Pulmonary Effects of Noninvasive Ventilation Combined with the Recruitment Maneuver After Cardiac Surgery

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BACKGROUND: The aim of our study was to evaluate the pulmonary effects of noninvasive ventilation (NIV) with or without recruitment maneuver (RM) after open heart surgery.

METHODS: One-hundred patients undergoing coronary artery bypass surgery were randomized into four groups after the operation: 1) RM with sustained inflation during mechanical ventilation postoperatively (RM group, $n = 25$); 2) RM combined with NIV applied for 1/2-h periods every 6 h in the first postoperative day after tracheal extubation (RM-NIV group, $n = 25$); 3) NIV after tracheal extubation (NIV group, $n = 25$); and 4) a control group consisting of patients receiving neither RM nor NIV (control group, $n = 25$). Pulmonary function tests, oxygenation index, and atelectasis on chest radiograph were evaluated and compared among the groups.

RESULTS: RM provided higher arterial oxygen levels during mechanical ventilation and after tracheal extubation compared to other interventions. Oxygenation was better in the RM-NIV and NIV groups than in the control group ($P = 0.02$ and $P = 0.008$, respectively) at the end of the study. The postoperative atelectasis score of the control group (median: 1) was higher than those of the RM (1; $P = 0.03$), RM-NIV (0; $P < 0.01$) and NIV (0; $P < 0.01$) groups. Pulmonary function of the NIV groups on postoperative day 2 was better than in the other groups, whereas the tests were similar among the groups on postoperative day 7.

CONCLUSIONS: NIV associated with RM provided better oxygenation both during and after the mechanical ventilation period. NIV either alone or in combination with RM provided lower atelectasis scores and better early pulmonary function tests compared to the control group, without a significant difference regarding the duration of mechanical ventilation, intensive care unit stay, and the length of hospitalization. NIV combined with RM is recommended after open heart surgery to prevent postoperative atelectasis and hypoxemia.

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Atelectasis is frequently observed after open heart surgery.[1] In addition to the effects of general anesthesia, cardiopulmonary bypass (CPB) may also contribute to postoperative atelectasis.[2,3] Cessation of pulmonary circulation and ventilation during extracorporeal circulation may lead to structural alterations of the lungs.[4] Pleural opening, phrenic nerve damage, pain, and use of mammary arteries are other contributing factors. If atelectasis is persistent or progressive, it may lead to hypoxemia, increased shunt fraction, increased work of breathing, and pulmonary complications in the postoperative period.[5]

Chest physiotherapy, voluntary deep breaths, incentive spirometry, high positive end-expiratory pressure (PEEP), alveolar recruitment maneuvers (RM) during mechanical ventilation, and noninvasive ventilation (NIV) are the methods used to prevent postoperative atelectasis.[6] RM are applied using sustained inflation to achieve alveolar recruitment after open heart surgery.[7] However, lung-expanding and oxygenation-improving effects of RM do not extend beyond the mechanical ventilation (extubation) period.[8]

NIV is successfully used in different types of respiratory failure, including cardiogenic pulmonary edema, acute excacerbations of chronic obstructive pulmonary disease, pneumonia, immunocompromised patients, and postoperative and hypoxemic respiratory failure.[9] NIV has been found to be as effective as conventional mechanical ventilation in improving gas exchange in patients with respiratory failure. It has also been shown to be associated with a shorter stay in the intensive care unit (ICU) compared to invasive ventilation.[10] Postoperative respiratory failure due to atelectasis has also been treated with NIV.[10]

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In this study, we evaluated the effects of three interventions on oxygenation and atelectasis after adult open heart surgery: 1) NIV applied after the extubation period, 2) RM applied during mechanical ventilation, and 3) NIV combined with RM during the mechanical ventilation period. We hypothetized that NIV combined with RM would provide better oxygenation and less atelectasis in the early postoperative period compared to NIV or RM alone.

METHODS

After Ethics Committee approval and written informed consent had been obtained, 100 patients undergoing coronary artery bypass (CABG) operations with CPB were prospectively enrolled in the study using a computer-generated table. Exclusion criteria included preexisting pulmonary disease, age >65 years, ejection fraction <40%, obesity (Body Mass Index >30 kg/m^2), and mean arterial blood pressure below 60 mm Hg during the RMs. The smokers who were enrolled had quit smoking 2 months before the surgery.

Total IV anesthesia was used in all patients. Mechanical ventilation was continued with a 40% oxygen–air mixture. All patients were intubated with a cuffed endotracheal tube and ventilated with volume-controlled ventilation (Servo 900C; Siemens, Solna, Sweden) which consisted of a tidal volume of 7 mL/kg on 5 cm H_2O PEEP. The respiratory rate was adjusted to between 12 and 14 breaths per minute to achieve a $Paco_2$ of 35 to 45 mm Hg and arterial pH within the physiologic range. The inspiratory/expiratory ratio was 1:2.

PEEP at a level of 3 to 5 cm H_2O with 40% oxygen in air was applied during the CPB period. Before discontinuation of CPB, lungs were manually inflated until visible atelectasis disappeared. Ventilation was started with a F_{IO_2} of 0.6, and reduced 15 minutes later to 0.4. Red blood cell concentrates were transfused to achieve a hemoglobin level of about 9 to 10 g dL^{-1} after CPB. The left internal thoracic artery was used and the left pleura was routinely opened in all patients. All patients were transferred to the ICU under deep sedation with propofol infusion on volume-controlled mechanical ventilation using the baseline ventilatory variables. Continuous analgesia was used with IV morphine sulfate. All patients had one mediastinal and one left pleural drain. None of the patients received inotropic drugs. Nitroglycerin was infused at a range of 0.5 to 1.5 micg kg^{-1} min^{-1} for 24 h postoperatively.

In the ICU, patients were randomized into four groups using a closed envelope system: 1) RM applied during mechanical ventilation combined with intermittent NIV after extubation (RM-NIV group, $n = 25$); 2) NIV after extubation (NIV group, $n = 25$); 3) RM during mechanical ventilation with sustained inflation and decremental PEEP without other intervention after the extubation period (RM group, $n = 25$); and 4) controls, receiving neither RM nor NIV during the study, and 5 cm H_2O PEEP during the mechanical ventilation period (CNT group, $n = 25$).

In the RM group, as soon as hemodynamic stability had been achieved (defined as systolic blood pressure >105 mm Hg, central venous pressure equal to baseline value or cessation of systemic blood pressure fluctuations with respiration, heart rate <100) and after administration of a nondepolarizing neuromuscular blocking drug, 40 cm H_2O peak inspiratory pressure was applied for 30 s using sustained inflation (continuous positive airway pressure [CPAP] mode) at an F_{IO_2} value of 40%, then pressure-controlled ventilation was begun using baseline respiratory frequency, 20 cm H_2O peak inspiratory pressure, and a PEEP value of 20 cm H_2O. The PEEP was decreased in 1 to 2 cm H_2O steps every 5 minutes until the lowest PEEP level above 5 cm H_2O providing the best Pao_2 had been achieved. At the end of the maneuver, ventilation was reinstituted with baseline ventilatory variables (volume-controlled ventilation) with the additional optimal PEEP. An F_{IO_2} value of 40% was used during determination of optimal PEEP in the RM group over a 25 to 30-minute period. The RM was repeated after PEEP titration to prevent derecruitment.

In the NIV group, NIV was used by a facemask for 1-h periods, beginning 1/2 h after the extubation, every 6 h throughout the first 24 h using pressure support ventilation (PSV) mode. Inspiratory positive airway pressure was adjusted to about 10 cm H_2O to achieve a tidal volume of 8 mL/kg, and 5 cm H_2O expiratory positive airway pressure, F_{IO_2} 0.4, was used during NIV. In the NIV combined with RM group, RM was used according to the protocol described for the RM group during the mechanical ventilation, then NIV was applied by a facemask after the extubation, as previously described.

In the CNT group, 5 cm H_2O PEEP was continued during the mechanical ventilation period after the randomization, and only chest physiotherapy was used after extubation. The oxygen concentration was set at 40% during the mechanical ventilation period in the ICU. All patients received rocuronium before the RM, and a closed suction system was used until the extubation. The patients were not disconnected from the ventilator during the mechanical ventilation period. Volume-controlled mode was used for the first 4 h after the maneuvers, and then the ventilation mode was switched to PSV. All patients were extubated according to the criteria defined by Ely et al.,[11] while ventilating with an F_{IO_2} of 0.4. All patients received oxygen via a venturi mask at a F_{IO_2} value of 0.5 after the extubation period. All patients were transferred from the ICU to a surgical acute care ward. None of the patients required reintubation and none died during the study period. Postextubation, all patients

Table 1. Demographic and Clinical Data of the Patients

	Group RM $n = 25$	Group RM-NIV $n = 25$	Group NIV $n = 25$	Group CNT $n = 25$
Gender [M/F]	20/5	18/7	21/4	22/3
Age [yr]	52 ± 9	57 ± 8	58 ± 6	57 ± 7
Weight [kg]	77 ± 10	80 ± 7	79 ± 9	76 ± 14
ACC time [min]	40 ± 13	45 ± 4	48 ± 14	43 ± 9
CPB time [min]	77 ± 32	86 ± 9	91 ± 25	70 ± 18
MVD [h]	6 ± 1.5	6.5 ± 1.4	6.7 ± 1	6 ± 0.4
ICU stay [h]	45 ± 7	46 ± 3	49 ± 9	47 ± 9
Hospitalization [d]	7.3 ± 1.5	7.7 ± 1	7.9 ± 1	7.5 ± 1

RM = recruitment maneuver; NIV = noninvasive ventilation; CPB = cardiopulmonary bypass; ACC = aortic cross-clamp; MVD = mechanical ventilation duration; ICU = intensive care unit.

received conventional chest physiotherapy, including coughing exercise, mobilization, and incentive spirometry.

To determine Pao_2/FIo_2 ratio and arterial partial carbon dioxide pressure, arterial blood was drawn and analyzed (EML 505, Radiometer, Copenhagen, Denmark) at 5 time points: after arrival in the ICU, after the RM (or at the corresponding time during mechanical ventilation in the other groups), and at 1/2 h, 12 h and 24 h after the extubation.

Vital capacity and forced expiratory volume in 1 s (FEV_1) were measured in semi-sitting position (Vitalograph Spirometer, Lameris, The Netherlands) before the operation and on postoperative days 2 and 7. The mean value of three consecutive measurements was recorded by the same respiratory therapist, who was blinded to the groups. The results were evaluated by a respiratory therapist.

Chest radiographs were taken in sitting position and during inspiration on postoperative day 1, and evaluated by a radiologist blinded to the groups in order to differentiate the pleural effusion from atelectasis and to determine the amount of atelectasis. Atelectasis was graded as 0: no atelectasis; 1: partial atelectasis of the left lower lobe; 2: total atelectasis of the left lower lobe; and 3: total atelectasis of the left lower lobe and other atelectatic lung regions.[12]

All values are reported as mean (±SD) except for the median values of atelectasis scores, fluid balance, chest tube drainage, and amount of transfusion, which were compared by the Kruskal-Wallis test. Distribution of the variables (P/F ratio) was evaluated with the Kolmogorov-Smirnov test of normality, which yielded a P value = 0.8. Therefore, P/F ratios were compared using parametric tests. Two-way analysis of variance and *post hoc* Tukey tests were used to compare means among the groups. Repeated measures of analysis of variance was used for within-group comparisons. This study was designed to have an 80% power to detect a difference of 100 between the mean Pao_2/FIo_2 ratios of the control and study group patients, with a significance level of (α) 0.05. A P value <0.05 was considered significant. Unistat version 5.0 for Windows (Unistat, London, UK) was used for the statistical analysis.

RESULTS

Demographic and operative group data were not statistically different, and none of the patients required reintubation during the study period. Duration of ICU stay, hospitalization, and mechanical ventilation were also similar among the groups (Table 1). All patients were extubated within 6 h after the interventions.

The Pao_2/FIo_2 ratios of the RM and RM-NIV groups were significantly higher than those of the CNT group during the mechanical ventilation period ($P = 0.01$ and $P = 0.03$, respectively) and after extubation ($P = 0.01$ and $P = 0.04$, respectively). Twenty-four h after extubation, the Pao_2/FIo_2 ratios of the groups RM-NIV and NIV were significantly higher than that of the CNT group ($P = 0.02$ and $P = 0.008$, respectively). The Pao_2/FIo_2 ratio of the RM group increased significantly from baseline until the extubation period, then returned to baseline values. However, increased oxygenation extended to the 24-h follow-up period only in the RM-NIV group (Fig. 1). PEEP values during mechanical ventilation were significantly higher in the RM-NIV and RM groups (10.3 ± 1 and 9 ± 1 mm Hg, respectively) compared to the NIV (5 ± 1 mm Hg; $P < 0.05$) and CNT (5 ± 1 mm Hg; $P < 0.05$) groups. Partial arterial CO_2 pressures

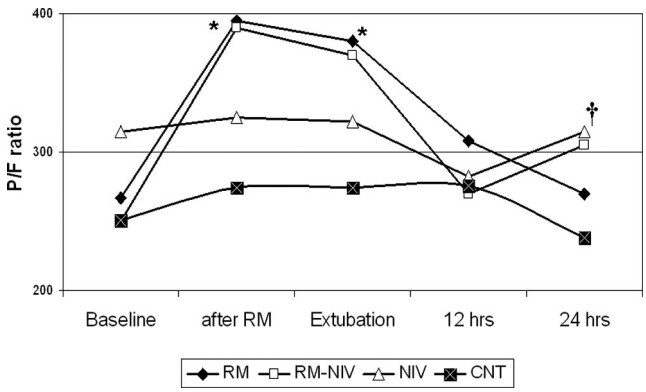

Figure 1. Pao_2/FIo_2 ratios of the groups during the study period. *Increased Pao_2/FIo_2 ratio of RM and RM-NIV groups compared to CNT group ($P < 0.05$). †Increased Pao_2/FIo_2 ratio of RM-NIV and NIV groups compared to CNT group ($P < 0.05$). NIV, noninvasive ventilation; RM, recruitment maneuver; CNT, control group.

Table 2. Partial Arterial CO_2 Pressure of the Groups

	Group RM $n = 25$	Group RM-NIV $n = 25$	Group NIV $n = 25$	Group CNT $n = 25$
Baseline	38 ± 7	42 ± 8	39 ± 11	41 ± 10
After RM	36 ± 5	38 ± 6	43 ± 6	41 ± 8
Following extubation	38 ± 7	39 ± 6	41 ± 7	40 ± 6
12 h after extubation	40 ± 6	38 ± 5	39 ± 8	40 ± 9
24 h after extubation	40 ± 7	38 ± 6	41 ± 6	41 ± 8

RM = recruitment maneuver; NIV = noninvasive ventilation; Pco_2, = partial arterial carbon dioxide pressure; CNT = control.

were identical among the groups throughout the study period (Table 2).

Median total operative fluid balance (850 mL in the RM group, 550 mL in the RM-NIV group, 660 mL in the NIV group, and 775 mL in the CNT group) and median red blood cell concentrate transfusion (2 U in RM, 2 U in RM-NIV, 2 U in NIV, 2 U in CNT) were not different among the groups. Total median chest tube drainage was 950 mL in the RM group, 825 mL in the RM-NIV group, 900 mL in the NIV group, and 900 mL in the CNT group.

Vital capacity and FEV_1 were identical among the groups preoperatively (Table 3), but significantly higher in both NIV groups compared to the CNT group on postoperative day 2. The variables were found to be identical among the groups on postoperative day 7.

The atelectasis score of the CNT group (median 1, range, 0–3) on postoperative day 1 was higher than those of the RM (median 1, range, 0–2; $P < 0.01$), RM-NIV (median 0, range, 0–1; $P < 0.01$) and NIV (median 0, range, 0–1; $P < 0.01$) groups. The number of patients with grade 2 atelectasis was 6 in. the RM group and 5 in the CNT group. None of the patients in either NIV group had grade 2 or 3 atelectasis. None of the patients in the RM group had grade 3 atelectasis (total atelectasis of the left lower lobe and other atelectatic lung regions) on the chest radiograph. Two patients in the CNT group had grade 3 atelectasis (Fig. 2). None of the patients showed evidence of pneumothorax.

DISCUSSION

The main findings of this study were that mechanical NIV combined with RM improved oxygenation during the perioperative period, and NIV either applied alone or combined with RM resulted in better early postoperative pulmonary function tests and less atelectasis without an effect on the duration of hospitalization and mechanical ventilation.

Patients usually suffer from atelectasis after open heart surgery. The incidence of atelectasis in the first postoperative days of CABG operations has been found to be 87.7%.[12] Although it decreases with time, the incidence has been shown to be high (30.4%) on the 6th postoperative day.[13] Atelectasis has been shown to be correlated with impaired gas exchange and increased shunt fraction, and therefore with reduced arterial Po_2 in the postoperative period.[14] Increased extravascular lung water and further collapse of the lung tissue may aggravate the shunt.[15] Pulmonary function tests obtained 6 days after CABG surgery have revealed a 26% decrease in FEV_1 and forced vital capacity in patients with a normal chest radiograph. The reduction reached 34% to 42% when atelectasis was present.

Atelectatic lungs have been shown to be re-opened using high inspiratory pressures and kept open with high levels of PEEP.[16–18] Peak end-inspiratory pressures of about 35 to 40 cm H_2O have been shown to provide lung recruitment.[19] RMs were generally thought to be well tolerated; however, several studies have revealed

Table 3. Preoperative and Postoperative Pulmonary Function Tests

	Group RM $n = 25$	Group RM-NIV $n = 25$	Group NIV $n = 25$	Group CNT $n = 25$
VC (L)				
Preoperative	3.9 ± 0.6	3.8 ± 0.5	3.6 ± 0.4	3.6 ± 0.6
POD 2	2.5 ± 0.4	2.8 ± 0.3*	2.8 ± 0.4*	2.4 ± 0.4
Decrease %	36	26.4	22.3	33.4
POD 7	2.8 ± 0.5	2.7 ± 0.6	2.6 ± 0.5	2.5 ± 0.5
Decrease %	28.3	29	28	31
FEV_1 (L/s)				
Preoperative	3.2 ± 0.6	3.4 ± 0.6	3.1 ± 0.4	3.1 ± 0.4
POD 2	2.2 ± 0.4	2.8 ± 0.7*†	2.6 ± 0.5*†	2.0 ± 0.4
Decrease %	31	18	17	35.5
POD 7	2.4 ± 0.6	2.5 ± 0.7	2.4 ± 0.5	2.1 ± 0.5
Decrease %	25	26.5	22.6	32.3

RM = recruitment maneuver; NIV = noninvasive ventilation; CNT = control group; POD = postoperative day; VC = vital capacity; FEV_1 = forced expiratory volume in 1 s.

* Significantly higher values of both NIV groups compared to CNT group ($P < 0.05$).

† Significantly higher values of both NIV groups compared to RM group ($P < 0.05$).

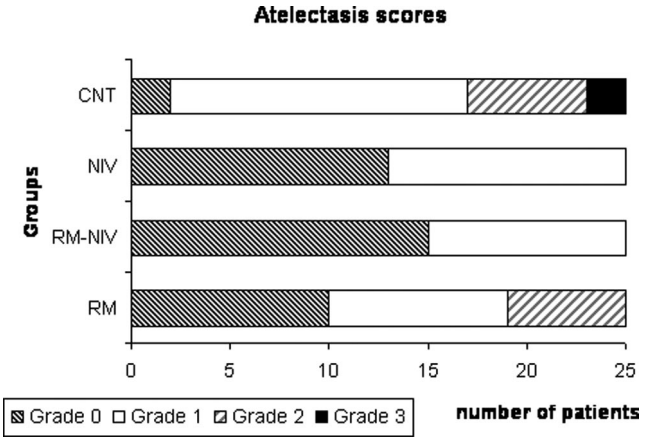

Figure 2. Radiologic atelectasis grades of the patients in each group according to chest radiograph. *Significantly higher median atelectasis score of the CNT group compared to RM, RM-NIV, and NIV groups ($P < 0.05$). Grade 0 = ▧; Grade 1 = □; Grade 2 = ▨; Grade 3 = ■.

that sustained inflation may reduce cardiac output and left ventricular end-diastolic area in hemodynamically stable patients after cardiac surgery and in experimental models.[20–22] Furthermore, the effects of RMs on oxygenation do not extend beyond the mechanical ventilation period.[7] However, in one study, RM performed after anesthesia induction was shown to provide improved functional residual capacity (FRC) extending beyond the extubation period after open heart surgery.[23]

Voluntary deep breaths and incentive spirometry are used to prevent atelectasis, and NIV is used to both prevent and treat atelectasis in the postoperative period.[6] NIV by means of CPAP or PSV has been shown to reduce venous admixture and restrictive lung pattern after adult open heart surgery.[6] CPAP can restore decreased FRC and prevent atelectasis and hypoxemia by increasing intrathoracic pressure. The result is decreased work of breathing.[24]

Other studies have shown that NIV using CPAP prevents postoperative atelectasis with partial efficacy after cardiac and abdominal surgery.[25,26] NIV with PSV seems to provide greater patient comfort than CPAP due to better alveolar opening and a decrease in work of breathing.[6,27,28] Furthermore, NIV with PSV is also superior to CPAP regarding the radiological improvement of atelectasis after open heart surgery.[29] However, this finding is not associated with other clinical benefits, such as improved oxygenation and pulmonary function tests and a short ICU stay. In the aforementioned study, the authors applied NIV 4 times a day, for 15 min in each session, which might be insufficient to open up all the atelectatic regions.

Prophylactic NIV with continuous nasal CPAP at airway pressures of 10 cm H_2O was found to reduce pulmonary morbidity and length of hospitalization after thoracoabdominal aortic aneurysm surgery, compared to an intermittent technique which was applied at 4-h intervals and lasted for 10 minutes.[30] In this study, the authors recommended prophylactic use of continuous nasal CPAP as a preventive measure against postoperative atelectasis because it is a well-tolerated and simple method for improving pulmonary function.

Early application of NIV in high-risk patients is recommended, because a decrease in FRC and deterioration of pulmonary function develop rapidly after extubation.[14] The reason for the intermittent NIV application in our study was to avoid gastric distention, restricted oral intake, nausea, and vomiting. The positive airway pressure value is of great importance during NIV. A study has revealed that only airway pressures of about 10 cm H_2O applied by a CPAP mask are effective in avoiding the derecruitment of lung areas.[31] This airway pressure provided a stable hemodynamic status throughout the NIV period in our study. Other studies have shown that target blood gas levels have been achieved at inspiratory and expiratory pressure levels of 8 and 4 cm H_2O, respectively, in most cases.[32,33] However, higher inspiratory pressure levels are required after abdominal surgery.[34]

Early treatment with CPAP has been shown to reduce the need for intubation, ICU length of stay, and the incidence of pneumonia, and sepsis in patients who develop acute hypoxemia after elective major abdominal surgery.[35] Prophylactic nasal CPAP application has been proven to reduce the incidence of major postoperative pulmonary complications and to shorten the length of hospitalization after thoracoabdominal vascular surgery.[30] There are no such data for patients undergoing open heart surgery. NIV has improved radiological atelectasis scores after cardiac surgery but, as the method lacks other clinical benefits, such as better oxygenation and pulmonary function and reduced length of stay, its clinical value is still being debated.[29] In clinical practice either NIV or RM is used to prevent or treat atelectasis and hypoxemia after open heart surgery.

Study Limitations

Evaluating atelectasis by means of chest radiograph instead of computed tomography or end-expiratory lung volumes is a major limitation of our study. However, it has been reported that it could be difficult to distinguish the pleural fluid from atelectasis after cardiac surgery even with thorax computed tomography.[3] The small number of patients participating in our study may have interfered with the outcome data, such as length of hospitalization and ICU stay. Another limitation of our study may be the low PEEP levels (5 cm H_2O) used during NIV to guarantee the hemodynamic stability. This was a preventive study rather than being a therapeutic intervention. A study in selected patients with postoperative atelectasis or low FRC would have given a different clinical outcome. Furthermore, using continuous instead of intermittent NIV would have yielded a different outcome.

In our study, the combination of RM and NIV resulted in improved postoperative oxygenation, pulmonary function tests, and atelectasis scores compared to the control group. These results were similar to those of NIV alone. The only benefit of the RM-NIV combination over the NIV method was better oxygenation obtained during the mechanical ventilation period. Prophylactic use of NIV either alone or in combination with RM after open heart surgery, has no effect on the duration of mechanical ventilation, ICU stay, or hospitalization period. Therefore, in light of the current study, we cannot see a justification for the routine use of RM combined with NIV after open heart surgery to prevent atelectasis and to achieve a better clinical outcome.

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