Original article

Efficacy and safety of noninvasive positive pressure ventilation in the treatment of acute respiratory failure after cardiac surgery

ZHU Guang-fa, WANG Di-jia, LIU Shuang, JIA Ming and JIA Shi-jie

Keywords: noninvasive positive pressure ventilation; acute respiratory failure; cardiac surgery; intensive care medicine

Background Although noninvasive positive pressure ventilation (NPPV) has been successfully used for various kinds of acute respiratory failure, the data are limited regarding its application in postoperative respiratory failure after cardiac surgery. Therefore, we conducted a prospective randomized control study in a university surgical intensive care unit to evaluate the efficacy and safety of NPPV in the treatment of acute respiratory failure after cardiac surgery, and explore the predicting factors of NPPV failure.

Methods From September 2011 to November 2012 patients with acute respiratory failure after cardiac surgery who had indication for the use of NPPV were randomly divided into a NPPV treatment group (NPPV group) and the conventional treatment group (control group). The between-group differences in the patients' baseline characteristics, re-intubation rate, tracheotomy rate, ventilator associated pneumonia (VAP) incidence, in-hospital mortality, mechanical ventilation time after enrollment (MV time), intensive care unit (ICU) and postoperative hospital stays were compared. The factors that predict NPPV failure were analyzed.

Results During the study period, a total of 139 patients who had acute respiratory failure after cardiac surgery were recorded, and 95 of them met the inclusion criteria, which included 59 males and 36 females with a mean age of (61.5±11.2) years. Forty-three patients underwent coronary artery bypass grafting (CABG), 23 underwent valve surgery, 13 underwent CABG+valve surgery, 13 underwent major vascular surgery, and three underwent other surgeries. The NPPV group had 48 patients and the control group had 47 patients. In the NPPV group, the re-intubation rate was 18.8%, tracheotomy rate was 12.5%, VAP incidence was 0, and the in-hospital mortality was 18.8%, significantly lower than in the control group 80.9%, 29.8%, 17.0% and 38.3% respectively, \( P < 0.05 \) or \( P < 0.01 \). The MV time and ICU stay (expressed as the median (P25, P75)) were 18.0 (9.2, 35.0) hours and 4.0 (2.0, 5.0) days, which were significantly shorter than in the control group, 96.0 (26.0, 240.0) hours and 6.0 (4.0, 9.0) days respectively, \( P < 0.05 \) or \( P < 0.01 \). The postoperative hospital stays of the two groups were similar. The univariate analysis showed that the NPPV success subgroup had more patients with acute lung injury (ALI) (17 vs. 0, \( P = 0.038 \)), fewer patients with pneumonia (2 vs. 7, \( P < 0.001 \)) and lower acute physiology and chronic health evaluation II (APACHE II) scores (16.1±2.8 vs. 21.8±3.2, \( P < 0.001 \)). Multivariate analysis showed that pneumonia (\( P = 0.027 \)) and a high APACHE II score >20 (\( P = 0.002 \)) were the independent risk factors of NPPV failure.

Conclusions We conclude that NPPV can be applied in selected patients with acute respiratory failure after cardiac surgery to reduce the need of re-intubation and improve clinical outcome as compared with conventional treatment. Pneumonia and a high APACHE II score >20 might be the independent risk factors of NPPV failure in this group of patients.

Anesthesia, surgical techniques and sites, and postoperative pain can induce respiratory derangement; postoperative pulmonary complications such as atelectasis, acute lung injury/pulmonary edema, acute cardiogenic pulmonary edema (CPE), pulmonary embolism or infection. All of these can impair pulmonary function and even cause acute respiratory failure (ARF), especially in patients with respiratory co-morbidities like chronic obstructive pulmonary disease (COPD). Some patients need re-intubation and invasive ventilation, and some eventually need tracheotomy and long-term mechanical ventilation. Use of artificial airway and invasive ventilation may cause loss of airway protecting mechanisms, more sedative use, and airway trauma, all of which may increase the risk of ventilator associated pneumonia (VAP), increase the hospital length of stay, morbidity, and mortality.

DOI: 10.3760/cma.j.issn.0366-6999.20131704
Department of Respiratory and Critical Care Medicine (Zhu GF and Liu S), Department of Surgical Intensive Care Unit (Jia M and Jia SJ), Beijing Anzhen Hospital, Capital Medical University; Beijing Institute of Heart, Lung and Blood Vessel Diseases, Beijing 100029, China
Intensive Care Unit, Beijing Tongren Hospital, Capital Medical University, Beijing 100730, China (Wang DJ)
Correspondence to: Dr. ZHU Guang-fa, Department of Respiratory and Critical Care Medicine, Beijing Anzhen Hospital, Capital Medical University; Beijing Institute of Heart, Lung and Blood Vessel Diseases, Beijing 100029, China (Tel: 86-10-64456773. Fax: 86-10-64456527. Email: gfzhuf63@hotmail.com)
ZHU Guang-fa and WANG Di-jia contributed equally to this article.
This Study was supported by a grant from Capital Medical Development Foundation of Beijing Health Bureau (No.2009-3111).
Conflict of interest: The authors declare they have no conflicts of interest in carrying out the research described in this paper.
Noninvasive positive pressure ventilation (NPPV) is a mechanical ventilation modality that does not require any artificial airway and, compared to invasive ventilation, requires lower sedation, improves comfort and reduces the occurrence of VAP.5 NPPV has primarily been applied in patients with acute exacerbations of COPD, CPE, and hypoxemic respiratory failure.5-9 In recent years NPPV has been also used to prevent the occurrence of or to treat ARF after abdominal, thoracic, cardiac or bariatric surgery.10-12

Rationale for postoperative NPPV use is the same as postextubation NPPV use13 plus the specificities due to the respiratory modifications induced by surgery and anesthesia as described above. In selected patients with ARF, postoperative NPPV can improve gas exchange, decrease the work of breathing, and reduce atelectasis, and therefore reduce the need of re-intubation and improve clinical outcome.11

However, there are only limited data regarding the application of NPPV to treat postoperative respiratory failure after cardiac surgery and randomized trials are lacking.14,15 To further evaluate the efficacy and safety of NPPV in ARF after cardiac surgery, a prospective randomized clinical study was performed based on our previous successful application of NPPV in various types of respiratory failure.16,17

METHODS

Patient selection
From September 2011 to November 2012, this study was carried out in the Surgical Intensive Care Unit of Beijing Anzhen Hospital, Capital Medical University. Patients between 18 years to 80 years who underwent valve surgery, coronary artery bypass grafting (CABG), valve surgery + CABG, and aortic surgery, were transported to surgical intensive care unit for postoperative recovery. The study protocol was approved by the local ethics committee of our hospital (No. 2009006). Informed written consent was obtained in all cases from either the patients or their proxy. After considering the inclusion and exclusion criteria, patients were randomly allocated to the NPPV group or the control group thereby dictating the method utilized after extubation.

Inclusion criteria
Patients enrolled in this study fulfilled all of the following criteria: (1) onset of ARF after initial extubation (ARF was defined by arterial partial O₂ pressure (PaO₂) ≤60 mmHg after oxygen therapy through nasalprong or PaO₂/fraction of inspired O₂ (PaO₂/FiO₂) ≤200 mmHg after oxygen therapy though a Venturi mask with or without respiratory acidosis (pH <7.35 with arterial partial CO₂ pressure (PaCO₂) >45 mmHg), a respiratory rate >25 breaths/min, or clinical signs of increased respiratory workload (muscle fatigue); (2) the patient was awake (Glasgow score ≥13), with the ability to protect their airway; (3) bleeding from mediastinal and pleural drainage less than 100 ml/h; (4) no obvious fever (T >38ºC) or hypothermia (T <35ºC); (5) hemodynamic stability, without the need of high doses of vasopressors (epinephrine ≤0.05 g·kg⁻¹·min⁻¹, dopamine ≤5 g·kg⁻¹·min⁻¹), no severe arrhythmia, and no use of intra-aortic balloon pump; (6) urine output ≥0.5 ml·kg⁻¹·h⁻¹.

Exclusion criteria
The patients were excluded if they meet any of the following criteria: (1) cardiac or respiratory arrest; (2) lack of consciousness; (3) with high-risk of aspiration like abdominal distention or swallowing reflex abnormality; (4) severe other organ dysfunction like refractory hypotension, severe arrhythmia, gastrointestinal perforation/bleeding, severe neurologic disease; (5) undrained pneumothorax or pneumomediastinum; (6) recent facial, esophageal, or upper airway surgery, or a facial deformity; (7) refusal of NPPV or psychomotor agitation requiring sedation; (8) need of immediate endotracheal intubation (ETI) for excessive airway secretions.

Treatment

NPPV group
All patients received standard medical care as needed. NPPV therapy was administered using the bilevel positive airways pressure (BiPAP) S/T mode (Resmed, VPAP III, Australia) via a properly fitted face mask (ZS-MZ-A, Zhongshan Technique Development Co., Shanghai). The head of the bed was raised to 30°-45° in order to minimize the risk of aspiration. The initial inspiratory pressure (IPAP) was set at 12 cmH₂O (1 cmH₂O = 0.098 kPa), and the initial expiratory pressure (EPAP) was set at 5 cmH₂O. Back-up respiratory frequency was set at 12 breaths/min. According to clinical efficacy and patient tolerance, we raised the IPAP and (or) EPAP by 2–3 cmH₂O every 5 to 10 minutes, but the IPAP/EPAP did not exceed 25/10 cmH₂O. FiO₂ was adjusted to maintain a pulse oxygen saturation (SpO₂) of around 92%. All patients continued to receive NPPV except for coughing, eating and talking until their condition was improved. Then NPPV was administered intermittently and the IPAP/EPAP was decreased gradually. When the support pressure level (IPAP-EPAP) reached ≤5 cmH₂O, a weaning trial was begun. If there was no sign of dyspnea at rest, GCS≥15, RR ≤25 breaths/min, pH ≥7.35, PaO₂ ≥60 mmHg, and SpO₂≥90% at room air or FiO₂ ≤40% with Venturi mask during spontaneous breathing and this condition was sustained for 48 hours, NPPV was considered successful (success). If there was a failure to meet above success criteria, NPPV was resumed until meeting the criteria or need of ETI (see ETI criteria below). A nasogastric tube was placed in all patients for feeding and (or) gastric intestinal drainage if gastric distension occurred.

Control group
All patients received standard medical care and oxygen therapy as needed. Patients were intubated and mechanically ventilated if their condition deteriorated and met the criteria for ETI (see ETI criteria below).

ETI criteria
Re-intubation was performed if one major or two minor
criteria were present. Major criteria were as following: (1) respiratory arrest; (2) loss of consciousness; (3) severe agitation; (4) hemodynamic instability; (5) cardiogenic shock. Minor criteria were as following: (1) respiratory rate more than 35 breath/min; (2) arterial pH less than 7.30 and lower than admission value; (3) PaO₂ less than 45mmHg despite oxygen supplementation; (4) neurologic deterioration; (5) weak cough reflex with secretion accumulation.

Measurements
Data were gathered on age, sex, body mass index, concomitant diseases, smoking history, type of surgery, causes of postoperative respiratory failure, and acute physiology and chronic health evaluation (APACHE II). Patient’s vital signs (heart rate, respiratory rate, blood pressure, SpO₂) and arterial blood gas analysis measured values (pH, PaO₂, PaCO₂) were recorded before the treatment and 2–4 hours after treatment. The primary outcome variables were the need for endotracheal intubation, tracheotomy rate, VAP incidence, in-hospital mortality, mechanical ventilation time after enrolled (MV time), ICU stay, and postoperative hospital stay.

Statistical analysis
SPSS16.0 statistical software was used for statistical analysis. Qualitative variables were expressed as frequency and percentage; quantitative variables expressed as mean±standard deviation (SD) when the data were in a normal distribution or expressed as median (P25, P75) when there was skewed distribution (MV time, ICU stay, postoperative hospital stay). For normal distribution and equal variance quantitative data, a two-sample Student’s t test was used to determine differences between and within the groups respectively. The nonparametric Mann-Whitney test was used for variables that were not normally distributed. Qualitative variables were tested using χ² or Fisher’s exact test. To identify risk factors for NPPV failure, univariate analysis was used to compare patients demographic and baseline characteristic data in the NPPV success and failure subgroup patients, then multivariate Logistic regression analysis was used to identify risk factors for NPPV failure. A P value <0.05 was considered statistically significant.

RESULTS
From September 2011 to November 2012, 139 consecutive post cardiac surgery patients presented with ARF after routine extubation. Of these, 44 patients met the exclusion criteria, including 36 patients who needed emergency intubation (23 with severe arrhythmia, seven with loss of consciousness, and six with hemodynamic instability), five with psychomotor agitation requiring sedation, two with excessive airway secretions, and one with nausea and vomit. Thus, 95 patients were eligible, 48 were allocated to the NPPV group and 47 to the control group based on a predetermined randomization protocol. All of these patients were included in the analysis (Figure 1).

Patients’ demographic and baseline characteristics
There were no significant differences between the NPPV group and the control group in patients’ age, gender, concomitant diseases, smoking, type of surgery, causes of postoperative ARF, APACHE II scores (Table 1).

NPPV application
All of the patients in the NPPV group accepted NPPV through face mask and the S/T modes. For this group, NPPV was delivered for an average period of 31 hours

Table 1. Patient demographic and baseline characteristics in two groups

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>NPPV group (n=48)</th>
<th>Control group (n=47)</th>
<th>χ²/t</th>
<th>P values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>62.0±10.3</td>
<td>61.0±12.2</td>
<td>0.423</td>
<td>0.673</td>
</tr>
<tr>
<td>Sex (male)</td>
<td>32 (66.7%)</td>
<td>27 (57.4%)</td>
<td>0.858</td>
<td>0.354</td>
</tr>
<tr>
<td>Hypertension</td>
<td>23 (47.9%)</td>
<td>31 (65.8%)</td>
<td>3.151</td>
<td>0.076</td>
</tr>
<tr>
<td>Diabetes</td>
<td>7 (14.6%)</td>
<td>12 (25.5%)</td>
<td>1.779</td>
<td>0.182</td>
</tr>
<tr>
<td>Smoking</td>
<td>25 (52.1%)</td>
<td>16 (34.0%)</td>
<td>3.151</td>
<td>0.076</td>
</tr>
<tr>
<td>BMI kg/m²</td>
<td>25.3±4.6</td>
<td>24±3.5</td>
<td>1.000</td>
<td>0.320</td>
</tr>
<tr>
<td>Type of surgery</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valve surgery</td>
<td>12 (25%)</td>
<td>11 (23%)</td>
<td>0.033</td>
<td>0.856</td>
</tr>
<tr>
<td>CABG</td>
<td>23 (47.9%)</td>
<td>20 (42.6%)</td>
<td>0.131</td>
<td>0.600</td>
</tr>
<tr>
<td>CABG+ Valve surgery</td>
<td>8 (16.7%)</td>
<td>5 (10.6%)</td>
<td>0.731</td>
<td>0.393</td>
</tr>
<tr>
<td>Major vascular surgery</td>
<td>4 (8.3%)</td>
<td>9 (19.1%)</td>
<td>2.352</td>
<td>0.125</td>
</tr>
<tr>
<td>Others</td>
<td>1 (2.1%)</td>
<td>2 (4.2%)</td>
<td>0.000</td>
<td>0.985</td>
</tr>
<tr>
<td>Causes of ARF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute CPE</td>
<td>17 (35.4%)</td>
<td>20 (42.6%)</td>
<td>0.509</td>
<td>0.476</td>
</tr>
<tr>
<td>ALI</td>
<td>17 (35.4%)</td>
<td>16 (34.0%)</td>
<td>0.020</td>
<td>0.888</td>
</tr>
<tr>
<td>Lobar atelectasis</td>
<td>7 (14.6%)</td>
<td>3 (6.4%)</td>
<td>0.937</td>
<td>0.333</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>9 (18.8%)</td>
<td>10 (21.3%)</td>
<td>0.095</td>
<td>0.758</td>
</tr>
<tr>
<td>COPD</td>
<td>3 (6.2%)</td>
<td>1 (2.1%)</td>
<td>0.240</td>
<td>0.625</td>
</tr>
<tr>
<td>RMP</td>
<td>2 (4.2%)</td>
<td>5 (10.6%)</td>
<td>0.663</td>
<td>0.415</td>
</tr>
<tr>
<td>APACHE II score</td>
<td>17.2±3.6</td>
<td>17.6±3.5</td>
<td>-0.501</td>
<td>0.618</td>
</tr>
</tbody>
</table>

NPPV: noninvasive positive pressure ventilation; BMI: body mass index; CABG: coronary artery bypass grafting; ARF: acute respiratory failure; CPE: cardiogenic pulmonary edema; ALI: acute lung injury; COPD: chronic obstructive pulmonary disease; RMP: respiratory muscle fatigue; APACHE II: acute physiology and chronic health evaluation II.”1 pericardiectomy surgery in NPPV group, 2 ventricular septal defect repair surgeries in the control group.
Compared with baseline, the heart rate, respiratory rate, SpO2 of the control group remained stable at baseline level, but the heart rate, respiratory rate, SpO2, PaCO2 and PaO2 of the two groups were not significantly different (Table 3).

Table 3. Comparison of MV time, ICU stay and postoperative hospital stay in two groups (median (P25, P75))

<table>
<thead>
<tr>
<th>Variables</th>
<th>NPPV group (n=48)</th>
<th>Control group (n=47)</th>
<th>Z</th>
<th>P values</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV time (hours)</td>
<td>18.0 (9.2, 35.0)</td>
<td>26.0 (20.0, 240.0)</td>
<td>-3.806</td>
<td>0.000</td>
</tr>
<tr>
<td>ICU stay (days)</td>
<td>4.0 (2.0, 5.0)</td>
<td>6.0 (4.0, 9.0)</td>
<td>-3.071</td>
<td>0.002</td>
</tr>
<tr>
<td>Postoperative hospital stay</td>
<td>14.0 (11.0, 20.0)</td>
<td>8.0 (11.0, 32.0)</td>
<td>-1.584</td>
<td>0.113</td>
</tr>
</tbody>
</table>

Table 4. Vital signs and arterial blood gas variables in two groups (mean±SD)

<table>
<thead>
<tr>
<th>Groups</th>
<th>Systolic pressure (mmHg)</th>
<th>Heart rate (min)</th>
<th>Respiratory rate (min)</th>
<th>SpO2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2–4 hours</td>
<td>2–4 hours</td>
<td>2–4 hours</td>
<td></td>
</tr>
<tr>
<td>NPPV group</td>
<td>128.2±25.7</td>
<td>126.5±18.1</td>
<td>102.2±16.2</td>
<td>96.0±3.0</td>
</tr>
<tr>
<td>Control</td>
<td>124.7±21.9</td>
<td>123.1±19.8</td>
<td>100.2±19.6</td>
<td>94.2±4.7</td>
</tr>
</tbody>
</table>

NPPV: noninvasive positive pressure ventilation; SpO2: pulse oximetry; PaCO2: partial pressure of carbon dioxide; PaO2: partial pressure of oxygen.

Comparisons of vital signs and arterial blood gas variables

As shown in Table 4, the basic systolic blood pressure, heart rate, SpO2 and arterial blood gas variables (pH, PaO2, PaCO2) were similar in the two groups (P>0.05). The respiratory rate of the NPPV group was slightly higher than the control group (P<0.05). Two to four hours after treatment, the systolic blood pressure in both groups and pH of the control group remained stable at baseline level, but the heart rate, respiratory rate, SpO2, PaCO2 and PaO2 of the two groups, and pH of the NPPV group were significantly improved compared with baseline (P<0.05 or P<0.01). The SpO2 in the NPPV group improved more significantly, and the respiratory rate in the control group decreased more prominently; the latter might be associated with the use of sedatives for the intubated patients.

Comlications

The VAP incidence in the two groups is shown in Table 2. Other NPPV associated complications occurred in 14 patients, including nine patients with gastric distensions which was controlled by negative pressure suction through a nasogastric tube, three patients with hypotension controlled by vasoactive drugs, and two patients with aspiration controlled by tracheal intubation. The latter two patients died of septic shock and MOF. Complications in the control group included two patients with pneumothorax controlled by chest drainage and one patient with a tracheoesophageal fistula which could not be managed and the patient died.

Analysis of the factors that affected the efficacy of NPPV

As indicated in Table 2, NPPV succeeded in 39 patients and failed in 7 patients; six patients died although prompt ETI was performed for all of them, four patients died of septic shock and two of MOF. To explore the factors that affected the efficacy of NPPV in the NPPV success and NPPV failure subgroups, univariate analysis was used to compare patient demographic and baseline characteristic data; age, gender, body mass index, concomitant diseases, smoking, types of surgery, reasons of ARF, and APACHE.
With the knowledge of severe complications associated with endotracheal intubation and tracheostomy invasive ventilation, the use of NPPV to treat ARF has become more common. ARF is one of the most severe complications after cardiac surgery, and artificial airway and invasive mechanical ventilation are needed in most of the patients. Artificial airway poses a serious problem associated with longer ICU and hospital stays, including a higher VAP incidence and hospital expenditure, and the mortality may be as high as 25%–50%. The results from this study showed that compared with the conventional treatment, NPPV can significantly reduce the re-intubation rate (18.8% vs. 80.9%), tracheostomy rate (12.5% vs. 29.8%), the incidence of VAP (0 vs. 17.0%) and mortality (18.8% vs. 38.3%) of ARF after cardiac surgery, and shorten the MV time and ICU stay. To our knowledge, this is the relatively early prospective randomized control clinical study to show that NPPV has significant advantages over conventional therapy to treat selected post cardiac surgery patients with acute respiratory failure after extubation.

NPPV is ordered routinely in ICUs, where it has demonstrated its effectiveness to treat ARF, especially in patients with COPD, acute heart failure, and immune suppression. It has been also used for respiratory failure after extubation in multiple surgical settings, such as abdominal surgery and pulmonary resection, achieving improvements in oxygenation and decreases in the re-intubation rate. Currently, there is only limited experience regarding the use of NPPV to treat respiratory failure after cardiac surgery. De Santo et al reported 43 cases of cardiac postoperative extubation failure with acute respiratory failure treated with NPPV. Results showed that 74.4% of the patients were successfully treated with NPPV, and the mortality was 14%. In the retrospective analysis by Boeken et al extubation failure with hypoxic respiratory failure after cardiac surgery were treated with immediate endotracheal intubation, continuous positive airway pressure (CPAP) and BiPAP, results showed the re-intubation rate of CPAP and BiPAP were 25.8% and 22.2%. The mortality of the three groups was 8.8%, 4.2%, and 5.6% respectively. The researchers claim that NPPV (CPAP or BiPAP) can significantly reduce the re-intubation rate and improve patient outcome. Compared with the two studies above, the re-intubation rate of our study was lower, and mortality was higher. The different results may be related to case selection, different research methods, and severity of disease.

In this study, acute CPE, ALI, lobar atelectasis, pneumonia, COPD and respiratory muscle fatigue were the main postoperative pulmonary complications (PPCs) that caused ARF (Table 1). The main expected benefits from applying NPPV in PPCs are an increase in lung gas volume, an improvement in gas exchange, a reduction of atelectasis and work of breathing without the need for endotracheal intubation, thus avoiding the risks of invasive mechanical ventilation. More importantly, NPPV induces lung volume and intrathoracic pressure changes, which can affect preload, afterload, heart rate, and myocardial contractility, result in improvement of cardiac function and resolution of acute CPE. Franco et al studied 26 cases after cardiac surgery that were randomly divided into NPPV and the conventional treatment groups. The postoperative recovery of lung function of the patients who received NPPV was significantly improved compared with the conventional treatment group, and NPPV was safe for patients. After a long-term study, Zarbock et al found that the prophylactic usage of NPPV in patients after cardiac surgery could effectively improve the oxygen saturation condition, reduce pulmonary complications such as CPE and pneumonia, and effectively reduce the re-intubation rate.

A careful search for any possible PPCs together with the individual characteristics of the patients is fundamental for increasing NPPV success. Our univariate analysis found that the NPPV success group had more patients with ALI (17 vs. 0, \(P=0.038\)), fewer patients with pneumonia (2 vs. 7, \(P <0.001\)) and lower APACHE II scores (16.1±2.8 vs. 21.8±3.2, \(P <0.001\)). Further, multivariate logistic regression analysis showed pneumonia (\(P=0.027\)) and high APACHE II score (>20) (\(P=0.002\)) were the independent risk factors of NPPV failure (Table 5).

### DISCUSSION

### Table 5. Multivariate regression analyses for identification of risk factors for NPPV failure

<table>
<thead>
<tr>
<th>Variables</th>
<th>Regression coefficient</th>
<th>SE</th>
<th>(P) values</th>
<th>OR 95.0% Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>APACHE II score &gt;20</td>
<td>2.928</td>
<td>1.325</td>
<td>0.027</td>
<td>18.691 (1.392-250.925)</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>3.975</td>
<td>1.296</td>
<td>0.002</td>
<td>53.227 (4.198-674.785)</td>
</tr>
</tbody>
</table>

II scores as shown in Table 1. The results show the NPPV success subgroup had more patients with ALI (17 vs. 0, \(P=0.038\)), fewer patients with pneumonia (2 vs. 7, \(P <0.001\)) and lower APACHE II scores (16.1±2.8 vs. 21.8±3.2, \(P <0.001\)). Further, multivariate logistic regression analysis showed pneumonia (\(P=0.027\)) and high APACHE II score (>20) (\(P=0.002\)) were the independent risk factors of NPPV failure (Table 5).

The results from this study showed that compared with the conventional treatment, NPPV can significantly reduce the re-intubation rate (18.8% vs. 80.9%), tracheostomy rate (12.5% vs. 29.8%), the incidence of VAP (0 vs. 17.0%) and mortality (18.8% vs. 38.3%) of ARF after cardiac surgery, and shorten the MV time and ICU stay. To our knowledge, this is the relatively early prospective randomized control clinical study to show that NPPV has significant advantages over conventional therapy to treat selected post cardiac surgery patients with acute respiratory failure after extubation.

In this study, acute CPE, ALI, lobar atelectasis, pneumonia, COPD and respiratory muscle fatigue were the main postoperative pulmonary complications (PPCs) that caused ARF (Table 1). The main expected benefits from applying NPPV in PPCs are an increase in lung gas volume, an improvement in gas exchange, a reduction of atelectasis and work of breathing without the need for endotracheal intubation, thus avoiding the risks of invasive mechanical ventilation. More importantly, NPPV induces lung volume and intrathoracic pressure changes, which can affect preload, afterload, heart rate, and myocardial contractility, result in improvement of cardiac function and resolution of acute CPE. Franco et al studied 26 cases after cardiac surgery that were randomly divided into NPPV and the conventional treatment groups. The postoperative recovery of lung function of the patients who received NPPV was significantly improved compared with the conventional treatment group, and NPPV was safe for patients. After a long-term study, Zarbock et al found that the prophylactic usage of NPPV in patients after cardiac surgery could effectively improve the oxygen saturation condition, reduce pulmonary complications such as CPE and pneumonia, and effectively reduce the re-intubation rate.
ARF, which is consistent with previous studies, although some earlier studies have failed to demonstrate this observation. Hence, it is important not only to select patients properly, but the duration of the NPPV trial also requires close observation with monitoring of clinical and blood gas parameters. Artificial airway and invasive ventilation should be instituted promptly to avoid the delay of treatment.

There is always a concern about the safety when using NPPV. In our study, NPPV associated complications occurred in 14 patients (29.2%), including nine patients with gastric distension which was controlled by negative pressure suction through a nasogastric tube, three patients with hypotension controlled by vasoactive drugs, and two patients with aspiration controlled by ETI who died of septic shock and MOF afterward. So all patients treated with NPPV require close observation and any complications should be managed as necessary.

Finally, our study has limitations. The major limitations of our study include the relatively small number of patients. Thus many of the conclusions regarding risk factors in our study have limitations because of the small number of patients in each group, especially in the NPPV failure subgroup. The small data set does not allow for a valid assessment of whether some of these conditions in the study population may or may not be a contributing factor for success or failure of NPPV.

In summary, our study indicated that NPPV can be applied in selected patients with ARF after cardiac surgery to reduce the need of re-intubation and improve clinical outcome as compared with conventional treatment. Patient with pneumonia and a high APACHE II score >20 might be the independent risk factors of NPPV failure. A large sample and multicenter prospective randomized controlled trial to further determine the indication and efficacy of NPPV in the treatment of ARF after cardiac surgery is warranted.

Acknowledgements: The authors would like to thank CAO Xiangrong, SONG Wei, ZHANG Hai-bo, LI Jin-hua, LAI Yi-heng, HUANG Xin-sheng, ZHENG Ju-bing, LI Hai-yang, SUN Guangrong, and LI-qun Chi of the Department of Cardiac Surgery, Beijing Anzhen Hospital; and DONG Ping, LIU Nan, SHANG Wei, YAN Long and Li-qun Chi of the Department of Cardiac Surgery, Beijing Anzhen Hospital; and CAO Xiangrong, SONG Wei, ZHANG Hai-bo, LI Jin-hua, LAI Yi-heng, HUANG Xin-sheng, ZHENG Ju-bing, LI Hai-yang, SUN Guangrong, SONG Wei, ZHANG Hai-bo, LI Jin-hua, LAI Yi-heng, WANG Xiao-lei, WAN Jiu-he, ZHOU Ye and ZHOU Xiao of the Surgical Anzhen Hospital; and DONG Ping, LIU Nan, SHANG Wei, YAN Long and LI-qun Chi of the Department of Cardiac Surgery, Beijing Anzhen Hospital, for her help in experimental design and statistical analysis of data.

REFERENCES

2. Weissman C. Pulmonary complications after cardiac surgery.
18. Trouillet JL, Combes A, Vaissier E, Luyt CE, Ouattara A, Pavie...


(Received July 4, 2013)  
Edited by WANG Mou-yue and LIU Huan