

Noninvasive Mechanical Ventilation in Patients with Acute Respiratory Failure after Cardiac Surgery

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ABSTRACT

Objective: To evaluate the feasibility and outcomes of protocol-driven noninvasive mechanical ventilation in patients with acute respiratory failure (ARF) after cardiac surgery.

Methods: From 2001 to 2004, a total of 2428 cardiac surgery patients admitted to our intensive care unit were observed. After exclusion of patients who received tracheostomy or were discharged while still on mechanical ventilation, 2261 patients with spontaneous breathing were further evaluated for ARF. Patients diagnosed with ARF were treated with intermittent noninvasive mechanical ventilation (NIV) if possible. Risk factors for the development of postoperative ARF as well as outcomes in patients with and without ARF were analyzed.

Results: In 2261 spontaneously breathing postoperative cardiac surgical patients after primarily successful extubation, 799 patients (35%) were diagnosed with ARF. Fifty-six patients (7%) did not tolerate NIV treatment. In 743 patients (33%) intermittent NIV was performed. In patients with ARF, ejection fraction was lower, combined cardiac surgical procedures were more frequent, postoperative mechanical ventilation time was longer, and the severity of illness score (SAPS II) was higher ($P < .05$). The duration of catecholamine support was longer, and the transfusion rate was higher in the NIV group ($P < .05$); however, mortality did not differ between patients with ARF treated by NIV and patients without ARF.

Conclusion: Our study demonstrates the feasibility of NIV in patients after cardiac surgery. These results might suggest that NIV should be considered as first-line ventilatory support in ARF after cardiac surgery. A large randomized trial is warranted to confirm these findings.

INTRODUCTION

Acute respiratory failure (ARF) is a common clinical problem after cardiothoracic surgery, contributing significantly to morbidity and mortality. There are several possible causes for

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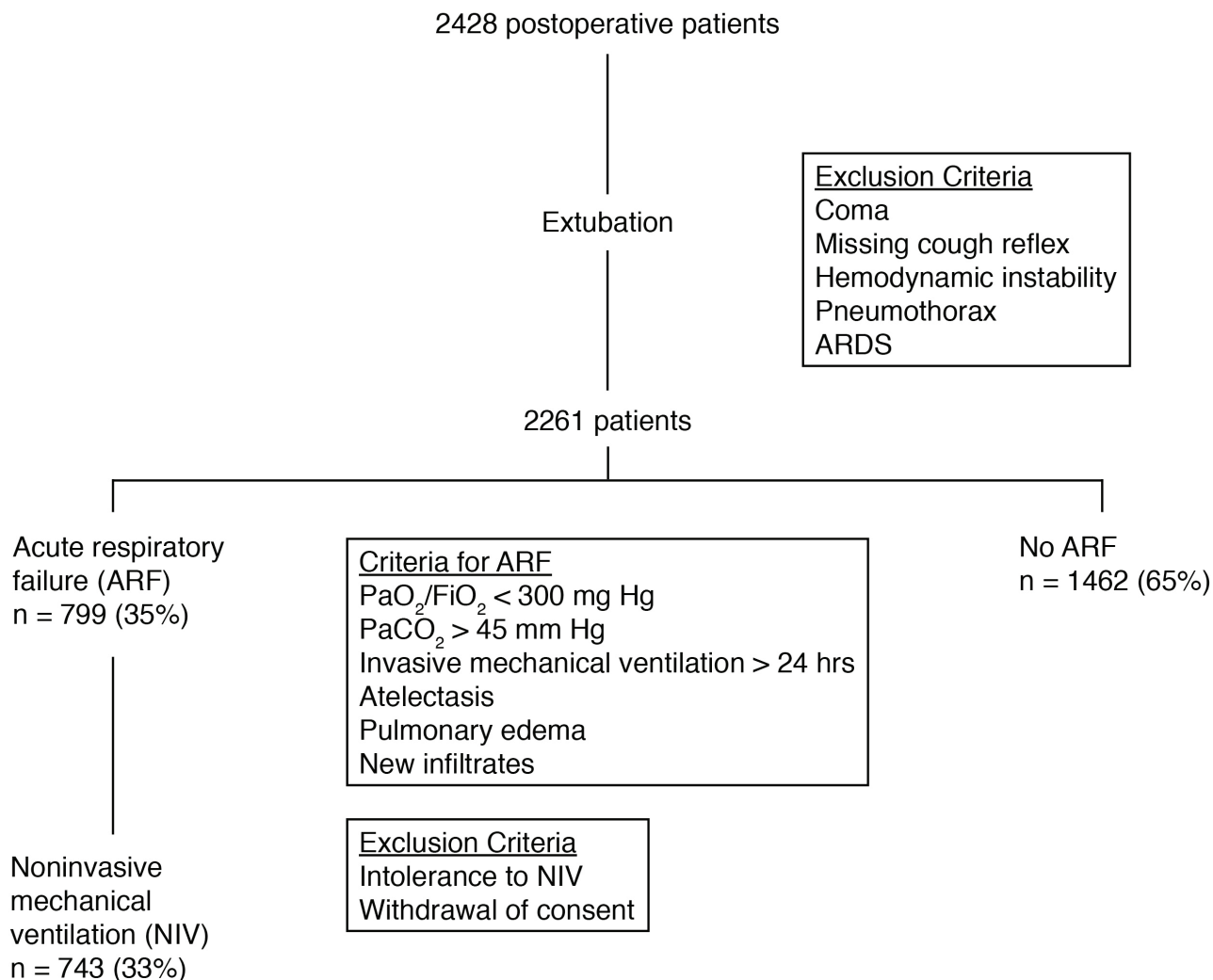
ARF after cardiac surgery. The surgical procedures, including median sternotomy and cardiopulmonary bypass (CPB), as well as depressed cardiac function, have been described to be associated with altered pulmonary function. Also, postoperative pulmonary complications, such as atelectasis and pneumonia, can result in ARF. Preoperative pulmonary morbidity, mostly chronic obstructive pulmonary disease, can lead to the development of postoperative ARF and has also been shown to be an important risk factor for postoperative morbidity after cardiac surgery [Bando 1997; Roques 1999; Canver 2003; Pasquina 2004; Celebi 2008; De Santo 2009].

In clinical practice, ARF after cardiothoracic surgery often presents with variable severity, ranging from mild and moderate hypoxemia/hypercapnia with little impact on the patients' well being and prognosis to severe respiratory failure requiring prolonged mechanical ventilation or reintubation. Based on positive experiences in clinical practice and the increasing evidence of the efficacy of noninvasive ventilation (NIV) in postoperative respiratory failure in the literature [Kilger 1999; Kindgen-Milles 2002; Pasquina 2004; De Santo 2009], it was our objective to evaluate the feasibility and outcomes of protocol-driven NIV in patients diagnosed with respiratory failure after cardiac surgery in a cardiothoracic intensive care unit (ICU).

PATIENTS AND METHODS

This prospective study was carried out in the cardiothoracic ICU of our university hospital. This study was approved by the Institutional Review Board, and patients provided informed consent upon entry into the study. All patients scheduled for cardiac surgery during the period between 2001 and 2004 were included.

Patients were further evaluated after successful postoperative extubation. Patients with 1 or more of the following conditions any time after primarily successful extubation during the postoperative ICU stay were diagnosed as having postoperative ARF [Kilger 1999; Canver 2003]: ratio of alveolar partial pressure of oxygen to fraction of inspired air ($\text{PaO}_2/\text{FiO}_2$) < 300 mm Hg; partial pressure of carbon dioxide (PaCO_2) > 45 mm Hg; invasive mechanical ventilation longer than 24 hours; significant atelectasis; significant pulmonary edema; or new infiltrates on the chest radiograph. Exclusion criteria consisted of 1 or more of the following conditions: coma; missing cough reflex; hemodynamic instability; pneumothorax; and acute respiratory distress syndrome (ARDS). Patients



diagnosed with ARF in the absence of exclusion criteria were assigned to receive NIV, and NIV was started immediately after ARF had been diagnosed. Patients who did not tolerate the treatment after starting NIV or who withdrew consent at this time point were excluded, as shown in the Figure. Besides the NIV protocol, standard postoperative care did not differ between patients with and without ARF.

All treating physicians as well as nurses had been trained and were experienced in the application of NIV. NIV had been institutionally implemented and in clinical use for postoperative respiratory failure for several years. NIV was performed in the individual patient using the same ventilator used for postoperative mechanical ventilation in the intubated patient (Servo Ventilator 300®, Siemens, Stockholm, Sweden, or Evita II®, Dräger, Lübeck, Germany). NIV was administered via an industrial sealed facial mask (Intersurgical® No. 3-5, Complete Respiratory System, Wokingham, UK). All patients were treated using the following pressure support mode (pressure support ventilation, PSV): initial pressure support (PS) of 5 cm H₂O; positive end-expiratory

pressure (PEEP) of 8 to 10 cm H₂O; FiO₂ of 0.5. The PS was increased in steps of 3 to 4 cm H₂O until a PS level compatible with comfortable breathing and a respiratory rate (RR) of less than 30 breaths per minute was reached. Arterial blood gas analysis was performed during the first minutes of NIV to monitor and adapt the treatment. The FiO₂ was then gradually decreased to 0.3 to 0.4, aiming to maintain arterial oxygen saturation (SaO₂) as monitored by pulse oximetry above 90%. NIV with PSV and PEEP was administered for a minimum of 30 minutes 4 to 6 times per day. The NIV periods were extended as long as the patient felt comfortable. During the periods without NIV, patients received supplemental oxygen to maintain an oxygen saturation > 90% and were allowed to drink and eat light meals, if otherwise possible. To minimize the risk of tracheal aspiration, the patients were instructed to remove the face mask by themselves in case of severe nausea. The headboard was kept elevated at a > 30° angle. NIV was preferentially used in a sitting position. The decision for reintubation was left to the discretion of the attending physicians.

Table 1. Patient Characteristics*

	ARF + NIV (n = 743)	No ARF (n = 1462)	P
Age, years	68 (61/74)	67 (60/73)	NS
EF, %	55 (61/74)	67 (60/73)	< .05
CABG, %	61	61	NS
Combined cardiac surgery, %†	15.3	10.7	< .05
Postoperative ventilation time, h	11 (7/22)	8 (6/13)	< .05
SAPS II, points	32 (28/40)	24 (20/30)	< .01
PaO ₂ /FiO ₂ after extubation, mm Hg	251 (222/289)	325 (302/347)	< .001
PaCO ₂ after extubation, mm Hg	52 (47/56)‡	38 (34/44)	< .01

*ARF indicates acute respiratory failure; NIV, noninvasive mechanical ventilation; EF, ejection fraction; CABG, coronary artery bypass grafting; SAPS II, Simplified Acute Physiology Score severity of illness score; PaO₂, partial pressure of oxygen in arterial blood; FiO₂, fraction of inspired oxygen; PaCO₂ partial pressure of carbon dioxide in arterial blood. Data are shown as median and quartiles, when appropriate.

†Combined cardiac surgery includes CABG surgery and any surgical valve procedure.

‡Only patients with hypercapnic respiratory failure are included.

Table 2. Results I*

	ARF + NIV (n = 743)	No ARF (n = 1518)	P
PaO ₂ /FiO ₂ at discharge	302 (266/319)†	309 (272/338)	NS
PaCO ₂ at discharge	44 (42/48)	37 (34/42)	< .05
Catecholamine support time, d	2 (1/3.5)	1 (0.5/2)	< .001
Red blood cell transfusion units, n	2 (0/4)	0 (0/2)	< .001
Length of ICU stay, d	3 (2/5)	2 (1/3)	< .001
Reintubation rate, %	6.9	1.9	< .001
Mortality, %	2.7	3.1	NS

*ARF indicates acute respiratory failure; NIV, noninvasive mechanical ventilation; PaO₂, partial pressure of oxygen in arterial blood; FiO₂, fraction of inspired oxygen; PaCO₂ partial pressure of carbon dioxide in arterial blood; ICU, intensive care unit. Data are shown as median and quartiles, when appropriate.

†The PaO₂/FiO₂ ratio in the NIV group at discharge is significantly higher than after extubation ($P < .05$).

Patient characteristics, including the simplified acute physiology score (SAPS II) [Le Gall 1993], as well as outcome parameters were compared between patients with ARF treated with NIV and patients without NIV. The reintubation rate for all patients, including patients with and without respiratory failure, was compared to a historical control group of the same center.

All statistical analyses were performed using the SPSS software (version 15.0 for Windows, SPSS, Inc., Chicago, IL). The Mann-Whitney U test was used to describe differences between the patients with ARF treated with NIV and the patients without ARF. A P value $< .05$ was considered statistically significant.

RESULTS

Between 2001 and 2004, a total of 2428 patients received postoperative mechanical ventilation for a median duration of 9 hours after cardiac surgery. After applying the exclusion criteria and after primarily successful extubation in 2261 patients, ARF was diagnosed in 799 patients (35%) according

to the predefined criteria, and NIV was performed in 743 patients (33%). In most patients, hypoxemic respiratory failure, mostly associated with atelectasis, was the primary symptom of ARF (578 patients; 78%). Hypercapnic respiratory failure was a less common (113 patients; 15%), as well as other pathologies (52 patients; 7%).

The characteristics of patients with ARF treated with NIV as well as patients without ARF are shown in Table 1. In the ARF with NIV group, SAPS II score was higher, the mean ejection fraction was lower, more patients underwent combined cardiac surgery, and the duration of postoperative mechanical ventilation ($P < .05$) was longer. In the group of patients with ARF and NIV, the PaO₂/FiO₂ ratio after extubation was lower, and the arterial PaCO₂ after extubation was higher compared to the patients without ARF.

The differences in outcome between the ARF with NIV treatment and the group of patients without ARF are shown in Tables 2 and 3.

The PaO₂/FiO₂ ratio after extubation was lower for all 3 subgroups of ARF patients (hypoxemic respiratory failure,

Table 3. Results II

Years	1998–2000	2001–2003
Reintubation	5.8% (122/2112 patients)	3.5% (79/2261 patients)

hypercapnic failure, and others); however, the parameter could be significantly improved by the time of ICU discharge ($P < .05$), and $\text{PaO}_2/\text{FiO}_2$ ratios at discharge did not differ from the values obtained in patients without ARF. In patients with ARF treated with NIV, mean PaCO_2 at discharge was increased compared to patients without ARF. For patients with hypercapnic failure, a significant decrease in PaCO_2 from extubation to discharge could be observed (52 mmHg versus 44 mmHg, $P < .05$). In patients with ARF treated with NIV, the duration of catecholamine support as well as the ICU stay was longer, the red blood cell transfusion rate was increased, and the reintubation rate was higher compared to patients without ARF. In-hospital mortality did not differ between the groups.

From 1998 to 2000, 2112 patients underwent cardiac surgery at our institution. In these patients, 122 patients (5.8%) had to be reintubated after primarily successful postoperative extubation. Compared to this historical control group, the reintubation rate during the study period was significantly lower (78/2261 patients; 3.5%).

DISCUSSION

We first found a high rate of patients with ARF after cardiac surgery (35%) according to our predefined criteria. The most frequent reason for respiratory failure after extubation in this study was hypoxemia (78%), mostly attributed to atelectasis.

Atelectasis contributes to the deterioration of pulmonary function and oxygenation and has been shown to occur in a high percentage (54%-92%) of patients after cardiac surgery [Pasquina 2004]. Pasquina et al compared continuous positive airway pressure (CPAP) to NIV (pressure support with positive end-expiratory pressure) in the treatment of atelectasis in postoperative cardiac surgery patients [Pasquina 2004]. NIV led to a radiological improvement in 60% of patients compared with 40% with CPAP but did not confer any clinical benefit. In the study of Celebi et al NIV either alone or in combination with recruitment maneuver provided lower atelectasis scores and better early pulmonary function test compared to the control group after 24 hours [Celebi 2008]. However, we could demonstrate a significant improvement in the $\text{PaO}_2/\text{FiO}_2$ ratio after NIV between the period of patient inclusion and discharge from the ICU. One reason for the clinical benefit in our NIV group may be the fact that a PEEP of 8 to 10 cm H_2O was used; a mask pressure of 9 to 10 cm H_2O has previously been shown to consistently improve pulmonary oxygen transfer in patients following thoracotomy [Kindgen-Milles 2002], although Pasquina et al used only a PEEP of 5 cm H_2O in their study [Pasquina 2004].

In the group of patients suffering from acute hypercapnic respiratory failure (15%), NIV was also found to be of benefit in terms of PaCO_2 correction. This result is consistent with those reported in the literature, where the use of NIV was most successful in patients with hypercapnia due to different causes [Lightowler 2003].

Compared with patients without ARF, patients diagnosed with ARF were generally sicker according to the SAPS II score, had a decreased left ventricular function corresponding to the lower ejection fraction, and required longer postoperative mechanical ventilation via endotracheal tube. These patients needed longer catecholamine support, a higher transfusion rate, and a longer length of stay in the ICU. The difference in outcome and especially the significantly higher reintubation rate in the ARF with NIV group should be expected in patients with ARF and can not be attributed to the NIV intervention. To date, published data report reintubation rates of 2% to 7% in a normal population after cardiac operations [Epstein 2000; Staton 2005], although this can increase to 10% to 20% for risk patients [Kern 2001; Bingol 2005]. The reintubation rate of 6.9% in our NIV group was minor compared to the literature and may be considered as a success of our NIV strategy [Kern 2001; Bingol 2005]. In a recently published study, De Santo et al could as well demonstrate that NIV is able to prevent reintubation after cardiac surgery in appropriate candidates [De Santo 2009].

A most important finding is that the mortality rate did not differ between the 2 groups, despite the ARF and NIV group having a lower ejection fraction, more combined cardiac surgery, a longer period on postoperative mechanical ventilation, and a higher SAPS II score (Table 1). To our knowledge, only a few publications have compared the level of SAPS II with the mortality rate after cardiac surgery. In the work of Martinez-Alario and co-workers, a mean SAPS II score of 28.6 ± 10.7 represented an overall hospital mortality rate of 5.6% [Martinez-Alario 1999]. Kern et al found a mean SAPS II of 32.5 ± 13.1 during a control period of 6 months after cardiac surgery with a hospital mortality rate of 4.3%. In this study, a hospital mortality of 2.7% in the NIV group was correlated with a calculated SAPS II score of 34 [Kern 1999].

This study encompasses the limitations associated with a nonrandomized trial. To our knowledge, however, this is the largest cohort of cardiac surgery patients with respiratory failure after extubation. Moreover, due to the single-center setting, the NIV procedure was homogeneous throughout the study period. Considering these aspects, the decrease in the reintubation rate between the years 1998-2000 (without the NIV protocol) and 2001-2003 (with the NIV protocol) can be explained.

In conclusion, this single-center study has demonstrated that NIV represents an efficacious technique of ventilatory support resulting in a lower reintubation rate and a mortality rate equal to patients without ARF. These results should encourage the use of NIV as a first-line intervention in acute respiratory failure after cardiac surgery. However, a large randomized trial is warranted to confirm these results.

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