NIV.

Other secondary outcomes of the study were the reintubation rate, mortality rate, and length of stay in the ICU and hospital.

Statistical Analysis

To calculate size, we conducted a pilot study with 8 patients in the CG and 5 in the RG. The mean $\pm$ standard deviation improvement of Pao₂ in the CG was $22.1\% \pm 6.8\%$ compared with the RG's $33.7\% \pm 5.7\%$. Using the maximum standard deviation (6.8%), it was estimated that 14 patients were required in each group (28 total) to detect a mean difference of 10% Pao₂ improvement between the initial (after extubation) and final (at ICU discharge) periods using a *t* test with a 95% power and 5% significance level.

The results of the study were described by absolute and relative frequencies for categorical variables and mean and standard deviation for continuous variables.

TABLE 1. Baseline characteristics of the patients and intraoperative data

Variable	Control group (n = 16)	Recruitment group (n = 18)
Age (y)	63.8 $\pm$ 9.3	68.7 $\pm$ 8.5
Men	14/16 (87.5)	14/18 (77.8)
Weight (kg)	86 $\pm$ 13.2	81.9 $\pm$ 13.5
Body mass index	29.4 $\pm$ 3.4	27.9 $\pm$ 3.7
Hypertension	14/16 (87.5)	18/18 (100)
Diabetes mellitus	8/16 (50)	11/18 (61.1)
Dyslipidemia	13/16 (81.2)	15/18 (83.3)
Previous acute myocardial infarction	4/16 (25)	6/18 (33.3)
Renal replacement therapy	1/16 (6.2)	1/18 (5.6)
Smoking	4/16 (25)	4/18 (22.2)
Pulmonary disease*	1/16 (6.2)	2/18 (11.1)
Previous cardiac surgery	2/16 (12.5)	4/18 (22.2)
Left ventricular ejection fraction (%)	61.8 $\pm$ 10.3	62.7 $\pm$ 7.6
Acute Physiology and Chronic Health Evaluation 2 score	8.7 $\pm$ 2.5	9 $\pm$ 2.7
Simplified Acute Physiology 3 score	27.8 $\pm$ 5.9	28.1 $\pm$ 4.9
Length of mechanical ventilation (h)	9.5 $\pm$ 3.9	7.1 $\pm$ 3.4
Cardiopulmonary bypass time (min)	88.6 $\pm$ 21.9	84.2 $\pm$ 22.2
Number of grafts = 1	4/16 (25)	4/18 (22.3)
Number of grafts = 2	8/16 (50)	8/18 (44.4)
Number of grafts = 3	4/16 (25)	4/18 (22.2)
Number of grafts = 4	0/16 (0)	2/18 (11.1)

Values are presented as mean $\pm$ standard deviation or n (%). *Global Initiative for Chronic Obstructive Lung Disease classification < 2 .

Comparisons between the groups (CG and RG) were performed with a Student *t* test for the continuous variables. When the Shapiro-Wilk test did not show the residuals' normal distribution, the Mann-Whitney test was performed.

The distribution of Pao₂ over time between the groups was evaluated according to the linear mixed-effects model with a normal distribution and random effect of intercept and slope. The interaction with time (postoperative days) and group was used as a fixed parameter.

A significance level of 5% was set for all statistical tests employed in this study. The statistical analysis was performed using software R version 3.3.3 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

A total of 109 patients were considered for the study between February 2015 and March 2017, and 75 patients were not enrolled, of whom 63 did not meet inclusion criteria and 12 were eligible but were not enrolled due to reoperation (3 patients) and declining to participate (9 patients). The trial enrolled 34 participants: 16 assigned to the CG and 18 to the RG (Figure E1). All patients completed the study and were followed until hospital discharge or death. The groups were similar in relation to the baseline characteristics and intraoperative surgical data (Table 1).

Ventilator parameters during NIV were similar, with statistical difference only for pressure support. The mean pressure support for the CG was 8.3 ± 1.5 cm H₂O and 6.7 ± 1.5 cm H₂O for the RG ($P = .005$) (Table 2).

To measure the efficacy of the primary end point, the increase in Pao₂ was calculated based on the difference between the initial (after extubation) and final (ICU

discharge) periods, showing the RG's significant improvement compared with the CG. The mean increase in the difference of the CG's Pao₂ was $12.6\% \pm 6.8\%$ versus $23.3\% \pm 8.5\%$ for the RG ($P < .001$) (Table 3). Figure E2 shows the daily evolution of Pao₂ in the ICU of the 34 participating patients.

Regarding the safety outcomes, there was no arrhythmia, barotrauma, hemodynamic instability, or complications during or after NIV with or without RM in both groups. We did not find differences between the groups in terms of the length of stay in the ICU and hospital, and neither reintubation nor death occurred (Table 3).

The distribution of Pao₂ over time was compared between the groups until the second day, when all the patients were still in the ICU. It can be estimated (according to the linear mixed-effects model with a normal distribution and a random effect of slope and intercept) that the absolute difference in Pao₂ measure between groups on the second day was: 6.69 mm Hg (95% confidence interval [CI], 1.66–11.7 mm Hg) ($P = .009$), which is equivalent to an increase of 11.3% in the RG's average of Pao₂ compared with the CG's. See Table 4 and Figure 1.

The final RAS comparison was significant between the RG and CG ($P < .001$). Figure 2 shows that 94.4% of patients in the RG changed to an atelectasis score of 0, versus 12.5% of patients in the CG.

We did not collect the number of NIV sessions per patient; however, we know that patients underwent NIV 3 times a

TABLE 2. Ventilator settings during noninvasive ventilation and hemodynamic variables

Variable	Control group (n = 16)	Recruitment group (n = 18)	Standardized mean difference (95% confidence interval)	P value
Pressure support (cm H ₂ O)	8.3 ± 1.5 8.0 (8.0–8.5)	6.7 ± 1.5 6.0 (5.2–8.0)	0.96 (0.34 to 1.59)	.00*
Fio ₂ (%)	34.1 ± 4.2 35.0 (30.0–36.2)	32.5 ± 5.8 30.0 (30.0–40.0)	0.31 (–0.38 to 1.00)	.30*
Tidal volume/predicted (mL)	396.6 ± 47.1 412.0 (378.2–429.0)	396.4 ± 48.4 415.0 (367.5–430.0)	0.01 (–0.70 to 0.71)	.93*
Tidal volume/patient (mL)	445.6 ± 56.3 450.0 (427.5–480.0)	444.4 ± 65.5 445.0 (405.0–490.0)	0.02 (–0.68 to 0.72)	.95†
Respiratory rate (breaths/min)	17.3 ± 2 17.0 (16.0–18.2)	16.3 ± 2.5 16.0 (14.0–17.8)	0.42 (–0.27 to 1.11)	.11*
MAP (mm Hg)	80.6 ± 6.9 79.5 (75.8–82.8)	79.8 ± 7.5 80.0 (73.5–85.0)	0.12 (–0.59 to 0.83)	.73†
Heart rate (bpm)	$89.9 \pm 7.190.0$ (85.8–94.0)	86.0 ± 7.1 85.5 (81.0–90.0)	0.53 (–0.15 to 1.22)	.12†
SpO ₂ (%)	97.0 ± 1.4 97.0 (96.0–98.0)	97.8 ± 1.2 98.0 (97.0–99.0)	–0.61 (–1.29 to 0.08)	.07†

Values are presented as mean $\pm$ standard deviation or median (interquartile range). Fio₂, Fraction of inspired oxygen; MAP, mean arterial pressure; SpO₂, peripheral oxygen saturation. *Mann-Whitney test. †Student *t* test.

TABLE 3. Outcome analysis

Variable	Control group (n = 16)	Recruitment group (n = 18)	P value
Pao ₂ /Fio ₂ during MV	235.8 ± 23.2	233.9 ± 32	.84*
Oxygenation outcome			
Initial Pao ₂ at room air (mm Hg)	59.8 ± 4.9	59.8 ± 5.1	.96*
Final Pao ₂ at room air (mm Hg)†	67.2 ± 5.9	73.7 ± 7.1	.007*
Pao ₂ difference (%)	12.6 ± 6.8	23.3 ± 8.5	<.001*
Safety outcome			
Arrhythmia	0	0	NA
Barotrauma	0	0	NA
Hemodynamic instability	0	0	NA
Secondary outcomes			
Reintubation rate	0	0	NA
Death in hospital	0	0	NA
ICU length of stay (d)	2.5 (2.0-3.0)	2.0 (2.0-2.0)	.11‡
Hospital length of stay (d)	8.5 (7.0-9.0)	7.0 (7.0-8.0)	.16‡

Values are presented as mean ± standard deviation or median (interquartile range). Pao₂/Fio₂, Ratio of arterial oxygen partial pressure to fraction of inspired oxygen; MV, mechanical ventilation; Pao₂, partial pressure of arterial oxygen; NA, not applicable; ICU, intensive care unit. *Student *t* test. †Final value was the Pao₂ in the last day in the ICU. ‡Mann-Whitney test.

day. The length of ICU stay was 2.5 days (95% CI, 2.0-3.0 days) for the CG and 2.0 days (95% CI, 2.0-2.0 days) for the RG, with no difference between groups ($P = .11$).

Patients were followed until hospital discharge, and we observed a significant difference in the use of oxygen at discharge from the ICU, with oxygen being used by 14 patients in the CG (87.5%) and 4 patients in the RG (22.2%) ($P < .001$). The number of days of oxygen supplementation at the ward was less in the RG compared with CG ($P < .001$) (Table 5).

DISCUSSION

RM with NIV compared with only NIV after cardiac surgery resulted in improved oxygenation and less atelectasis during the ICU period. Patients in the RG also required fewer days of oxygen supplementation at the ward, and fewer patients in this group needed supplemental oxygen at ICU discharge.

As far as we know, this is the first study of the RM during NIV in cardiac postoperative patients and it showed an improvement in oxygenation and atelectasis safely. Previous studies used NIV not associated with RM or used the RM during invasive mechanical ventilation. In a study by Cammarota and colleagues,¹⁸ 24 patients underwent a PEEP increase from 10 cm H₂O to 25 cm H₂O for 8 seconds during NIV, with good tolerance and improvement of oxygenation and without hemodynamic instability. However, the study population consisted of patients with pneumonia, not patients who were in postoperative of cardiac surgery.

Studies on the RM in postoperative cardiac surgery under invasive mechanical ventilation have shown favorable results, with a significant improvement in oxygenation and without impairment of hemodynamic parameters.¹⁹⁻²¹ However, there are disagreements regarding the achievements of the RM. The recently published results of the Alveoli Recruitment for Acute Respiratory Distress Syndrome Trial²² did not recommend routinely performing RM and PEEP titration in patients with moderate acute respiratory distress syndrome due to an increase in the mortality rate.

However, RM in cardiac surgery seems to be helpful, according to Leme and colleagues.²³ They randomized 350 patients with hypoxemia after cardiac surgery to a moderate recruitment group ($n = 163$) and an intensive recruitment group ($n = 157$). Patients in the intensive recruitment group were submitted to RM with PEEP of 30 cm H₂O and then maintained at a PEEP of 13 cm H₂O. In the moderate recruitment group, the patients received sustained breaths in continuous positive airway pressure (CPAP) mode with PEEP of 20 cm H₂O, and then PEEP was set to 8 cm H₂O. After 4 hours, they received RM again and were weaned from the ventilator. The RM was safe and presented only a transient alteration of blood pressure during application, most evident in the intensive recruitment group. That study suggested that intensive RM would be more beneficial in cardiac postoperative patients; however, the RM was performed while patients were under invasive mechanical ventilation, which requires sedation. Our study has shown some good results for the RM during NIV, so this could be a strategy to improve pulmonary function after a patient is out of invasive mechanical ventilation.

It has been suggested that intermittent postoperative NIV for up to 3 hours should be part of standard clinical practice despite the paucity of evidence. In their study, Al Jaaly and colleagues²⁴ conducted a trial introducing bilevel NIV in the postoperative routine for patients undergoing CABG and concluded that patients who received NIV after surgery were fit for discharge 1 day earlier than were control patients.

In a study by Lopes and colleagues,²⁵ 100 postcardiac surgery patients were randomly assigned to an NIV group, with 50 patients who received NIV with PEEP of 5 cm H₂O after extubation for at least 30 minutes and presented improved oxygenation. The control group with the other 50 patients only used oxygen catheter.

Pasquina and colleagues⁴ included 150 postcardiac surgery patients with RAS ≥ 2 and who were randomized to a CPAP group or noninvasive positive-pressure ventilation group. Both received PEEP of 5 cm H₂O and performed the therapy 4 times a day for 30 minutes. The noninvasive positive-pressure ventilation group presented a significant reduction in the RAS in relation to the CPAP group, but with no significant difference in gas exchange. Despite

TABLE 4. Arterial oxygen partial pressure (P_{aO_2}) value at the second intensive care unit (ICU) day for control group and recruitment groups

Variable	Control group	Recruitment group
P_{aO_2} at room air (mm Hg), postoperative day 1	59.8 $\pm$ 4.9 (n = 16)	59.8 $\pm$ 5.1 (n = 18)
P_{aO_2} at room air (mm Hg), postoperative day 2*	65.8 $\pm$ 6.7 (n = 16)	72.3 $\pm$ 8.1 (n = 18)
P_{aO_2} at room air (mm Hg), postoperative day 3	64.9 $\pm$ 6.2 (n = 8)	67.5 $\pm$ 11.8 (n = 4)
P_{aO_2} at room air (mm Hg), postoperative day 4	58.9 $\pm$ 3.1 (n = 2)	52.7 $\pm$ NA (n = 1)

Values are presented as mean $\pm$ standard deviation. P_{aO_2} , Partial pressure of arterial oxygen; NA, not applicable. *Absolute difference P_{aO_2} between groups on the second day was 6.69 (95% confidence interval, 1.66-11.7) ($P = .009$).

the improvement in the atelectasis score, 149 of 150 patients were discharged from the ICU with persistent atelectasis.

Our study showed RAS improvement in both groups with a significant difference for the RG: 94.4% of patients' RAS was 0 (ie, without atelectasis) versus 12.5% in the CG. In addition to the radiologic improvement, we obtained a significant result in the RG's oxygenation compared with the CG. We believe we obtained such results by using a higher PEEP and RM.

We confirmed the oxygenation enhancement found by Zarbock and colleagues,²⁶ in whose study postoperative

cardiac surgery patients received NIV and presented an improvement in oxygenation. However, the duration of the NIV therapy was shorter in our study, in which patients performed the therapy for 30 minutes 3 times a day until discharged from the ICU, whereas in the study by Zarbock and colleagues,²⁶ the patients in the protocol group used at least 6 hours of preventive CPAP after extubation. Reducing the duration of NIV therapy could be beneficial because longer periods of NIV may be uncomfortable and reduce patient's adherence to therapy.

In a multicenter study, Stephan and colleagues²⁷ assessed the noninferiority of high-flow nasal cannula versus NIV. The primary outcome was treatment failure. High-flow nasal cannula was not inferior to NIV, and did not improve oxygenation, which was the primary outcome in our study. In the study by Stephan and colleagues,²⁷ NIV was applied with low levels of PEEP (4 cm H_2O) and there was no use of RM. However, although CABG was the larger group of patients, the study included other types of surgery.

Regarding safety issues, in a study by De Santo and colleagues,²⁸ a safety evaluation in the implementation of NIV in postcardiac surgery patients with respiratory failure was performed. It prevented intubation in 74.4% of patients with an approximately safety of 97.7%.

In our study, no hemodynamic changes occurred during or after RM with NIV. It should take into account that the recruitment was performed after extubation, when a patient had already passed the critical first hours of ICU admission and was conscious and stable.

FIGURE 1. The evolution of partial pressure of arterial oxygen (P_{aO_2}) in the postoperative period of coronary artery bypass grafting in the control and recruitment group in the intensive care unit. Means and confidence intervals (CIs) estimated by linear mixed-effects model with random intercept and slope, considering fixed effects postoperative days as the continuous variable interacting with group. Group mean difference at day 2 was 6.69; 95% CI, 1.66-11.7; $P = .009$.

FIGURE 2. The comparison of the baseline (admission) and final (intensive care unit [ICU] discharge) radiological atelectasis score between control group and recruitment group. χ^2 test $P = .999$ at baseline and $P < .001$ at ICU discharge.

Westerdahl and colleagues²⁹ evaluated pulmonary function and quality of life in postoperative patients 1 year after cardiac surgery and concluded that measurements of static lung function and dynamic lung volume were not fully restored. In the past decade, there has been an improvement in the 30-day mortality rate of postoperative cardiac surgery patients, but the 1-year mortality has remained unchanged.³⁰

Finally, no patient received RM during invasive mechanical ventilation in the ICU or during the intraoperative period.

Our findings suggest that by minimizing atelectasis during the intrahospital phase, pulmonary function might have a positive influence on a patient's long-term health because

atelectasis and ventilatory insufficiency are among the major causes of postoperative morbidity. Furthermore, patients in the RG used less supplemental oxygen at ICU discharge and during hospitalization, which may represent a cost reduction in this group.

Our study showed the efficacy of the RM with NIV when compared with the CG, and we considered it safe to apply to postoperative CABG patients because no patient had hemodynamic instability or complications during or after the RM. However, we emphasize that RM must be carried out by a skilled team and will require multicenter studies that corroborate this safety. In our study, there was no reintubation or death in either group.

Limitations of the Study

There are some limitations to this study. Among them is the fact that it was performed in a single center with a small number of patients. In addition, we only included postoperative CABG patients who underwent cardiopulmonary bypass, and we do not know whether the results can be replicated in other surgeries, cardiac or otherwise. Only the physiotherapists were informed of patient group allocations; however, we cannot guarantee that the patients and the ICU team were blind to the intervention. During the RM, it was necessary to hold the full-face mask against the patient's face to prevent air leakage; we cannot guarantee that all participants in the RG reached the PEEP level established for a given time. Patients were followed until hospital discharge; we do not have readmission data and long-term follow-up data and we did not record the exact number of NIV treatments per patient. Finally, because

TABLE 5. Number of patients using oxygen at intensive care unit (ICU) discharge and number of days using supplemental oxygen on the ward

Variable	Control group (n = 16)	Recruitment group (n = 18)	P value
With supplemental oxygen at ICU discharge	14/16 (87.5)	4/18 (22.2)	<.001*
Days with supplemental oxygen on the ward			<.001*
0	2/16 (12.5)	14/18 (77.8)	
1	2/16 (12.5)	3/18 (16.7)	
2	8/16 (50)	0/18 (0)	
3	2/16 (12.5)	0/18 (0)	
4	2/16 (12.5)	0/18 (0)	
12	0/16 (0)	1/18 (5.6)	

Values are presented as n (%). * χ^2 test.

the sample size calculation was based on oxygenation improvement, more patients would be necessary for the secondary outcomes.

CONCLUSIONS

The level of oxygenation improved significantly in the RG compared with the CG. The atelectasis score showed improvement in both groups, with a substantial difference between them for the RG (94.4% of patients without atelectasis). No hemodynamic instability, barotrauma, arrhythmia, extubation failure, or death occurred in either group.

The use of RM during NIV could be a strategy to improve the pulmonary function of patients with hypoxemia following CABG with cardiopulmonary bypass once a patient is out of invasive mechanical ventilation. Future research should be conducted to better evaluate other outcomes, such as reintubation rate, length of stay, and safety.

Conflicts of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: noninvasive ventilation, myocardial revascularization, coronary artery bypass grafting, pulmonary atelectasis, hypoxia, positive end-expiratory pressure, cardiopulmonary bypass

FIGURE E1. Flowchart of study patients after coronary artery bypass grafting. Pao_2/FiO_2 , Ratio of arterial oxygen partial pressure to fractional inspired oxygen; *CPB*, cardiopulmonary bypass; *RAS*, radiological atelectasis score; *NIV*, noninvasive ventilation.

FIGURE E2. Individual evolution of partial pressure of arterial oxygen (Pao_2) in study patients after undergoing extubation in the intensive care unit.