Noninvasive Ventilation in Acute Cardiogenic Pulmonary Edema
Systematic Review and Meta-analysis

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Context In patients with acute cardiogenic pulmonary edema noninvasive ventilation may reduce intubation rate, but the impact on mortality and the superiority of one technique over another have not been clearly established.

Objective To systematically review and quantitatively synthesize the short-term effect of noninvasive ventilation on major clinical outcomes.

Data Sources MEDLINE and EMBASE (from inception to October 2005) and Cochrane databases (library issue 4, 2005) were searched to identify relevant randomized controlled trials and systematic reviews published from January 1, 1988, to October 31, 2005.

Study Selection and Data Extraction Included trials were all parallel studies comparing noninvasive ventilation to conventional oxygen therapy in patients with acute pulmonary edema. Comparisons of different techniques, either continuous positive airway pressure (CPAP) or bilevel noninvasive pressure support ventilation (NIPSV), were also included.

Data Synthesis Fifteen trials were selected. Overall, noninvasive ventilation significantly reduced the mortality rate by nearly 45% compared with conventional therapy (risk ratio [RR], 0.55; 95% confidence interval [CI], 0.40–0.78; P = .72 for heterogeneity). The results were significant for CPAP (RR, 0.53; 95% CI, 0.35–0.81; P = .44 for heterogeneity) but not for NIPSV (RR, 0.60; 95% CI, 0.34–1.05; P = .76 for heterogeneity), although there were fewer studies in the latter. Both modalities showed a significant decrease in the “need to intubate” rate compared with conventional therapy: CPAP (RR, 0.40; 95% CI, 0.27–0.58; P = .21 for heterogeneity), NIPSV (RR, 0.48; 95% CI, 0.30–0.76; P = .24 for heterogeneity), and together (RR, 0.43; 95% CI, 0.32–0.57; P = .20 for heterogeneity). There were no differences in intubation or mortality rates in the analysis of studies comparing the 2 techniques.

Conclusions Noninvasive ventilation reduces the need for intubation and mortality in patients with acute cardiogenic pulmonary edema. Although the level of evidence is higher for CPAP, there are no significant differences in clinical outcomes when comparing CPAP vs NIPSV.

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main outcomes (intubation and mortality) comparing the 2 techniques to each other and to conventional oxygen therapy.

METHODS

Search Strategy

We aimed to identify all randomized controlled trials assessing the efficacy of NIV in patients with acute pulmonary edema. The electronic search strategy applied standard filters for identification of randomized clinical trials. Databases searched were the Cochrane Central Register of Controlled Trials (CENTRAL, The Cochrane Library Issue 4, 2005), MEDLINE (from inception to October 2005), and EMBASE (from inception to October 2005). We did not apply language restrictions. In addition to the electronic search, we checked cross-references from original articles and reviews and sometimes contacted authors to obtain additional unpublished data. Our search included the following: continuous positive airway pressure (Medical Subject Headings [MeSH]); continuous positive airway*; biphasic intermittent positive airway; bilevel positive airway*; noninvasive ventilatory-assistance apparatus; noninvasive support ventilation; noninvasive ventilator*; non-invasive ventilator*; CPAP; Bipap; pulmonary edema (MeSH); acute pulmonary edema; heart failure, congestive (MeSH); edema, cardiac (MeSH); acute cardiogenic edema linked with randomized controlled trial OR controlled clinical trial OR randomized controlled trials OR random allocation OR double-blind method OR single-blind method OR clinical trial OR clinical trials in various combinations.

Selection of Studies

We restricted the analysis to parallel randomized trials comparing NIV to conventional oxygen therapy or to another NIV modality. Study designs containing inadequately adjusted planned cointerventions and crossover trials were not included. Studies that analyzed the application of NIV in patients with acute pulmonary edema as a part of a group of patients with acute respiratory failure were excluded, as were studies published only in abstract form and those written in a non-accessible language after failure to obtain more complete data.

Data Collection

The initial selection was performed by distributing references among pairs of independent reviewers. A full-text copy of all studies of possible relevance was obtained and data from each study was extracted independently by paired reviewers, using a prestandardized data abstraction form. Data extracted were checked by a third reviewer (J.M. or M.R.) for accuracy. The reviewers decided which trials fitted the inclusion criteria focusing on study design, patients’ characteristics, protocol of the interventions, outcomes measured, and main results. Any disagreement appearing during the process was solved by discussion and team consensus.

Methodological quality of the included trials was assessed collecting data on key domains related to validity:14,15: reporting of allocation concealment, description of an adequate randomization method, and specification of loss of subjects.

The primary outcomes for the included trials were treatment failure, endotracheal intubation, myocardial infarction, resolution time, therapeutic success at 2 hours, 48-hour mortality, inhospital mortality, and specific laboratory or physiological parameters. The primary outcomes for the present study were treatment failure and inhospital mortality because all the included trials presented data about these items. However, treatment failure was often reported using different definitions. It was endotracheal intubation in some studies, “criteria for intubation” (which was not necessarily performed) in others, and some arbitrary clinical or blood gas criteria at different intervals of time in others. For this item, we finally decided to select the variable “need to intubate,” which included those patients who were intubated and those who needed to be intubated but were not, either due to successful rescue NIV, patient’s refusal, or a medical decision on account of serious comorbidities.

Myocardial infarction was considered a secondary outcome in the present study. This complication was computed whether it was identified as the cause of acute pulmonary edema or was
REFERENCES

Bellone et al,36
Kelly et al,31
Nava et al,34
Räsänen
Park et al,8
Levitt,33 2001
1 ED in the United
L’Her et al,7
Park et al,30
Masip et al,9
Takeda et al,29
Lin et al,5
Bersten et al,4
Crane et al,32

In addition, in almost all the studies hypoxemia was required for diagnosis, whether assessed by pulse-oximetry or arterial blood gas samples.

**Analysis**

We summarized available data for all trials reporting results on need to intubate or mortality, computing pooled risk ratios (RRs) and their respective 95% confidence intervals (CIs) by means of a fixed-effects meta-analysis model. We examined heterogeneity using a χ² test. All statistical analyses were performed with Review Manager (Revman version 4.2 for Windows, Oxford, England), the Cochrane Collaboration’s software for preparing and maintaining Cochrane systematic reviews. Although the main analysis was made considering available data as finally published by authors, an intention-to-treat sensitivity analysis was also performed in order to obtain more exact results, assuming that lost or withdrawn patients experienced outcomes (either need to intubate or death). Three-arm trials were analyzed as 2-arm separate trials in each comparison, duplicating the control group data. A sensitivity analysis was performed correcting for this artificial sample size increase, showing no relevant differences with respect to the main analysis.

**Table.** Randomized Studies Analyzing Noninvasive Ventilation

<table>
<thead>
<tr>
<th>Source</th>
<th>Location</th>
<th>Sample Size</th>
<th>Mask</th>
<th>CPAP/cm H₂O</th>
<th>IPAP/EPAP/cm H₂O</th>
<th>Primary Outcomes</th>
<th>Other Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Räsänen et al,2 1985</td>
<td>1 ICU in Finland</td>
<td>40</td>
<td>Full face</td>
<td>10</td>
<td></td>
<td>Clinical outcomes</td>
<td></td>
</tr>
<tr>
<td>Bersten et al,7 1991</td>
<td>1 ICU in Australia</td>
<td>40 (39)</td>
<td>Full face</td>
<td>10</td>
<td></td>
<td>Intubation</td>
<td></td>
</tr>
<tr>
<td>Lin et al,1995</td>
<td>1 ICU in Taiwan</td>
<td>100</td>
<td>Full face</td>
<td>2.5-12.5</td>
<td></td>
<td>Intubation In-hospital mortality</td>
<td></td>
</tr>
<tr>
<td>Takeda et al,29 1997</td>
<td>1 ICU in Japan</td>
<td>30 (29)</td>
<td>Full face or nasal</td>
<td>4-10</td>
<td></td>
<td>Laboratory parameters</td>
<td>Measurement of plasma endothelin 1</td>
</tr>
<tr>
<td>Kelly et al,31 2002</td>
<td>1 ED and ICU in the United Kingdom</td>
<td>58</td>
<td>Full face</td>
<td>7.5</td>
<td></td>
<td>Clinical outcomes Laboratory parameters</td>
<td>Measurement of plasma neurohormonal concentrations</td>
</tr>
<tr>
<td>L’Her et al,7 2004</td>
<td>4 EDs in France</td>
<td>89</td>
<td>Full face</td>
<td>7.5</td>
<td></td>
<td>48-h mortality</td>
<td>Elderly patients (&gt;75 y)</td>
</tr>
<tr>
<td>Masip et al,9 2000</td>
<td>1 ICU in Spain</td>
<td>40 (37)</td>
<td>Full face</td>
<td>20/5, Mean</td>
<td></td>
<td>Intubation Resolution time</td>
<td>IPAP was adjusted to tidal volume</td>
</tr>
<tr>
<td>Levitt,33 2001</td>
<td>1 ED in the United States</td>
<td>38</td>
<td>Full face or nasal</td>
<td>9/3 Initial</td>
<td></td>
<td>Intubation</td>
<td>Prematurely interrupted when the study by Mehta et al was published</td>
</tr>
<tr>
<td>Nava et al,34 2003</td>
<td>5 EDs in Italy</td>
<td>130</td>
<td>Full face</td>
<td>14.5/6.1, Mean</td>
<td></td>
<td>Intubation</td>
<td>Post hoc analysis in hypercapnic patients</td>
</tr>
<tr>
<td>Park et al,30 2001</td>
<td>1 ED in Brazil</td>
<td>26</td>
<td>Full face and nasal</td>
<td>5-12.5</td>
<td>8/3 Initial</td>
<td>Intubation</td>
<td>Full-face mask for CPAP and nasal for NIPSV</td>
</tr>
<tr>
<td>Crane et al,32 2004</td>
<td>2 EDs in the United Kingdom</td>
<td>60</td>
<td>Full face</td>
<td>10</td>
<td>15/5 Fixed</td>
<td>Success in ED (2 h) In-hospital mortality</td>
<td>Prehospital nitrates therapy evaluated</td>
</tr>
<tr>
<td>Park et al,38 2004</td>
<td>1 ED in Brazil</td>
<td>83 (80)</td>
<td>Full face</td>
<td>10 Initial up to 16</td>
<td></td>
<td>Intubation</td>
<td></td>
</tr>
<tr>
<td>Mehta et al,35 1997</td>
<td>1 ED in the United States</td>
<td>27</td>
<td>Nasal and full face</td>
<td>10</td>
<td>15/5 Fixed</td>
<td>Intubation Physiological improvement</td>
<td>Prematurely stopped for higher rate of AMI in NIPSV group</td>
</tr>
<tr>
<td>Bellone et al,36 2004</td>
<td>1 ED in Italy</td>
<td>36</td>
<td>Full face</td>
<td>10</td>
<td>15/5 Initial</td>
<td>AMI</td>
<td>Study restricted to patients with hypercapnia</td>
</tr>
<tr>
<td>Bellone et al,37 2005</td>
<td>1 ED in Italy</td>
<td>46</td>
<td>Full face</td>
<td>10</td>
<td>15/5 Initial</td>
<td>Resolution time</td>
<td>Primary end point was AMI rate Only nonischemic APE</td>
</tr>
</tbody>
</table>

**Abbreviations:** AMI, acute myocardial infarction; APE, acute pulmonary edema; CPAP, continuous positive airway pressure; ED, emergency department; EPAP, positive expiratory airway pressure (equivalent to CPAP); ICU, intensive care unit; IPAP, inspiratory positive airway pressure; NIPSV, bilevel noninvasive pressure support ventilation.

*Numbers in parentheses denote the number of patients finally included after withdrawals.*
Publication bias was assessed applying the Egger et al.\textsuperscript{10} and Begg et al.\textsuperscript{17} statistical tests to the 2 main outcomes of the included trials: intubation and in-hospital mortality. Publication bias was studied separately for trials comparing NIV with control and for trials comparing modalities of NIV.

RESULTS

Study Selection

Our initial electronic search identified 559 studies. Of these, 532 were excluded because they were not randomized trials, did not evaluate NIV in patients with acute pulmonary edema, were duplicated references, or were not relevant. Twenty-seven studies were retrieved for more detailed analysis, 11 of which were excluded. Two were excluded because of crossover design\textsuperscript{18,19}, 1 for out-of-hospital setting with inappropriate allocation\textsuperscript{20}, 1 for recruitment of patients with acute pulmonary edema as a part of a series with acute respiratory failure\textsuperscript{21}, 1 for study design containing inadequately adjusted planned cointerventions\textsuperscript{22}, 2 for duplicated publications, partial\textsuperscript{23} or complete\textsuperscript{23}, 3 for results reported exclusively in proceedings\textsuperscript{24-26}, and 1 study published in a nonaccessible language.\textsuperscript{27}

The flow diagram of the trial selection process is shown in Figure 1. Sixteen studies were selected, one of which was finally excluded because the reported outcomes did not meet our selection criteria.\textsuperscript{28} Thus, we included 15 trials in the meta-analysis.\textsuperscript{3-5,7-9,29-37}

Study Description

Trial characteristics are summarized in the Table. Although all were published in English, they represent an international experience, including data from 11 countries. Three studies were multiple-center trials, whereas the others were conducted in a single center.

Causes of acute pulmonary edema were reported in 11 of the studies\textsuperscript{3-5,7-9,29,30,34,36,37} and were described as acute coronary syndrome in 203 (31%) of the patients, hypertension in 178 (27%), or worsening heart failure in 92 (14%). Other precipitants like respiratory tract infection, arrhythmia, volume overload, or treatment noncompliance, accounted for 28% of the cases. Causes of death were reported in few studies\textsuperscript{8,9,30,35,36} and half of the cases were related to shock.

All trials used full face masks (oral-nasal) but nasal masks were also used in 27% of them. Nine studies compared CPAP with conventional oxygen therapy\textsuperscript{3-5,7,8,29-32} 3 of them involved in a 3-branch design concomitantly analyzing NIPSV.\textsuperscript{8,30,32} Six studies compared NIPSV with conventional oxygen therapy\textsuperscript{8,9,30,32-34} 3 being those mentioned with 3 branches. Finally, 6 studies compared CPAP with NIPSV\textsuperscript{8,30,32,35,37} and again, 3 of them also compared conventional therapy. The CPAP level used in these trials ranged from 2.5 to 12.5 cm H\textsubscript{2}O although the most frequent pressure was 10 cm H\textsubscript{2}O. The level of NIPSV was variable. Average IPAP ranged from 14.5 to 20 cm H\textsubscript{2}O with 15 cm H\textsubscript{2}O being the most repeated value. Conversely, EPAP was set at 5 cm H\textsubscript{2}O in most trials. Ventilators used for NIPSV differed substantially from one study to another. Intensive care unit ventilators were used in one trial,\textsuperscript{9} whereas specific NIV portable ventilators were used in the others. Early studies used very simple devices.

In general, methodological quality was acceptable. Eleven out of 15 trial reports described the use of appropriate randomization methods, mainly computer-generated randomization lists.\textsuperscript{4,7-9,31-37} Nine of the studies described the use of a concealed allocation method, all but one using sealed envelopes with or without external randomization.\textsuperscript{3,7-9,31,32,34,36,37} and all studies reported the number of patients, if any, lost to follow-up. Nine studies included sample-size calculations.\textsuperscript{4,7-9,33-37}

![Figure 2. Effects of Noninvasive Ventilation on Death](image-url)
Nine of the studies found significant improvement in at least 1 of the main outcomes for which the trial was designed, whereas all the studies found significant improvement in secondary outcomes. The analysis of the publication bias yielded no significant results for either test or comparison group.

Evidence Synthesis

NIV and Conventional Oxygen Therapy. Pooled data included 727 patients. Overall, NIV significantly reduced the risk of mortality compared with conventional oxygen therapy (P < .001; Figure 2). The results were significant for CPAP, whereas NIPSV tended toward a 40% reduction in the risk of mortality (P = .07). However, the number of patients studied with NIPSV was lower than with CPAP and the proportional weight for NIPSV in the pooled data analysis was only 35%.

When the analysis was performed by intention-to-treat, computing withdrawals as events, RRs and 95% CIs from a random-effects model did not differ significantly, showing a global reduction in mortality risk of 43% for NIV (RR, 0.57; 95% CI, 0.41-0.79; P = .73 for heterogeneity), which was 46% for CPAP (RR, 0.54; 95% CI, 0.36-0.82; P = .40 for heterogeneity) and 37% for NIPSV (RR, 0.63; 95% CI, 0.37-1.06; P = .87 for heterogeneity). Taken together the 2 NIV modalities demonstrated a significant 57% reduction in the need-to-intubate risk (P < .001; Figure 3). The decrease was statistically significant either for CPAP or NIPSV. Similar results were seen when the analysis was performed by intention to treat: 56% reduction in need-to-intubate risk for pooled data (RR, 0.44; 95% CI, 0.34-0.59; P = .31 for heterogeneity), 60% reduction for CPAP (RR, 0.40; 95% CI, 0.28-0.58; P = .23 for heterogeneity), and 49% for NIPSV (RR, 0.51; 95% CI, 0.33-0.78; P = .42 for heterogeneity).

The overall myocardial infarction rate for NIV was 78 (22.5%) of 346, which was similar to that observed for conventional therapy, 78 (26.8%) of 292 (RR, 0.89; 95% CI, 0.69-1.17; P = .99 for heterogeneity). In about 60% of the cases, myocardial infarction was reported as a cause of acute pulmonary edema. Adverse effects like vomiting, abdominal distention, clausrophobia, or skin reactions were infrequent and were reported only in a few patients.

Comparison Between CPAP and NIPSV. Six studies compared CPAP with NIPSV, and 3 of these also compared the 2 techniques with conventional treatment. Overall, the number of patients included in these studies was 219. No differences were seen in the main outcomes, mortality and need-to-intubate rate, in the studies comparing CPAP to NIPSV (Figure 4). Although a slight tendency in favor of NIPSV was observed in relation to the intubation rate, no directional trend in mortality was seen.

COMMENT

This systematic review and meta-analysis demonstrates the effectiveness of noninvasive ventilation to reduce intubation rate and mortality in patients with acute pulmonary edema. In a previous systematic review published in 1998,38 CPAP was associated with a decrease in need for intubation (risk difference -26%) and a trend to decrease mortality, but there was insufficient evidence on the effectiveness of NIPSV, either compared with standard therapy or CPAP, because there were no randomized trials at that time. Nevertheless, in the last 7 years, many studies have been published evaluating either CPAP or NIPSV in patients with acute pulmonary edema. Probably as a result of increased sample size, our meta-analysis including these trials has clearly reinforced the role of CPAP in comparison with conventional therapy, showing a dramatic reduction in the need for intubation (reduction in risk 60%) and a decrease in mortality (47%), which reached
statistical significance. Parallel to these results, NIPSV demonstrated a similar reduction in the need for intubation (52%) and a trend to decrease mortality in comparison with conventional therapy. As in the previous meta-analysis with CPAP, the impact of NIPSV on mortality did not reach statistical significance, possibly because the number of patients included in the model remains underpowered to demonstrate a substantial decrease in mortality. Although additional research would resolve this issue, current evidence on the effectiveness of NIV, especially CPAP, over conventional treatment supports the use of this technique as standard therapy and further comparisons between NIPSV and conventional oxygen therapy would not be considered acceptable.

In the comparison of NIV modalities, NIPSV has the potential advantage over CPAP of assisting the respiratory muscles during inspiration, which would result in faster alleviation of dyspnea and exhaustion. Nevertheless, these physiological benefits did not translate into primary outcomes in our meta-analysis, which did not find differences between CPAP and NIPSV in terms of intubation or mortality. This equivalence remained whether some nonpublished trials not included in the analysis, were incorporated into the model (data available on request). In addition, even in patients with acute pulmonary edema and hypercapnia, a condition usually associated with muscle fatigue, a recent study did not demonstrate differences between these techniques either. Hypercapnic patients were expected to be the target population for NIPSV for physiological reasons and especially after the favorable results in the post hoc analyses of some studies using NIPSV.

The incidence of myocardial infarction for the interventional therapies analyzed in the studies was similar. Although a preliminary study described a higher rate of acute myocardial infarction with NIPSV, no other trial found this incidence and a recent study, specifically addressing this issue, showed no differences between both techniques. Therefore, the question of whether one technique offers advantage over the other and what subset of patients would benefit more with either one of these techniques remains unresolved.

The present meta-analysis has several limitations. First, criteria for diagnosis of acute pulmonary edema are not well established. In the new guidelines on the diagnosis and treatment of acute heart failure proposed by the European Society of Cardiology, 2 types of acute pulmonary edema are recognized: hypertensive crisis and non–hypertensive pulmonary edema. The prognosis in terms of intubation and mortality differs and the proportion of each type of acute pulmonary edema included in the studies was not well defined. Second, the characteristics of the ventilators (displays, leakage compensation, FiO₂ range, trigger, etc), the level of NIPSV used and the experience of the teams were relatively different in the trials and all of these variables may influence the results of this technique. This is not the case for CPAP because it is less dependent on the experience or the device and shows much lower variability in the studies. Third, besides ameliorating fatigue, the main advantage of NIV is to avoid intubation and its associated complications, subsequently reducing the mortality rate. Several studies used rescue NIV, sometimes NIPSV in CPAP groups or either NIPSV or CPAP in conventional groups. This might have introduced some conservative bias in the estimation of the mortality rate. Fourth, although our analysis did not find significant publication bias, this result must be taken with caution due to the low power of tests analyzing this issue when the number of trials is small. Finally, although many trials of this meta-analysis included a small sample size, more than half were powered enough to demonstrate significant differences between interventions in the main outcomes. The limited size of some of these trials, however, reinforces the necessity of our meta-analysis. In addition, it should be men-

![Figure 4. Effects of Continuous Positive Airway Pressure vs Noninvasive Pressure Support Ventilation](image-url)
tioned that the critical phase of acute pulmonary edema, when patients are eligible, may be extremely short because some patients may require immediate intubation or may rapidly ameliorate after starting medical therapy. This rapid evolution has seriously limited the recruitment capacity of the studies.

Despite these limitations our quantitative systematic review of existing literature demonstrates that NIV reduces intubation rate and mortality in patients with acute pulmonary edema. Noninvasive ventilation has recently been categorized as class Ila, level of evidence A, in the guidelines on the diagnosis and treatment for acute heart failure by the European Society of Cardiology.40 Based on some of the trials analyzed in the present study,3,6,9,22,31,35 Given the results of our review, we think that NIV should be strongly considered as a first-line treatment.

Author Contributions: Dr Masip had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Masip, Roque, Sánchez, Fernández.
Acquisition of data: Masip, Roque, Sánchez, Subirana, Expósito.
Analysis and interpretation of data: Masip, Roque, Sánchez, Subirana, Expósito.
Drafting of the manuscript: Masip.
Critical revision of the manuscript for important intellectual content: Masip, Roque, Sánchez, Fernández, Subirana, Expósito.
Statistical analysis: Masip, Roque.
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REFERENCES


