



Acute Respiratory Failure: Noninvasive Ventilatory Support in the Emergency Department

For patients with congestive heart failure, asthma, or COPD who have stable airways, noninvasive ventilatory support may avert the need for intubation and mechanical ventilation, shorten inpatient stays, and decrease patient charges. The emergency department indications and contraindications for the use of noninvasive ventilatory support (CPAP and Bi-PAP) for acute respiratory failure will be described. A limited discussion of related pulmonary physiology will also be presented.

- Discuss the physiology of positive airway pressure support.
- List the emergency department indications and contraindications for noninvasive ventilatory support in the management of patients with acute respiratory failure.
- Describe the differences between CPAP and Bi-PAP.

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*NONINVASIVE VENTILATORY SUPPORT IN THE
EMERGENCY DEPARTMENT*

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I. A History of Noninvasive Ventilatory Support in the Acute Care Setting

- Definition of "noninvasive ventilatory support" (NIVS): any technique that increases alveolar ventilation and oxygenation without placement of an endotracheal tube

- NIVS actually predates endotracheal tubes
 - negative pressure ventilators were reported in the European literature over 150 years ago
 - "iron lung," other "body ventilators" in US during polio epidemics of this century

- Positive Pressure Ventilation (PPV) and endotracheal tubes (ETT) came to the fore in the late 1950s, 1960s
 - interest in noninvasive techniques waned
 - decade-long interest in intermittent positive pressure breathing (IPPB) as a noninvasive therapeutic adjunct for bronchospasm followed; generated much controversy

- Interest in NIVS revived in late 1980s
 - some chronic hypoventilatory states can be managed by nocturnal NIVS with relatively "normal daytime life"
 - better facemasks for CPAP (continuous positive airway pressure--noninvasive equivalent of PEEP)
 - development of method of differential support of inspiration and expiration--BL-PAP (bilevel positive airway pressure)
 - greater appreciation for medical complications of intubation and prolonged ICU stays: *we might not have to intubate as many people as we previously had been*

- Interest in NIVS maintained and strengthened in the 1990s
 - greater appreciation for fiscal complications of intubation and prolonged ICU stays: *we might not want to intubate as many people as we previously had been*
 - cross-pollination of EM training with intensive care training, and "lateral transfer" of technology and interest to ED
 - palliative support in era of "advanced directives"

- Patients who might benefit
 - intact airway, intact but inadequate ventilatory drive; *if both of these are not present, the patient is NOT a candidate for NIVS*

II. Historical and Current Options for Noninvasive Ventilatory Support in the Acute Care Setting

- Why consider the use of NIVS?
 - disadvantages of endotracheal intubation/mechanical ventilation (ETI/MV) expressly addressed by NIVS:
 - sedation, paralysis, and other difficulties of achieving and maintaining an artificial airway
 - need for continuous, intensive monitoring
 - barotrauma
 - nosocomial infections
 - anxiety, discomfort, inability to verbalize
- Limitations of NIVS:
 - does not allow definitive control of the airway
 - does not allow definitive control of ventilation
 - cannot use in apneic patients
 - need for patient cooperation
 - difficulty with secretions
 - aerophagia
 - facial skin necrosis
 - hemodynamic and ICP concerns
- **IPPB**
 - delivers momentary burst of pressure support as patient initiates inspiration; uses mouthpiece or mask
 - IPPB was postulated to
 - decrease work of breathing
 - promote bronchopulmonary drainage
 - deliver aerosolized particles more deeply than those driven by simple nebulizers
 - multiple controlled studies, composite analysis (Gonzalez) revealed no reproducible benefit
 - severely compromised patients mostly not studied
 - fiscal considerations
 - role today
- **Inspiratory Pressure Support Ventilation (IPSV)**
 - delivers more prolonged inspiratory pressure support that ceases before patient's inspiratory effort ends; assist ventilation that is pressure-triggered and pressure-limited
 - was earliest form of NIVS reported with consistent results after IPPB debate ended
 - reduces work of breathing by supporting inspiration in normal controls and in
 - acute COPD exacerbations
 - bronchitis and pneumonia
 - pulmonary edema
 - oversedation

- **Mask Mechanical Ventilation (MMV)**
 - delivers essentially any mode of "mechanical ventilation" noninvasively
 - substitute facemask for ETT as interface between ventilator and patient
 - offers benefits of familiarity, no new equipment
- **Noninvasive PSV**
 - **CPAP**
 - delivers baseline continuous positive airway pressure, below which airway pressure never drops
 - facemask or nose mask
 - physiology: CPAP
 - increases transpulmonary pressure at end-expiration, thereby increasing FRC
 - expands collapsed alveoli; consequent increase in lung volume may lead to increases in lung compliance
 - consistently reduces CO and RBF
 - studies have focused on pulmonary edema; clearly reduces work of breathing
 - may also be useful in
 - blunt thoracic trauma with lung contusion
 - asthma
 - **BL-PAP**
 - adds inspiratory pressure support to CPAP, allowing differential support of inspiratory and expiratory effort
 - operator sets an IPAP (2-25cm H₂O) and an EPAP (2-20cm H₂O); IPAP must be higher than EPAP and the difference between the two is the amount of PSV. When patient initiates an inspiratory effort, negative pressure (as little as 40cc/sec over 30msec) in the circuit is detected, and the IPAP is imposed through the mask. As inspiratory flow decreases, the pressure-supported breath is terminated synchronously with the patient's own breathing pattern. The pressure in the circuit then automatically cycles down to the preset EPAP to allow exhalation with PEEP support. Ordinarily, the patient maintains his own respiratory pattern and expiratory time, but the tidal volume is augmented with relatively little WOB expended.
 - decreases work of breathing in a smooth and synchronous manner
 - shown to be effective in
 - elderly and pediatric patients
 - hypercapnic and hypoxic respiratory distress, whether bronchospastic, infectious, or metabolic in etiology
 - may allow reduction of F_iO₂ to avoid oxygen toxicity

- **Mechanisms of action of noninvasive ventilatory support:**
 - positive pressure is transmitted intermittently through the upper airway to the alveoli, increases transpulmonary pressure, inflates the lungs, and assists alveolar ventilation--same as PPV through an artificial airway
 - patients must learn--on the fly--to coordinate their breathing efforts with the machine so that their spontaneous breathing can be assisted. This typically requires at least 5-20 minutes, so that a trial of NIVS should ideally not be considered "failed" for that long.
 - physiologic studies (summarized in Meyer, 1994) have indicated that
 - NIVS relieves fatigue of respiratory muscles
 - NIVS reverses microatelectasis
 - NIVS reduces overall work of inspiration (see also Elliott, 1994)

III. Studies of Interest to Emergency Physicians

- General Indications for Use of NIVS in the ED:
 - hypoxia and/or hypercarbia
 - urgent need for ventilatory support without an emergent need for endotracheal intubation
 - COPD exacerbation
 - pulmonary edema
 - status asthmaticus
 - neuromuscular weakness
 - DNI patients
 - post-extubation rescue
- Contraindications to Use of NIVS:
 - apnea
 - threat to airway (rare exception)
 - pneumothorax, pneumomediastinum
 - inability to tolerate aerophagia

Classic and New Studies, to early 1999

• Pulmonary edema

- Bersten et al (1991)

INDEX	OXYGEN (N = 20)		OXYGEN PLUS CPAP (N = 19)		P VALUE†
	ENTRY	30 MIN	ENTRY	30 MIN	
Respiratory rate (breaths/min)	32±6	33±9	35±8	27±6	0.008
Arterial pH	7.15±0.11	7.18±0.18	7.18±0.08	7.28±0.06	<0.001
PaCO ₂ (mm Hg)	64±17	62±14	58±8	46±4	<0.001
PaO ₂ :FiO ₂ ratio	136±44	126±47	138±32	206±126	0.01
Arterial plasma lactate (mmol/liter)	4.2±2.5	2.9±1.4	3.5±1.8	2.2±1.2	0.066
Heart rate (beats/min)	117±17	116±15	113±21	104±19	0.037
Systolic BP (mm Hg)	166±32	149±37	177±37	145±27	0.50
Diastolic BP (mm Hg)	99±17	86±17	100±15	87±17	0.77

In this oft-quoted article, 39 patients in acute CHF were randomized to receive CPAP + diuretics and oxygen or diuretics and oxygen only. Within 30 minutes, the CPAP-treated patients had lower respiratory rates, lower PaCO₂, higher pH, and higher PaCO₂:FiO₂ ratios. None required ETI, compared with 7 in the control group. By 24h, however, the differences had disappeared, and there was no difference in mortality or hospital LOS.

- Lin et al (1995)

100 patients admitted to a CCU were treated for CHF with and without intermittent CPAP. All patients had hemodynamic monitoring via a Swan-Ganz catheter. The CPAP group:

- had greater increases in PaO₂
- had greater reduction of intrapulmonary shunt and A-a gradient
- had a higher stroke volume index
- was less likely to require ETI/MV

There was no difference in short-term mortality or hospital LOS.

- Mehta et al (1997)

In the ED of the RI/Brown Hospital, 27 patients in acute pulmonary edema were randomized to receive either BL-PAP or CPAP in addition to standard medical treatment. 13 received CPAP at 10 cm H₂O and 14 received BL-PAP at 15/5. Outcome measures were RR, HR, BP, PaCO₂, pH, and dyspnea scores. After 30 min of treatment, the BL-PAP patients showed significant improvements in all parameters. Only RR improved in the CPAP group. Interestingly, the BL-PAP group sustained a higher incidence of AMI than the CPAP group (CK-MB criteria). This phenomenon has not been reproduced in other studies, nor has it been explained to date.

• Asthma

The application of pressure support to patients with acute

asthma--an air-trapping disease--seems counterintuitive because of the risks of barotrauma and adverse hemodynamic effects. Several studies have shown, however, that CPAP may improve subjective dyspnea and reduce work of breathing in acutely bronchospastic patients. The proposed mechanism is a CPAP-induced relaxation of respiratory muscles that need no longer concern themselves with holding terminal alveoli open. These muscles can then relax momentarily before being recruited to assist inspiration, thereby reducing inspiratory work of breathing. This is directly analogous to the spontaneous pursed-lip breathing exhibited by many bronchospastics, and is clinically evident by abolishment of paradoxical thoracoabdominal motion with CPAP. Similarly, mechanically ventilated asthmatics show reduced air trapping and peak inspiratory pressures when PEEP is applied.

- Martin et al (1982)

Eight asthmatics had acute wheezing induced with aerosolized histamine. CPAP 12cm H₂O was then applied, and FRC, pleural pressures, transdiaphragmatic pressures, and work of breathing were measured. CPAP increased FRC by only 0.27 ± 0.12 L while improving the efficiency and decreasing the energy expenditures of inspiratory muscles.

- Shivaram et al (1987)

Twenty-one acutely ill asthmatics were treated with CPAP at sequential levels of 5, 7.5, and 10cm H₂O. Patients achieved significant comfort levels at 5.3 ± 2.8 cm H₂O. This was attributed to a reduction in pulmonary resistance.

- Shivaram et al (1993)

Twenty-one patients with acute asthma were treated with CPAP for 30 minutes at 5cm H₂O, then 20min without CPAP, then 30min at 7.5cm H₂O, and then 20min without CPAP. Significant reductions in RR occurred at both levels of CPAP, *and these persisted after treatment was discontinued*. There were no significant changes in hemodynamic parameters, but sensation of breathlessness improved significantly at both levels of CPAP. No complications were encountered.

- Lin et al (1995)

Sixteen asthmatics had wheezing induced with methacholine and then were treated with nasal CPAP at 8cm H₂O. FEV₁ increased significantly with CPAP, and indicators of bronchial reactivity and sensitivity both trended in favorable directions. These authors also combined CPAP with β_2 -agonist therapy and noted even greater improvement.

- Pollack et al (1995)

Despite our familiarity with the trials and tribulations of

IPPB in the management of bronchospasm, we tested BL-PAP as an alternative means of delivering beta-adrenergic aerosol agents in unselected patients with acute asthma exacerbation. Unlike IPPB, CPAP is known to improve respiratory mechanics in asthma; since BL-PAP is even better tolerated and clearly reduces work of breathing, we hypothesized that aerosol deposition and overall response might be enhanced with BL-PAP support. We compared standard small-volume nebulizer (SVN) with BL-PAP-augmented (IPAP/EPAP 10/5) delivery of albuterol in two treatments, 20min apart. Peak expiratory flow rate (PEFR and %-predicted PEFR), pulse oximetry, and pulse and respiratory rates were measured at baseline and after each treatment. BL-PAP patients showed a significantly greater increase in PEFR; other parameters were similar. These data warrant further investigation. Our suspicion was that we might see significant beneficial results from treating severe asthmatics with continuous BL-PAP in the ED. Its use in this setting, of course, will require careful clinical monitoring and titration of settings.

- Meduri et al (1996)

17 patients in status asthmaticus were managed initially with BL-PAP for 16 + 21 hrs. Mean IPAP was 18 + 5 cm H₂O; there was no problem with secretions, and oral intake with a liquid diet was preserved. Two patients required sedation. Two of the noninvasively managed patients required ETI/MV. In comparison with these two and four other intubated patients in SA, peak inspiratory pressures were markedly lower in the noninvasive patients.

- COPD

- Bott et al (1993)

This was a randomized, controlled trial of nasal volume-cycled NIVS in 60 patients with COPD/ARF. Patients randomized to NIVS experienced improvement in breathlessness, pH, and P_aCO₂ compared to the control group. Mortality was higher in the control group.

- Confalonieri et al (1996)

This study compared 24 long-term COPDers who originally presented in acute-on-chronic ARF and were treated with BL-PAP and then followed for one year, with 24 matched historical controls over the same interval. 2 BL-PAP patients required intubation; 9 controls were intubated. Hospital stay was significantly shorter in survivors of the BL-PAP group (22/24) than in the control group (21/24) (NS), and 6- and 12-month survival and hospitalization-free interval were better in the group managed noninvasively.

- Brochard et al (1995)

This was a randomized, controlled trial of NIVS in 85 patients with COPD/ARF. Strict criteria for intubation were set. Standard treatment was provided. The NIV group required intubation less frequently (26% vs 74%), and those who failed NIV and were intubated experienced a mortality rate similar to those intubated without prior NIVS, suggesting that there is no increase in mortality associated with the delay.

- Keenan et al (1997)

These authors published a meta-analysis of studies that employed NIVS to treat ARF. A total of seven trials were analyzed. NIVS was associated with decreased mortality (OR = 0.29) and a decreased need for ETI (OR = 0.20). The effect appeared to be restricted to COPD patients.

- Celikel et al (1998)

30 patients in hypercapnic ARF were randomized to standard therapy vs NIVS. All respiratory parameters improved in the NIVS patients. One NIVS patient required rescue intubation. Interestingly, 6 patients in the standard treatment group deteriorated and they were switched to NIVS; this was successful in 4, and 2 required ETI/MV.

• **Pneumonia**

- Wysocki et al (1995)

Among patients in an ARF study there were 16 patients with pneumonia as their primary etiology. None of the 7/16 randomized to NIVS avoid intubation, although there were no untoward effects from the trial.

- Benhamou et al (1992), Pollack et al (1996), and

Meduri et al (1996)

On the other hand, these three studies found at least a neutral effect of NIVS in pneumonia patients. Some of these patients had underlying COPD, some did not. Potential reasons for lack of success of NIVS in pneumonia include secretions, high ventilatory requirements, reduced lung compliance, and focal consolidation.

• **Acute Respiratory Failure**

- Pennock et al (1994)

110 patients with acute respiratory failure "being considered for intubation and mechanical ventilation" were managed instead with BL-PAP and aggressive medical therapy for the underlying condition. The authors reported an 80% success rate and also cited the importance of "talking the patient through" adjusting his/her breathing to the external support.

- Pollack et al (1996)

We used BL-PAP as a management adjunct to aggressive pharmacologic therapy in an uncontrolled study of 50 adult patients who

presented to the ED in acute respiratory distress of any etiology. We enrolled patients who by our clinical judgment (1) would ordinarily have been intubated, put on a ventilator, and admitted to the ICU; (2) would ordinarily have been intubated and put on a ventilator, short-term at least, during management of an acute condition anticipated to be somewhat readily reversible; (3) or required intubation but had DNI advance directives.

<u>etiology</u>	<u>n</u>	
CHF	16	Final IPAP 9 - 22cm H ₂ O
COPD	9	Final EPAP 3 - 9cm H ₂ O
CHF/COPD	3	clinical/ABG improvement in 43/50
Pneumonia	10	2 did not tolerate
Status asthmaticus	6	5 treatment failures
Acute vent failure	6	3 eventually intubated; 2 DNI
Subset: DNI	(10)	

Of the 40 patients who were not DNI and would presumably have been admitted to the ICU in the absence of BL-PAP support, 52.5% were admitted to step-down areas. Our conclusion was that BL-PAP is a useful and efficacious treatment modality in the ED for acute respiratory distress of multiple etiologies.

- Meduri et al (1996)

158 patients with hypoxemic ARF (41), hypercapnic ARF (52), hypercapnic acute respiratory insufficiency (22), ARF with DNI (26), and 17 with other ARF were treated with mask ventilation set as CPAP plus PSV titrated per ABGs. Mean duration of support was 25 + 24 hours. There was an 80% improvement rate and a 65% ETI avoidance (excluding DNI patients). Survival was 93% in nonintubated patients and 79% in intubated patients. The higher the initial P_aCO₂, the less likely was the patient to respond. In hypercapnic patients, response of pH and P_aCO₂ within 2h predicted success.

- Antonelli et al (1998)

64 patients with hypoxemic ARF were randomized to conventional therapy vs NIVS. Improvement was quicker and more striking in the NIVS group. Rates of rescue intubation, mortality, and serious complications were significantly lower in the NIVS group. There was no difference in pneumonia outcomes.

- Wood et al (1998)

This is an ED study from Barnes-Jewish Hospital. 27 patients were randomized to NIVS or conventional support for ARF of various etiologies. The authors were concerned that the need for

intubation and mortality rates were actually *higher* in the NIVS group, although the differences were not significant. However, accurate inclusion criteria were not employed in this study, and there is some concern that ETI/MV was unduly delayed in some patients assigned to NIVS who ultimately were intubated.

- **Pediatrics**

- Fortenberry et al (1995)

This is the first study of more-than-a-few pediatric patients treated with BL-PAP for acute respiratory distress. Twenty-eight patients (age 4m-14y) with acute hypoxemic respiratory failure were studied. The most common underlying problem was pneumonia; neuromuscular disease was next. Mean duration of BL-PAP support was 72h. Salutary effects were noted on RR, P_{aO_2} , pulse oximetry, pH, A-a gradient, and $P_{aO_2}:F_{iO_2}$ ratio. Only 3 patients required intubation (89% success rate).

- Padman et al (1998)

This was a prospective study of 34 patients (age 6 mos-20 yrs) with impending ARF. There was no randomization. There was improvement in over 90% of patients, only 8% of who required intubation. NIVS failure was characterized by an inability to stabilize progression of respiratory fatigue.

- **Setting up BL-PAP**

To set up BL-PAP for an ED patient, I suggest that you start with a setting of IPAP/EPAP 8/3 to 10/5. Remember always that COPD'ers and, to a lesser extent, asthmatics, always have PEEP on board (so-called "auto-PEEP"), so these patients typically will not require as high an EPAP as will patients with, for example, pulmonary edema. Titration of the settings requires *close clinical monitoring* of the patient, just as does the use of a formal ventilator. Remember that the titratability of BL-PAP is both a blessing and a curse! To titrate, **move IPAP and EPAP in tandem**. That is, move from 8/3 to 10/5 to 12/7 as you see benefits to therapy. Remember that the longer the patient wears the mask, the easier it becomes for him/her to "breathe with" the machine. For COPD'ers, you may wish to disengage the EPAP from the IPAP at EPAP > 9cm H₂O or so. In our series of CHF patients, the average final settings were 12/6; for COPD'ers, the average was 13/4; for status asthmaticus, 16/5; and for pneumonia/hypoxia, 14/6; these average settings by themselves, please note, have no clinical significance. It is important to give experienced respiratory care practitioners the autonomy to perform this titration independently.

IV. Potential Fiscal Impact of Noninvasive Ventilatory Support in the Acute Care Setting

- Habib has presented data from 82 patients at Kaiser-Vallejo who were placed on BL-PAP either in the ED or shortly after ICU admission for acute respiratory distress. 64 (78%) were successfully supported; the average duration of BL-PAP support was 1.6 days, compared to historical controls of 6.8 days on ETT/MV. He projected that 324 ICU days were avoided, at a cost savings of almost \$400,000.

- Our data revealed that over 50% of patients ordinarily requiring ICU admission for acute respiratory distress could be admitted to a lower level of care if BL-PAP is used as an adjunct to aggressive pharmacologic therapy in the ED.

V. Directions for the Future

The best growth opportunity for NIVS in emergency medicine is in its proper utilization for acute ventilatory support and the appropriate avoidance of ETT/MV to optimize patient care. We are simply translocating technology and expertise that is currently utilized in the intensive care units to a *different* critical care setting. Larger studies are needed to encourage this development.

The use of BL-PAP in pediatric patients is only beginning to be explored. There is a growing experience in the PICU with patients with anatomic abnormalities that impede ventilation, and in patients with cystic fibrosis. I think we are seeing a similar course of development to that of several years ago when BL-PAP first began to be used in adult intensive care units. Hopefully, emergency medicine can help lead the research into pediatric use of BL-PAP.

The prehospital application of BL-PAP is an area of interest to emergency physicians, as research into its utility there is entirely within our bailiwick. The machines are compact, light, and easy to use. The difficulty in this area of research will be establishing criteria for patient selection.

A final potential utility for NIVS in the ED is the "re-charging" of relatively stable COPD patients. This is analogous to regimens in some ED observation units by which patients with chronic CHF report regularly for diuresis and a few hours of a low-dose dobutamine infusion. Patients with severe stable COPD and chronic hypercapnia have been managed with regular 2h BL-PAP treatments and avoided formal hospitalization (and, presumably, ED visits) (Ambrosino).

Emergency physicians who are unfamiliar or uncomfortable with this technology are encouraged to consult their colleagues in critical care/pulmonary medicine or their Respiratory Therapy Department. In addition, please feel free to write or e-mail me with any comments or questions.

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