Application of Noninvasive Ventilation in Acute Respiratory Failure after Cardiovascular Surgery

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Summary
Objective: To examine ventilatory response, oxygenation-related, and hemodynamics of patients with hypoxemic acute respiratory failure (ARF) submitted to noninvasive mechanical ventilation (NIV) during the postoperative phase of cardiovascular surgery in order to identify predictive variables of success, and to compare the different types of NIV.

Methods: Seventy patients with hypoxemic ARF were randomized to one of three modalities of NIV - continuous positive airway pressure (CPAP) and ventilation with two pressure levels (PEEP + SP and BiPAP®). Ventilation, oxygenation-related, and hemodynamics variables were analyzed at pre-application, and 3, 6, and 12 hours after the protocol began.

Results: Thirteen patients were excluded. Thirty-one patients progressed to independence from ventilatory support and comprised the success group, and 26 required orotracheal intubation and were considered the nonsuccess group. Age, initial heart rate (HR), and respiratory rate (RR) showed elevated levels in the nonsuccess group (p=0.042, 0.029, and 0.002, respectively). A greater number of intraoperative complications were seen in the nonsuccess group (p=0.025). Oxygenation variables increased only in the success group. Among the NIV types, 57.9% of patients in the ventilator group, 57.9% in the two-pressure levels group, and 47.3% in the CPAP group progressed with success. Oxygenation and RR variables showed improvement only in the groups with two pressure levels.

Conclusion: Patients with hypoxemic ARF in the postoperative stage after cardiovascular surgery showed better oxygenation, RR, and HR during NIV application. In older patients and those with higher baseline RR and HR values, NIV was not sufficient to reverse ARF. The two-pressure level modes showed better results. (Arq Bras Cardiol 2007;88(5):270-276)

Key words: Respiration, artificial; anoxemia; respiratory insufficiency; thoracic surgery.

Introduction
Cardiac operations are associated with modifications in gas exchange and respiratory mechanics that can progress to acute respiratory failure (ARF), responsible for high postoperative morbidity and mortality rates.

Among treatment alternatives, noninvasive ventilatory assistance has been used and it aims to improve alveolar ventilation and gas exchange, increase lung volumes, decrease respiratory work, and decrease mechanical ventilation time, thus avoiding reintubation and, consequently, cutting duration of stay in the intensive care unit. There are also benefits in hemodynamics, such as a decreased preload because of a reduction in venous return and decreased left ventricle postload due to reduced transmural pressure, leading to improved cardiac performance and increased cardiac output.

There are two methods for noninvasive mechanical ventilation (NIV) application with positive pressure: continuous positive airway pressure (CPAP) and ventilation with two levels of pressure (two-pressure level). NIV is well established in the treatment of respiratory failure secondary to exacerbations of chronic obstructive pulmonary disease (CPOD), in obstructive sleep apnea, and in cardiogenic pulmonary edema. However, in postoperative hypoxemic respiratory failure, the clinical response to the use of NIV has not been totally established and needs further investigation.

This study was developed with the objective of: 1) examining the ventilatory response, oxygenation-related, and hemodynamics of patients with hypoxemic acute respiratory failure submitted to NIV application in the postoperative period of cardiovascular surgery, seeking possible predictive variables of success for this treatment modality; 2) comparing these results to those obtained with the application of different NIV modalities and equipment.
The original article discusses the implementation of noninvasive ventilation (NIV) after cardiovascular surgery. The study included 57 patients undergoing cardiovascular operations, with 22 undergoing only myocardial revascularization (MR), 13 undergoing valvar operations (combined or not), 5 undergoing correction of an aneurism or dissection of the aorta, 3 undergoing thromboendarterectomy for chronic pulmonary embolism, and 15 undergoing combination operations.

Statistical analysis revealed that patients with a greater number of postoperative complications were more likely to require NIV. The study concluded that NIV was effective in managing postoperative respiratory failure and improving patient outcomes.

Results

Seventy patients were enrolled in the study, and 13 of them were excluded for different reasons, including lack of arterial gasometry, noncompliance with the protocol, presence of pneumothorax, and modification of the ventilatory modality. Of the 57 patients included, 22 underwent only myocardial revascularization (MR), 13 underwent valvar operations (combined or not), 5 underwent correction of an aneurism or dissection of the aorta, 3 underwent thromboendarterectomy for chronic pulmonary embolism, and 15 patients underwent combination operations.

Success X Nonsuccess - Of the 57 patients who completed the study, 31 (54.4%) progressed to independence from ventilatory support and comprised the success group, and 26 (45.6%) progressed with a need for orotracheal intubation and were considered the nonsuccess group for NIV strategy. Causes for orotracheal intubation were: a) worsening of respiratory insufficiency (n=11); b) worsening of the ARF associated with hemodynamic instability (n=7); c) lowered level of consciousness (n=6); and d) hemodynamic instability.

Weaning from the NIV was carried according to the observation of improvement in signs and symptoms of acute respiratory failure, and was performed by progressively increasing the intervals between applications and decreasing the application time. NIV treatment was considered successful when the patient presented normalization of clinical signs and symptoms of acute respiratory failure in a maximal period of 72 hours. Nonsuccess was defined as worsening of signs and symptoms requiring orotracheal reintubation at any time, or continuation of NIV for more than 72 hours.

The ventilator-patient interface was produced by using a facial mask; with the mechanical ventilator Gibeck model (Gibeck Dryden®), masks were used, whereas for BiPAP S/TD 30 and Solo/Sullivan devices, Respironics® facial or nasal masks were used.

Statistical analysis - The variables of heart rate and respiratory rate (with NIV measurements made during preapplication, 6 hours, and 12 hours after study began), pH, PaCO₂, PaO₂, and SaO₂ (with NIV measurements at preapplication, 3 hours, and 12 hours after study began) were analyzed in each group and comparatively among the groups, using variance analysis testing (ANCOVA with Kruskal – Wallis One-Way Analysis of Variance on Ranks, Tukey test, and the Two-Way Repeated Measures Analysis of Variance). For the other variables analyzed, non-paired t test and chi-squared test were used to examine occurrences of events.
In analysing the clinical-surgical data, we observed that the nonsuccess group showed a larger number of patients who smoked, had undergone previous cardiovascular operations, and had experienced a greater number of intraoperative surgical complications, as is displayed on Table 1. The mean values for the preceding left ventricular ejection fraction (LVEF) were 58% in the success group and 56% in the nonsuccess group, with no significant difference between the groups.

The anthropometric data from both groups are shown on Table 2. Patients in the nonsuccess group were older than those in the success group.

Oxygenation-related, ventilation, and hemodynamics data are shown for both the groups on Table 3 in mean ± standard deviation, and in Figure 1 for the three measurements obtained over time. The success group presented blood elevations of PaO\(_2\) and SaO\(_2\), reaching higher levels at the 12th hour of the study. Oxygenation in the nonsuccess group did not improve, even with installation of ventilatory support.

Respiratory rate was high in both groups at the beginning of the study, but proved significantly higher in the nonsuccess group (p = 0.002). After 6 hours and 12 hours, mean values were significantly lower than in the pre-study situation, although with no difference between the groups.

Mean pre-study values of HR were statistically higher in the nonsuccess group, and were significantly lower at the 12th hour. For the success group, HR behavior was similar over time.

Two-pressure level, CPAP, and Ventilator Treatment Modalities

Patients were regrouped according to the modality of NIV applied, producing three groups of 19 patients each: two-pressure level, CPAP and ventilator. Eleven (57.9%) patients progressed to suppression of the noninvasive ventilatory support in the ventilator group, 11 (57.9%) in the two-pressure level group, and 9 in the CPAP group (47.3%).

Groups were homogenous as to age, weight, height, and BMI, as is displayed on Table 4.

Oxygenation-related, ventilation, and hemodynamics data are shown on Table 5 and illustrated in Figure 2. As to oxygenation values (PaO\(_2\) and SaO\(_2\)), statistically significant increases were observed only in the ventilator and two-pressure level groups over time, although with no difference between these two modalities.

Respiratory rate did not show a statistically significant difference among the groups, but there was a significant reduction of its values in the two-pressure level and ventilator groups over time when compared to the initial levels.

The HR did not differ among the groups, but there was a statistically significant reduction in the 3rd measurement when compared to the pre-values in the CPAP group. MAP did not show any significant changes among the groups over time.

Discussion

Our results show that the application of NIV in patients with hypoxemic ARF post cardiovascular surgery avoided reintubation in 54.4% of the cases. Several studies have already demonstrated the efficacy of NIV in preventing or avoiding orotracheal intubation in situations of hypoxemic acute respiratory failure. Recent randomized studies involving a heterogeneous population of patients with hypoxemia have reported success in avoiding orotracheal intubation in 69 to 79%. The difference in percentage of success among the various studies, including ours, is because of the different causes that lead to hypoxemic ARF. Antonelli et al\(^{20}\) studied 354 patients with hypoxemic ARF, observing a 51% success rate in patients with acute respiratory distress syndrome (ARDS), 50% in patients with nosocomial pneumonia, and 69% in patients with atelectasia. These numbers are similar to our results, which can be explained by the fact that most of the patients with hypoxemic ARF in the postoperative phase after cardiovascular operations have lung collapse and infiltration processes as the main causes. Although our patients had ARF, in most cases the primary basis of this involvement was correlated to cardiac dysfunction, since most unsuccessful patients showed a greater number of intraoperative events such as cardiorespiratory arrest (CRA) and hemodynamic instability requiring mechanical circulatory assistance, and bleeding.

Predictors of nonsuccess for the use of NIV are not well characterized. In the study by Meduri et al\(^{17}\) gasometry improvement was associated with the NIV success, but no predictive correlation for success was found for hypoxemic ARF. Rana et al\(^{31}\) observed patients with acute pulmonary injury and noted that shock, metabolic acidosis, and serious
hypoxemia were predictors of nonsuccess for NIV strategy. Antonelli et al.\(^\text{20}\) found the variables of age, initial respiratory rate, and lack of oxygenation improvement within one hour of the treatment application as correlated to nonsuccess of NIV.

Our data show that before NIV application, there were statistically significant differences as to age, heart rate, and respiratory rate, with the highest values in the nonsuccess group. It is known that aging provokes a series of cardiorespiratory changes, translated as a decrease of cardiorespiratory reserve. This condition is a predisposing factor for respiratory failure in cases of infectious, traumatic, and surgical aggressions. Our patients who progressed to nonsuccess were older, and at the beginning of the study presented higher heart rates

### Table 3 - Mean values and SD of oxygenation-related, ventilatory and hemodynamic variables of the groups that progressed to success and failure of NIMV

<table>
<thead>
<tr>
<th></th>
<th>Success</th>
<th></th>
<th>Insuccess</th>
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<tbody>
<tr>
<td></td>
<td>1(^{\text{st}})</td>
<td>2(^{\text{nd}})</td>
<td>3(^{\text{rd}})</td>
<td>1(^{\text{st}})</td>
</tr>
<tr>
<td>PH</td>
<td>7.42 ± 0.06</td>
<td>7.43 ± 0.05</td>
<td>7.42 ± 0.05</td>
<td>7.41 ± 0.05</td>
</tr>
<tr>
<td>PaCO(_2)</td>
<td>36.2 ± 5.1</td>
<td>35.8 ± 5.9</td>
<td>38.2 ± 7.5</td>
<td>36.1 ± 5.8</td>
</tr>
<tr>
<td>PaO(_2)</td>
<td>66.2 ± 15.5</td>
<td>74.4 ± 15.6</td>
<td>88.0 ± 23.9(^\dagger)</td>
<td>74.4 ± 27.7</td>
</tr>
<tr>
<td>SaO(_2)</td>
<td>90.7 ± 4.3</td>
<td>93.9 ± 2.9(^*)</td>
<td>95.0 ± 2.9(^*)</td>
<td>91.8 ± 5.7</td>
</tr>
<tr>
<td>RR</td>
<td>26.7 ± 4.9</td>
<td>23.4 ± 5.7(^*)</td>
<td>22.2 ± 4.9(^*)</td>
<td>29.5 ± 5.5(^\dagger)</td>
</tr>
<tr>
<td>HR</td>
<td>97.8 ± 10.5</td>
<td>96.0 ± 15.4</td>
<td>95.3 ± 15.0</td>
<td>107.1 ± 20.1(^\dagger)</td>
</tr>
<tr>
<td>MAP</td>
<td>84.1 ± 11.4</td>
<td>83.4 ± 8.2</td>
<td>87.5 ± 12.2</td>
<td>81.7 ± 16.9</td>
</tr>
</tbody>
</table>

\(^*\)p<0.05 regarding 1\(^{\text{st}}\) measurement; \(^\dagger\)p<0.05 regarding 2\(^{\text{nd}}\) measurement; \(^\text{‡}\)p<0.05 Success vs. failure.

**Fig. 1** - Mean values and SD of variables in the groups success and failure, at three moments assessed. A) PaO\(_2\); B) SaO\(_2\); C) RR and D) HR, \(^*\)p<0.05 regarding 3\(^{\text{rd}}\) measurement; \(^\dagger\)p<0.05 regarding 2\(^{\text{nd}}\) measurement; \(^\text{‡}\)p<0.05 success vs. failure.
and respiratory rates, which could be suggestive of a greater ventilatory and hemodynamic overload, contributing to a respiratory deterioration more difficult to reverse with NIV.

We observed that along the first 12 hours of the protocol, the variables $\text{SaO}_2$ and $\text{PaO}_2$ showed significant increases in the success group, whereas in the nonsuccess group there was no such change. These results are similar to those found by Antonelli et al\textsuperscript{20}, and Rana et al\textsuperscript{21}, suggesting that patients who showed an improvement in oxygenation during the first hours of treatment have better results in terms of avoiding orotracheal intubation.

The respiratory rate showed a similar behavior between the two groups, with a significant reduction in the first 12 hours within each group, albeit with no difference between the groups.

Thus, NIV was an effective ventilatory strategy in most cases, avoiding installation of invasive mechanical ventilation; nevertheless, factors such as age, and previous heart rate and respiratory rate can compromise the efficacy of the ventilatory support.

**Two-pressure level, CPAP, and Ventilator Treatment Modalities**

Comparing the three NIV modalities as to the occurrence of success and nonsuccess, we found no statistically significant difference among them ($p=0.531$), although there was a tendency towards better results with the use of two-pressure level modalities, which contributed to avoid reintubation in most of the cases studied in each group (57.9%). In the CPAP modality, there was a greater number of reintubations, with 47.3% success, even though the difference between the groups was not significant.

Ventilator and two-pressure level modalities were also responsible for significant improvements over time. The ventilator and two-pressure level groups showed oxygenation rises in the first 12 hours of application, while in the CPAP group, this change was discreet. Matte et al\textsuperscript{22} studied 96 patients in the postoperative phase of myocardial revascularization surgery and compared the use of an incentive support.

**Table 4 - Mean values and SD of anthropometric variables of the groups of patients characterized by the NIMV modality received**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Ventilator</th>
<th>Two-pressure level</th>
<th>CPAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$</td>
<td>19</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Age (years)</td>
<td>58.5 ± 15.4</td>
<td>54.9 ± 15.4</td>
<td>60.3 ± 13.3</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>67.2 ± 15.2</td>
<td>68.9 ± 17.7</td>
<td>73.2 ± 10.8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>1.60 ± 0.07</td>
<td>1.64 ± 0.10</td>
<td>1.62 ± 0.07</td>
</tr>
<tr>
<td>BMI (Kg/m2)</td>
<td>25.78 ± 4.47</td>
<td>25.2 ± 4.5</td>
<td>27.8 ± 3.38</td>
</tr>
</tbody>
</table>

* $p<0.05$ regarding 1st measurement; † $p<0.05$ regarding 2nd measurement.

**Table 5 - Mean values and SD of oxygenation-related, ventilatory and hemodynamic variables of the groups of patients characterized by the NIMV modality received**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Ventilator</th>
<th>Two-pressure level</th>
<th>CPAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pH$</td>
<td>7.42 ± 0.05</td>
<td>7.42 ± 0.06</td>
<td>7.40 ± 0.06</td>
</tr>
<tr>
<td>$\text{PaCO}_2$</td>
<td>36.6 ± 4.6</td>
<td>35.5 ± 5.2</td>
<td>38.0 ± 6.9</td>
</tr>
<tr>
<td>$\text{PaO}_2$</td>
<td>68.5 ± 19.0</td>
<td>73.6 ± 23.6</td>
<td>81.1 ± 20.2*</td>
</tr>
<tr>
<td>$\text{SaO}_2$</td>
<td>91.0 ± 4.6</td>
<td>92.0 ± 5.3</td>
<td>94.1 ± 5.3*</td>
</tr>
<tr>
<td>F</td>
<td>28.3 ± 5.6</td>
<td>24.9 ± 6.0*</td>
<td>21.6 ± 6.0</td>
</tr>
<tr>
<td>FC</td>
<td>102 ± 15</td>
<td>96 ± 16</td>
<td>95 ± 19</td>
</tr>
<tr>
<td>PAM</td>
<td>84.6 ± 16</td>
<td>82.4 ± 14.0</td>
<td>86.4 ± 14.0</td>
</tr>
</tbody>
</table>

* $p<0.05$ regarding 1st measurement; † $p<0.05$ regarding 2nd measurement.
inspirometer, CPAP, and two-pressure level in preventing deterioration of lung function and gasometry values in these patients with no signs of ARF. The study showed that both CPAP and two-pressure level afforded an improvement of PaO₂ over 24 hours of application, but there was no significant difference between the modalities. In treating 83 patients with cardiogenic pulmonary edema, Park et al compared the use of oxygen therapy (n=27), CPAP (n=27), and two-pressure level (n=29), and noted that with 30 minutes of application, there was a significant increase of PaO₂ in the two-pressure level and CPAP groups. In this study, the respiratory rates of patients from the two-pressure level and CPAP groups were lower than those of the oxygen therapy group. The behavior of the respiratory rate in our patients was similar to that seen in the study by Matte et al, who showed a decrease in the two-pressure level group during the first 12 hours of application, whereas in the CPAP group there was a small elevation in the same period, producing a statistically significant difference between the two methods.

Macintyre et al, using pulmonary complacency and airway pressure measurements in Intensive Care Unit patients with stable pulmonary and hemodynamic conditions, demonstrated a reduction in respiratory muscle work function when using two-pressure level, showing that this method reduces inspiratory effort and respiratory work. Mechanical work is equal to the force multiplied by the dislocation. In the respiratory system, the work generated by the inspiratory muscles creates a pressure that causes dislocation of the air. Therefore, when additional positive pressure is used helping muscular function during inspiration, there is a reduction in respiratory work.

The heart rate and arterial blood pressure were not modified during application of positive pressure, and their mean values remained within normal limits during most of the protocol. A statistically significant change was noted in the HR over time only in the CPAP group. Philip-Jöet et al, when studying hemodynamic modifications resulting from the use of CPAP and two-pressure level methods, found no significant differences in patients with normal left ventricular function. There was a modification of the cardiac output in patients who already presented a decrease in mean pulmonary artery pressure (less than 12 mmHg). In our study, it was not possible to correlate this information with the hemodynamic condition, since the left ventricular function was not assessed in these patients.

In conclusion, patients with hypoxemic ARF in the postoperative phase after cardiovascular surgery improved...
oxygenation, respiratory rate, and heart rate during NIV application. In older patients and those with higher initial respiratory and heart rates, NIV may not be sufficient for reversing the hypoxemic respiratory failure condition.

The methods with two pressure levels showed results superior to those of the CPAP method.

Potential Conflict of Interest
No potential conflict of interest relevant to this article was reported.

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There were no external funding sources for this study.

Study Association
This study is not associated with any graduation program.

References