PRELIMINARY REPORTS

PREHOSPITAL USE OF CONTINUOUS POSITIVE AIRWAY PRESSURE (CPAP) FOR PRESUMED PULMONARY EDEMA:

A PRELIMINARY CASE SERIES

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ABSTRACT

Objective. To describe the prehospital use of a continuous positive airway pressure (CPAP) system for the treatment of acute respiratory failure presumed to be due to cardiogenic pulmonary edema. **Methods.** Prospective case-series analysis. Paramedics administered CPAP via face mask at 10 cm H_2O to patients believed to be in cardiogenic pulmonary edema and in imminent need of endotracheal intubation (ETI). Data from run sheets and hospital records were analyzed for treatment intervals, vital signs, complications, admitting diagnoses, need for ETI, and mortality. **Results.** Nineteen patients received prehospital CPAP therapy. Mean duration of therapy was 15.5 minutes. Pre- and post-therapy pulse oximetry was available for 15 patients and demonstrated an increase from a mean of 83.3% to a mean of 95.4%. None of the patients were intubated in the field. Two patients who did not tolerate the CPAP mask required ETI upon arrival in the emergency department (ED); an additional five patients required ETI within 24 hours. There was one death in the series and two additional adverse events (one aspiration pneumonia, one pneumothorax); none of these were attributable to the use of CPAP. The diagnosis of cardiogenic pulmonary edema was corroborated by the ED or in-hospital physician in 13 patients (68%). Paramedics reported no technical difficulties with the CPAP system. **Conclusion.** For patients with acute respiratory failure and presumed pulmonary edema, the prehospital use of CPAP is feasible and may avert the need for ETI. Future controlled studies are needed to assess the utility and cost–effectiveness of prehospital CPAP systems. **Key words:** continuous positive airway pressure; emergency medical services; heart failure; pulmonary edema.

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Cardiogenic pulmonary edema is associated with significant morbidity in the prehospital setting.[1] While prehospital therapy with oxygen, nitrates, morphine, and furosemide is often effective, patients with progressive respiratory failure generally require ventilatory support. Administering continuous positive airway pressure (CPAP) by face mask has been shown to reduce the need for endotracheal intubation (ETI) and mechanical ventilation in hospitalized patients with severe cardiogenic pulmonary edema.[2–5] Although the decision to use CPAP is dependent on a variety of factors, the presumption is that the earlier therapy is instituted, the greater the likelihood of averting ETI. Modern systems for delivering CPAP are compact and simple to operate, making the prehospital use of CPAP conceivable. On the other hand, paramedics face challenges unique to the prehospital setting that may affect how well CPAP performs and how well patients tolerate it. This paper describes our initial experience with the prehospital use of CPAP for patients with respiratory failure and presumed pulmonary edema. We direct particular attention to issues of patient selection, safety, and potential avoidance of ETI.

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Methods

EMS System

The City of Cincinnati uses a two-tiered, fire department-based emergency medical services (EMS) response system, employing approximately 600 basic emergency medical technicians (EMT-Bs) and 120 paramedics. Engine companies are the first-responding units and are primarily staffed by EMT-Bs. Patients are taken to area hospitals by one of six EMT-B-staffed ambulances or four paramedic-staffed transport units, depending on the level of acuity. Approximately 32,000 patient transports are made annually.

CPAP System

Each of the four paramedic transport units was equipped with the Caradyne Whisperflow System (Caradyne Limited, Galway, Ireland). This system uses a precision Venturi device attached to a high-pressure oxygen source to generate flows of up to 150 L/min. Flow was delivered via 22-mm disposable ventilator circuitry to a twin-port, soft-seal face mask, with a threshold resistor valve set to maintain CPAP at 10 cm H_2O. This level of positive pressure was chosen based on the results of controlled trials of CPAP for acute pulmonary edema in hospitalized patients.[2–4] An in-line oxygen analyzer was added to allow measurement of fractional inspired oxygen concentration (F_iO_2). When the system was in use, minimum F_iO_2 was 35%, but this could be increased up to 95% by adjusting the oxygen-to-air entrainment ratio of the Venturi device. Figure 1 depicts the CPAP system installed in one of the paramedic transport units.

Paramedic Training

Paramedics received a minimum of four hours of instruction before they were authorized to use CPAP.[6] Courses consisted of a one-hour lecture focusing on appropriate patient selection, with discussion of specific indications for and contraindications to CPAP, followed by three hours of small-group sessions, including hands-on training with the CPAP system led by experienced physicians and respiratory therapists. Training was reinforced with periodic site visits to station houses. An ongoing dialogue was maintained with the paramedics to elicit any concerns regarding technical or methodological issues.

Table 1. Clinical Criteria for the Use of Continuous Positive Airway Pressure (CPAP) in the Prehospital Setting

Indications for CPAP
Severe retractions or accessory muscle use
Respiratory rate > 25 breaths/min
Bilateral or diffuse rales
History consistent with heart failure or volume overload
Contraindications to CPAP
Respiratory or cardiac arrest
Inability to maintain airway patency
Unresponsiveness to speech
Systolic blood pressure <90 mm Hg
Vomiting or active upper gastrointestinal bleeding

Patient Selection

Any patient with respiratory distress transported by a paramedic transport unit to one of three participating emergency departments (EDs) between January and April 2000 was potentially eligible for CPAP therapy. At the discretion of the paramedics, CPAP was administered to patients who were believed to be in acute cardiogenic pulmonary edema and in imminent need of ETI. For purposes of this study, specific indications and contraindications for CPAP (Table 1) were taught in training sessions and posted in each of the paramedic transport units. These criteria were adapted for the prehospital setting from controlled trials of CPAP for cardiogenic pulmonary edema in hospitalized patients.[2–4]

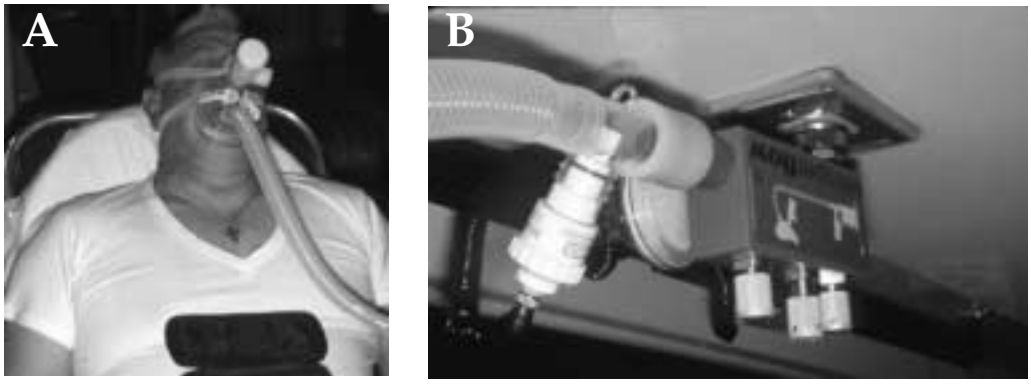

Figure 1. (**A**) The system for delivering continuous positive airway pressure (CPAP) in the prehospital setting. The Venturi device (**B**) is attached to a high-pressure oxygen source on the ceiling. Flow is delivered via 22-mm disposable tubing to a face mask equipped with a threshold resistor valve set to maintain CPAP at 10 cm H_2O.

TABLE 2. Characteristics of Patients Who Received Prehospital Continuous Positive Airway Pressure (CPAP) Therapy*

			Pre-CPAP		Post-CPAP			Intubation			
	Age	Sex	RR	Pulse Ox	RR	Pulse Ox	Treatment Time Prehospital (Min)	Field	Hospital	Primary Diagnosis	LOS (Days)
Patient 1	60	Female	32	62	Agonal	98	20	No	Yes	CHF	13
Patient 2	84	Male	50	84	32	87	20	No	No	CHF	3
Patient 3	71	Female	28	84	20	100	20	No	No	COPD	4
Patient 4	61	Female	60	82	45	94	5	No	Yes	CHF	12
Patient 5	76	Female	40	62	40	86	10	No	Yes	Pneumonia	11
Patient 6	75	Female	32	82	32	95	5	No	No	CHF	9
Patient 7	74	Male	30	94	UTO	UTO	<1	No	Yes	CHF	8
Patient 8	51	Female	26	96	30	97	14†	No	No	COPD	6
Patient 9	75	Female	28	84	32	98	15	No	No	CHF	3
Patient 10	62	Male	28	UTO	36	93	15	No	No	CHF	6
Patient 11	62	Female	30	94	36	97	19	No	No	CHF	2
Patient 12	90	Female	28	UTO	27	99	18	No	No	CHF	3
Patient 13	64	Female	40	84	44	89	15	No	No	Pneumonia	9
Patient 14	52	Male	28	UTO	32	98	22	No	No	CHF	9
Patient 15	88	Female	28	85	32	98	8	No	Yes	CHF	7
Patient 16	63	Female	30	86	34	98	20	No	No	CHF	1
Patient 17	61	Male	36	82	38	92	14	No	Yes	COPD	10
Patient 18	58	Male	38	88	28	98	28	No	Yes	ICH	6‡
Patient 19	83	Female	34	84	28	100	10	No	No	CHF	2
Mean	68.9		34	83.3	33.3	95.4	15.5				6.6
Median	64		30	85	32	98	15				6.5

*RR = respiratory rate (breaths/min); Pulse Ox = pulse oximetry (%); LOS = length of stay; UTO = (paramedics) unable to obtain; CHF = congestive heart failure; COPD = chronic obstructive pilmonary disease; ICH = intracranial hemorrhage.

†Patient was receiving CPAP at home when emergency medical services arrived.

‡Death.

Protocol for Administering CPAP

Upon arrival of first responders, patients were placed on standard high-flow oxygen via non-rebreather face mask. Once inside a paramedic transport unit, CPAP was applied at a fixed level (i.e., 10 cm H_2O), with F_iO_2 adjusted according to pulse oximetry and degree of dyspnea. The use of standard prehospital medical therapy for congestive heart failure (e.g., nitroglycerin, furosemide, morphine) was unrestricted. Paramedics were instructed to notify the receiving ED that a patient had been placed on CPAP so that the ED staff would have a CPAP device ready to use upon patient arrival. Any deterioration in mental status, vital signs, pulse oximetry, or degree of dyspnea was reported to medical control and managed in accordance with existing EMS protocols, including discontinuation of CPAP and preparation for ETI if necessary. If a patient was unable to tolerate the face mask, CPAP was promptly discontinued. Upon arrival at the receiving ED, patient care was assumed by ED staff, and the decision whether to continue CPAP was left to the ED physician.

Data Analysis

During the period of study, a log of all paramedic transports for respiratory distress was compiled. Call identification numbers of patients who received CPAP therapy were flagged for future data retrieval. The EMS run sheets, ED records, and hospital discharge summaries were recovered for all CPAP patients and analyzed with respect to demographics, treatment intervals, vital signs (pre- and post-CPAP therapy), complications (vomiting, aspiration, pneumothorax, hypotension, mask intolerance), protocol violations, and admitting diagnoses (i.e., the primary etiology of respiratory failure). The pre-CPAP respiratory rate and pusle oximetry were taken from the first set of vital signs recorded with the patient receiving oxygen via non-rebreather face mask. The post-CPAP respiratory rate and pulse oximetry were taken from the final set of vital signs recorded in the field, or (if no post-CPAP vital signs were recorded in the field) from the first set of vital signs recorded upon arrival to the ED. Specific outcomes investigated were rate of ETI (prehospital and in-hospital), length of hospital stay (LOS), and mortality. Descriptive statistics, including percentages, means, medians, and ranges, were reported.

Study Approval

Approval for this study was obtained from Cincinnati Fire Division and from the institutional review board (IRB) of each of the receiving hospitals. Written, informed consent was obtained from all patients or next-of-kin at the time of entry into the study.

Results

During the period of study, 182 patients with respiratory distress were taken by paramedic transport unit to one of the three receiving EDs. Nineteen patients (10.4%) received prehospital CPAP therapy. Patient age ranged from 51 to 90 years, with a mean of 68.9 years. Table 2 summarizes the study population.

The mean duration of prehospital CPAP therapy was 15.5 minutes, with a range from less than 1 minute to 28 minutes. One patient was using a nonportable CPAP device at home when EMS arrived and was switched over to the paramedic transport unit's CPAP system for transport. Pre- and post-therapy respiratory rates were available for 17 patients. The mean respiratory rate was 34.0 breaths/min before CPAP and 33.3 breaths/min after CPAP. Pre- and post-therapy pulse oximetry readings were available for 15 patients and demonstrated an increase from a mean of 83.3% to a mean of 95.4%.

None of the CPAP patients was intubated in the field. Two patients did not tolerate the CPAP mask and required ETI immediately upon arriving in the ED. An additional five patients required ETI within 24 hours of presentation (mean time to ETI = 157 min). Three of these patients ultimately had non-congestive heart failure (non-CHF) diagnoses. Of the two remaining patients who required ETI, one presented with acute pulmonary edema in the context of ST-elevation myocardial infarction and was intubated electively for emergent angioplasty; the other patient became progressively fatigued while on CPAP and was intubated semi-electively 60 minutes after arrival.

Among the patients who survived to hospital discharge, median LOS was 6.5 days: 11 days for patients who required ETI (range: 7–13 days) and 3.5 days for patients who did not (range: 2–9 days).

No adverse event was related to prehospital CPAP therapy. One patient was diagnosed as having aspiration pneumonia. Vomiting, aspiration, and resultant respiratory distress had preceded the application of CPAP, and the patient remained on noninvasive ventilatory support for 72 hours without complications. One patient developed a simple pneumothorax. He had failed CPAP, requiring ETI shortly after arriving in the ED for what was felt to be a severe exacerbation of chronic obstructive pulmonary disease (COPD). The pneumothorax did not become evident radiographically until after 24 hours of positive pressure ventilation. No patient developed hypotension as a consequence of CPAP therapy. The one death in this series occurred in a patient with a massive intracranial hemorrhage that precipitated respiratory failure in the field and ultimately proved to be fatal.

The diagnosis of cardiogenic pulmonary edema was corroborated by ED or in-hospital physicians in 13 patients (68%). Of the six patients with other primary diagnoses (three COPD, two pneumonia, one intracranial hemorrhage), three required ETI within the first 24 hours, and median LOS among survivors was 9 days (range: 6–11 days).

The paramedics reported no technical or logistical problems with the prehospital CPAP system. With respect to four patients, paramedics failed to recognize potential contraindications to CPAP therapy (one patient with history of vomiting, two patients with altered level of consciousness, one patient with both). No complication resulted from the use of CPAP in these situations, but three of the four ultimately required ETI.

Discussion

Over the past two decades, noninvasive approaches to delivering positive airway pressure have been increasingly advocated as a means of averting the hazards and complications associated with ETI and mechanical ventilation.[7] In the case of patients with severe cardiogenic pulmonary edema, mask-applied CPAP has clearly been shown to reduce the need for ETI.[2–4] Data also suggest that the use of CPAP may be associated with a trend toward decreased mortality in these patients.[5] In theory, the benefits of CPAP would be expected to carry over to the prehospital setting, where patients with acute cardiogenic pulmonary edema are first encountered. In European countries, CPAP is used in physician-staffed mobile intensive care units.[8] But aside from anecdotal descriptions, the prehospital use of CPAP has not been reported in this country.[9] Our case series demonstrates the successful use of CPAP by paramedics to treat patients believed to be in acute cardiogenic pulmonary edema and in imminent need of ETI.

Continuous positive airway pressure improves lung mechanics by recruiting atelectatic alveoli, improving pulmonary compliance, and reducing the work of breathing.[10] At the same time, and particularly in patients with CHF, CPAP improves hemodynamics, by reducing preload and afterload.[11] Positive airway pressure reduces venous return to the left ventricle, and in the context of a failing left ventricle, this reduction in preload may improve cardiac function.[12] Positive airway pressure is also transmitted to the left ventricle, reducing transmural pressure and thereby enhancing left ventricular performance.[13,14]

In our case series, most patients had noticeable improvement in oxygenation within minutes of administering CPAP. This is consistent with prior reports from case series and controlled trials of CPAP among hospitalized patients with pulmonary edema.[2–4,14–16] The response to CPAP in terms of respiratory rate was less apparent, as has been observed previously.[2,3] The fact that most of our patients

showed improvement within minutes suggests that CPAP may be valuable even in an environment where transport times are relatively short. Even for those patients who ultimately require ETI, CPAP may serve as a bridge for patients until they arrive in the ED where the airway can be managed in a more controlled setting.

Two of the patients in our series were intolerant of the CPAP mask and required ETI upon arrival to the ED. Previous trials of CPAP among hospitalized patients have generally not reported significant rates of face-mask intolerance. Although it is conceivable that this disparity is due to a feature of the particular face mask used, we think it is more likely a consequence of the prehospital treatment environment. Patients frequently experience apprehension and require coaching to leave a CPAP mask in place. In some circumstances, readjusting the mask fit or titrating the amount of positive pressure can help improve patient tolerance. In the hospital setting (and particularly in the context of an ongoing trial), this type of support is provided by a dedicated respiratory therapist. In contrast, the paramedic operating in the prehospital setting is unlikely to have the time or the expertise to fully attend to these matters. Future trials of prehospital CPAP systems should take this into consideration.

Overall, 12 of the 19 patients in our series (63%) avoided the need for ETI. This is comparable to the 57% success rate seen among hospitalized patients treated with CPAP for non-differentiated respiratory failure.[17] Trials of CPAP for confirmed cardiogenic pulmonary edema have reported rates of success ranging from 65% to 100%.[2–4,15,16,18] Some of this variability is undoubtedly due to differences in patient selection, as evidenced by a range of ETI rates among the control populations of various trials. Moreover, a number of previous trials have excluded patients who required ETI early in their courses.[4,16,18] Our case series is unique in that selection of patients for CPAP was made early and entirely on clinical grounds, without benefit of blood gases, chest radiography, or invasive hemodyanamic monitoring. To truly assess the efficacy of CPAP in the prehospital setting, a well-designed, prospective, controlled clinical trial is required.

Among the 18 patients in our series who survived to hospital discharge, median LOS was 6.5 days. Studies among hospitalized patients have reported median LOSs in the same range and have found trends towards reduced LOS in patients treated with CPAP.[3,4] In our series, the LOS for patients who required ETI appeared to be longer than the LOS for patients treated successfully with CPAP, though this most likely reflects the severity of their underlying illness. The possibility that averting ETI in and of itself contributed to a reduction in LOS can neither be confirmed nor refuted without a large, controlled trial.

In our case series, no major complication was attributable to the use of CPAP, consistent with the safety profile of CPAP reported in other settings.[19] Clinically significant gastric insufflation is rare at pressures of less than 30 cm H_20, and aspiration of gastric contents has a very low incidence.[19] In our case series, the one case of documented aspiration pneumonia preceded CPAP therapy. Pneumothorax, although a theoretical consideration, has not been previously reported with conventional CPAP. The one patient in our case series who developed a pneumothorax did so following ETI and mechanical ventilation. Because positive airway pressure can reduce venous return to the heart, patients receiving CPAP are considered at risk for developing hypotension. None of the patients in our series had this problem. Minor, local complications such as skin abrasions, sinus complaints, and conjunctivitis are the problems most commonly reported with CPAP. However, given the short duration of therapy, we were unlikely to encounter these problems in our case series.

Only slightly more than two-thirds of the patients in our series were given an admitting diagnosis of cardiogenic pulmonary edema. We did not attempt to validate the diagnoses made by hospital physicians or to clarify the basis for divergent opinions. For the purposes of this study, we assumed that the in-hospital diagnoses were the more likely to be accurate. Ours is not the first study to suggest that prehospital diagnosis of pulmonary edema can be difficult. Previous studies have found that paramedics are correct in their diagnosis of cardiogenic pulmonary edema only 70% to 89% of the time.[1,20,21] Emergency physicians have an equally hard time making this diagnosis on entirely clinical grounds.[22] In our study there may also have been individual cases where the paramedics instituted CPAP therapy even though they were uncertain whether the primary etiology of respiratory failure was cardiogenic.

Although the numbers in our series were small, CPAP appeared to be less likely to avert ETI in patients who did not have cardiogenic pulmonary edema. This may simply be reflective of the underlying severity of illness among patients with alternative diagnoses, as evidenced by their increased median LOS. In fact, several reports have suggested that CPAP is useful for the treatment of respiratory distress due to noncardiogenic etiologies, such as pneumonia[23] and COPD.[24–26] Larger, controlled trials are needed in order to distinguish how well CPAP performs with respect to alternative etiologies of respiratory failure.

No technical or logistical problem with the prehospital CPAP system was reported. Although no formal attempt was made to receive feedback from every paramedic, we believe that the ongoing dialogue between researchers and paramedics promoted an

atmosphere in which any concerns would have been freely raised.

As our study was designed, the paramedics were taught criteria on which to base the use of CPAP, but individual decisions were left to their discretion. Analysis of the run sheets demonstrated that all patients who received CPAP met the basic indications set forth with regard to respiratory rate, work of breathing, and presence of rales. However, four patients were given CPAP in spite of potential contraindications. Although no complication resulted from the use of CPAP in these instances, the inclusion of these patients (three of four of whom required ETI) adversely affected the overall success rate. Future efforts should focus attention on the important contraindications to CPAP.

The success of CPAP therapy depends on appropriate patient selection, and caution must be taken to avoid any intervention that could be deleterious in the prehospital setting. For patients with compromised upper airway function or significantly altered level of consciousness, ETI should remain the treatment of choice. Also, patients with cardiac arrest, unstable cardiac rhythms, or cardiogenic shock are generally not considered to be candidates for CPAP and have been excluded from major clinical trials.[2–4] Patients with excessive secretions are poor candidates for CPAP because there is no direct access for removal of secretions, and frequent expectoration interferes with the maintenance of positive airway pressure. Finally, in the setting of severe myocardial ischemia or infarction, ETI with full ventilatory support may be preferable to CPAP, because the work of breathing increases myocardial oxygen demand.[5]

On the basis of this case series alone, CPAP cannot be recommended for general use in the prehospital setting. Larger, controlled clinical trials are required to demonstrate not only safety and efficacy, but also cost–effectiveness. For example, the expense of equipment, maintenance, training, and quality assurance may end up being prohibitive for some EMS systems. Prehospital CPAP may prove to be most useful in EMS systems in which transport times are long and personnel with advanced airway skills are not readily available. However, at present prehospital CPAP remains an investigational therapy that should not be routinely implemented outside the context of an IRB-approved research study.

Conclusions

This case series suggests that for patients with respiratory failure and presumed pulmonary edema, the prehospital use of CPAP is feasible and may avert the need for ETI. Future work should focus on helping paramedics to identify patients most likely to benefit from early application of CPAP. Controlled clinical trials are needed to address the overall utility and cost–effectiveness of CPAP systems in the prehospital setting.

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Instructions for Authors of Case Conferences

The case conference format may be used for the presentation of interesting or unusual EMS encounters. This format can illustrate specific medical entities, unusual approaches to field management, or complex administrative issues that a field scenario may present. Authors should pay particular attention to the educational value of the manuscript, and avoid a purely descriptive approach. Features such as a team approach and innovative solutions to atypical problems should be stressed. While an abstract and specific section headings are not required, the following sections should be considered:

1. overall description of the scene, types of responding agencies and personnel, etc.
2. specific challenges encountered
3. solutions developed to address the challenges
4. discussion of medical issues involved, with review of the literature where appropriate
5. discussion of logistic and administrative issues

Title page, group authorship and acknowledgments page, references, and tables and figures (where appropriate) should follow the same format as for general manuscripts (see the "Manuscript Preparation" section of the "Instructions for Authors" following the text of most issues of *Prehospital Emergency Care).*