Estimates of Cost-Effectiveness of Prehospital Continuous Positive Airway Pressure in the Management of Acute Pulmonary Edema

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Abstract

Objective. To estimate the cost-effectiveness of continuous positive airway pressure (CPAP) in managing prehospital acute pulmonary edema in an urban EMS system. **Methods.** Using estimates from published reports on prehospital and emergency department CPAP, a cost-effectiveness model of implementing CPAP in a typical urban EMS system was derived from the societal perspective as well as the perspective of the implementing EMS system. To assess the robustness of the model, a series of univariate and multivariate sensitivity analyses was performed on the input variables. **Results.** The cost of consumables, equipment, and training yielded a total cost of $89 per CPAP application. The theoretical system would be expected to use CPAP 4 times per 1000 EMS patients and is expected to save 0.75 additional lives per 1000 EMS patients at a cost of $490 per life saved. CPAP is also expected to result in approximately one less intubation per 6 CPAP applications and reduce hospitalization costs by $4075 per year for each CPAP application. Through sensitivity analyses the model was verified to be robust across a wide range of input variable assumptions. **Conclusion.** Previous studies have demonstrated the clinical effectiveness of CPAP in the management of acute pulmonary edema. Through a theoretical analysis which modeled the costs and clinical benefits of implementing CPAP in an urban EMS system, prehospital CPAP appears to be a cost-effective treatment.
Keywords:EMS, emergency medical services, paramedic, continuous positive airway pressure, pulmonary edema, cost-effectiveness

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Introduction

Approximately 5 million Americans suffer from heart failure with an estimated 550,000 new cases diagnosed in the United States each year.[1] With a 5-year mortality rate approaching 50%, CHF is the most common cause of hospitalization in patients over the age of 65 and is one of the most expensive diagnoses in the U.S. health care system.[2]

Recently, the use of prehospital continuous positive airway pressure has been suggested as an effective treatment strategy for acute pulmonary edema (APE).[3–4] In a previous report comparing standard therapy with CPAP against standard therapy alone in the prehospital setting, we noted a 16% absolute risk reduction in the need for intubation and an 18% absolute risk reduction in mortality.[4] For CPAP to be implemented widely, however, it is necessary to demonstrate the procedure is cost-effective. The purpose of this study was to estimate the cost-effectiveness of prehospital CPAP therapy compared with no CPAP in the management of cardiogenic pulmonary edema in an urban EMS system.

Methods

With approval of the Western Carolina University IRB, we developed a cost-effectiveness model of prehospital CPAP from the societal perspective as well as a cost analysis of the implementing EMS system. The base-case calculations of cost-effectiveness were derived, in part, from our previously reported evaluation of CPAP in an urban EMS system with 14 ambulances, 114 employees, and 29,500 annual responses, of which 0.41% (4 per 1000 EMS responses) are patients identified by the treating paramedic as having APE.[4] All cases of presumed APE were included using an intent to treat methodology. Where necessary, additional data for input variables and sensitivity analyses were gathered from the published literature.

Estimation of CPAP Costs and Benefits

The costs of implementing CPAP include equipment, training, disposable goods, and oxygen. We treated the initial purchase of the CPAP unit as a capital expenditure which was expensed over a projected useful lifespan of 5 years. The training costs were based on two hours of training per year for personnel whose average hourly wage rate was $17.22 including benefit costs. The cost per patient for disposable goods was estimated at $35 for the mask and circuit and $5 for oxygen. All of the costs associated with CPAP are reported in 2006 U.S. dollars (Table 1).

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TABLE 1. Base-Case Cost-Effectiveness Calculations for Prehospital CPAP

EMS system characteristics	
Call volume	29,500
CPAP use as % of call volume	0.41%
Projected annual CPAP uses	120
Projected annual CPAP uses per 1000 EMS responses	4.06
Total employees	114
Total ambulances	14
CPAP training costs	
CPAP training time (hours)	2
Costs per hour of training time per employee	$17.22
Total training costs for 114 employees	$3,926.16
Total training costs per CPAP use	$32.72
CPAP equipment costs	
Cost per CPAP unit	$700.00
Total CPAP costs for 14 ambulances	$9800.00
CPAP life cycle (years)	5
Total annual CPAP unit costs	$1,960.00
Annual CPAP Unit cost per use	$16.33
CPAP supply costs	
Oxygen cost per use	$5.00
Cost of disposable goods per use	$35.00
Total supply costs per use	$40.00
Total CPAP cost per use (training + equipment + supplies)	$89.05
Cost of CPAP per life saved	
Potential CPAP uses	120
Expected deaths without CPAP (23.16% mortality rate)	28
Expected deaths with CPAP (5% mortality rate)	6
Additional lives saved with CPAP	22
Additional lives saved with CPAP per 1000 EMS responses	0.746
Total annual CPAP costs (training + equipment + supplies)	$10,686.16
Total cost per additional life saved	$490.43
Reduction in hospitalization costs	
Percentage of non-CPAP patients intubated	25.26%
Percentage of CPAP patients intubated	8.93%
Total number of non-CPAP patients expected to require MV	30
Total number of CPAP patients expected to require MV	10
Reduction in number of patients requiring intubation and MV	20
Number needed to treat (NNT) to avoid 1 intubation	6
Excess LOS for patients requiring MV	4.98
Mean cost for excess days of MV per patient in 2002 U.S. dollars	$20,874
Adjustment factor to convert 2002 dollars into 2006 dollars	1.20
Mean cost for excess days of MV per patient in 2006 U.S. dollars	$24,986
Total annual cost savings through reduction of ICU MV days	$499,717
Total annual cost of prehospital CPAP	$10,686
Net annual cost reduction of prehospital CPAP	$489,031
Average cost reduction per application of CPAP	$4,075

For the point estimates of prehospital CPAP clinical benefits, we used the absolute risk reduction in mortality rate of 18% and intubation rate of 16% from our previous study.[4] A reanalysis of our data revealed that patients who required mechanical ventilation had a mean hospital length of stay of 10.82 days compared with 5.84 days for those who avoided mechanical ventilation ($p = 0.01$). We assumed that all of the additional 5 hospital days for intubated patients were ICU days with mechanical ventilation. This is consistent with the findings of Seneff, et al who reported a mean of 5.16 ventilator days for CHF patients requiring mechanical ventilation.[5]

Estimation of Hospitalization Costs

Hospitalization costs were estimated based on the findings of Dasta, et al. who analyzed the daily costs of an intensive care unit stay.[6] In their analysis of 13,419 medical ICU admissions requiring mechanical ventilation, they reported a mean daily cost of $5,366, $4,306, and $3,759 for ICU days 1, 2, and 3 respectively. All days beyond day 3 incurred costs at the same rate as day 3 ($3,759). These costs were reported in 2002 U.S. dollars, which we converted to 2006 dollars using the consumer price index for medical services.[7]

Sensitivity Analysis

To assess the robustness of our model, we performed a series of univariate sensitivity analyses by modifying input variables to assess their impact on cost-effectiveness. The variables of interest were the intubation rate, mortality rate, potential number of annual CPAP applications, duration of mechanical ventilation, and the cost per ICU day with mechanical ventilation. The relevant ranges across which these variables were altered were established using both evidence-based and speculative ranges. The variables that produced maximum changes were then combined in a multivariate sensitivity analysis.

A meta-analysis was performed to establish the evidence-based relevant ranges for the sensitivity analyses on mortality and intubation rates for CPAP. Because only one report of prehospital CPAP relevant to our analysis exists, we chose to incorporate studies of patients treated with CPAP in the emergency department to establish feasible ranges for these variables. A search of Pubmed was performed using the key words "continuous positive airway pressure and pulmonary edema," "CPAP and pulmonary edema," "noninvasive ventilation and pulmonary edema," and "NIPPV and pulmonary edema." The searches were limited to English language publications of comparative studies or controlled clinical trials. The following inclusion criteria were used to select articles to include in the pooled analysis: 1) patients older than 18 years of age and presented with presumed cardiogenic pulmonary edema; 2) treatment was begun in the prehospital setting or emergency department; 3) outcome measures included mortality and intubation rates; 4) treatment group received CPAP via face mask; and 5) patients were compared against similar patients who received standard medical therapy (oxygen, nitrates, diuretics, and morphine). A random-effects model was used to calculate the pooled risk difference in mortality rate and intubation rate with 95% confidence intervals using Comprehensive Meta-analysis version 2.2 (Biostat, Englewood NJ) and heterogeneity was assessed using the Q-statistic. The 95% confidence interval of the pooled data was used to establish the upper and lower bounds of the feasible range for the sensitivity analyses of intubation and mortality rates.

In the base case, we modeled cost-effectiveness using the proportion of patients receiving CPAP in our previous study (0.41% of total call volume).[4] Because the allocation of fixed costs associated with CPAP is responsive to the number of patients treated, we conducted a one-way sensitivity analysis on this variable. There were no prehospital studies reporting potential uses of CPAP as a proportion of overall call volume, so we used the point estimate and 95% confidence interval from our previous study as the relevant range for the sensitivity analysis for this variable.

There were no prehospital studies on which to perform a meta-analysis for the duration of mechanical ventilation. Consequently, for the sensitivity analysis on this variable, we used the point estimate and 95% confidence interval from our original study as the feasible range.[4] In addition, there were no suitable studies for establishing the relevant range of the cost of ICU stay with mechanical ventilation. This estimate was varied by ±15% of the base-case, providing a relevant range of $21,238 to $28,734 for the sensitivity analysis on this variable.

Results

Base Case Cost-Effectiveness

For the base case scenario, the projected overall initial capital cost of the CPAP units was $9,800, assuming that one unit would be placed on each of 14 ambulances at a cost of $700 per unit. The expected duty cycle of each unit is 5 years yielding an amortized cost of capital of $1,960 per year. Assuming that the CPAP units would be used a combined total of 120 times per year, the amortized capital cost per use is $16.33 (Table 1). Providing 2 hours of training to 114 personnel at a mean cost of $17.22 per hour, generates a total training cost of $3,926 per year. Amortizing this cost across 120 annual uses generates a training cost allocation of $32.72 per use. In addition to the amortized fixed costs of the equipment, each application of CPAP required disposable goods at a cost of $35 and oxygen at a cost of $5. Consequently, the combined cost of consumables, plus the allocated capital and training costs, yields a total cost of $89.05 per application to the implementing EMS agency (Table 1).

The cost per life saved was calculated using our previously reported mortality rates of 5% (standard medical therapy with CPAP) and 23% (standard medical therapy alone).[4] The absolute risk reduction of mortality of 18% results in an additional 22 lives saved (0.75 lives saved per 1000 EMS responses) in 120 applications per year, yielding a cost per life saved of $490 (Table 1).

We previously reported an intubation rate of 8.93% among patients receiving prehospital CPAP and 25.26% among patients receiving standard therapy, yielding an absolute risk reduction of 16.33%.[4] When applied across 120 CPAP applications per year (4 applications per 1000 EMS responses), this would be expected to result in approximately 20 fewer intubations, yielding a number needed to treat (NNT) of 6 to avoid one intubation (Table 1). From our original data we found that patients who required intubation and mechanical ventilation had their hospital stays extended an extra 4.98 days. Assuming that all of these excess days were ventilator days, and using the cost estimates of mechanical ventilation from Dasta,[6] each intubation would result in $24,986 of added hospital costs. Consequently, the combined cost savings associated with preventing 20 intubations is $499,717, yielding a net annual savings of $489,031 after deducting the annual costs of implementing prehospital CPAP (Table 1).

Sensitivity Analysis

All of the cost and savings projections in Table 1 are based upon a series of estimated input variables. Each of these variables was subjected to a univariate sensitivity analysis to gauge the impact of deviations in each variable on cost-effectiveness.

From our previous study, we observed a 0.41% rate of CPAP use among all EMS responses.[4] Using the standard formula for the confidence interval of a proportion, we calculated a 95% confidence interval of 0.34%–0.48%. Varying the proportion of CPAP uses across this interval resulted in a cost range of $544–$450 per life saved and the reduction in hospitalization costs varied between $414,874 and $563,149 per year. (Table 2).

The relevant range for the sensitivity analysis on mortality rate and intubation rate was established by conducting a meta-analysis on studies of CPAP use in the prehospital and emergency department settings. The initial search identified 320 studies. After deleting duplicate studies, studies using bilevel positive airway pressure, and applying the inclusion criteria, a total of 6 studies were included in the final analysis (Figure 1). These studies are summarized in Table 3.

Because there were some methodological differences in the studies as well as statistical evidence of heterogeneity (Q-value = 24.70; $p = 0.000$), a random effects model was used to calculate the pooled risk difference for intubation. The Egger's test ($p = 0.104$) did not suggest any significant publication bias. The risk difference for intubation of the pooled data was −0.115 (95% CI -0.223 to −0.007) (Figure 2). The 95% confidence interval was used as the relevant range for the sensitivity analysis on intubation rate. Within this range, the reduction

TABLE 2. Results of the Univariate Sensitivity Analysis on Cost per Life Saved and Reduction in Hospitalization Costs

Variable (Base Case)	Range Varied	Cost per Life Saved	Reduction in Hospitalization Costs
Percent of Call Volume Using CPAP (0.41%)	0.34%–0.48%	\$544–\$450	\$414,874–\$563,149
Absolute Risk Reduction in Mortality Using CPAP (18%)	10.2%–22.9%	\$874–\$387	N/A
Absolute Risk Reduction for Intubation Using CPAP (16%)	0.7%–22.3%	N/A	\$14,300–\$663,932
Excess LOS for Mechanical Ventilation (4.98 days)	1.252–8.718	N/A	\$153,548–\$825,414
Cost for 4.98 ICU Days with Mechanical Ventilation (\$24,986)	\$21,238–\$28,734	N/A	\$414,074–\$563,989

in hospital costs varied between \$14,300 and \$663,932 per year (Table 2).

Using a random effects model, the risk difference for mortality was −0.166 (95% CI −0.229 to −0.102) (Figure 3). There was no statistical evidence of heterogeneity (Q-value = 4.343; p = 0.501), and Egger's test (p = 0.708) did not suggest any significant publication bias. Using the 95% confidence interval as the relevant range for the sensitivity analysis, the cost per life saved varied between \$387 and \$874 (Table 2).

From our original data set, we used the 95% confidence interval of the difference in hospital length of stay between intubated and non-intubated patients (95% CI −1.252 to −8.718) as the feasible range for the sensitivity analysis on excess length of stay, assuming that all of these excess days required mechanical ventilation. Across this range, the reduction in hospitalization costs varied between \$153,548 and \$825,414 per year (Table 2).

The cost of excess ICU stay and mechanical ventilation was varied by ± 15% of the base-case, providing a relevant range of \$21,238 to \$28,734 for the sensitivity analysis on this variable. Given this range, the reduction in total hospitalization costs attributed to CPAP therapy varied between \$414,074 and \$563,989 per year (Table 2).

With respect to hospitalization costs, the cost-effectiveness of prehospital CPAP was most sensitive to changes in the intubation rate and the duration of mechanical ventilation. A multivariate sensitivity analysis was performed by simultaneously altering these variables across their previously established relevant ranges (Table 4) (Figure 4). CPAP produced cost savings at all but the most pessimistic limit of the intubation rate and optimistic limit of duration of mechanical ventilation. Assuming an intubation rate of 24.56% and an average duration of mechanical ventilation of 1.25 days, CPAP would add a negligible \$2,474 to the cost of treating 120 pulmonary edema patients (\$20.62 per patient). When either of these variables retreats even slightly from their most unfavorable cost-effective limits, cost savings are realized. At the extreme favorable cost-effective limits of the relevant range for the intubation rate (2.96%) and mean duration of mechanical ventilation (8.72 days), prehospital CPAP is expected to save \$1,118,050 per year in hospitalization costs or \$9,317 per patient.

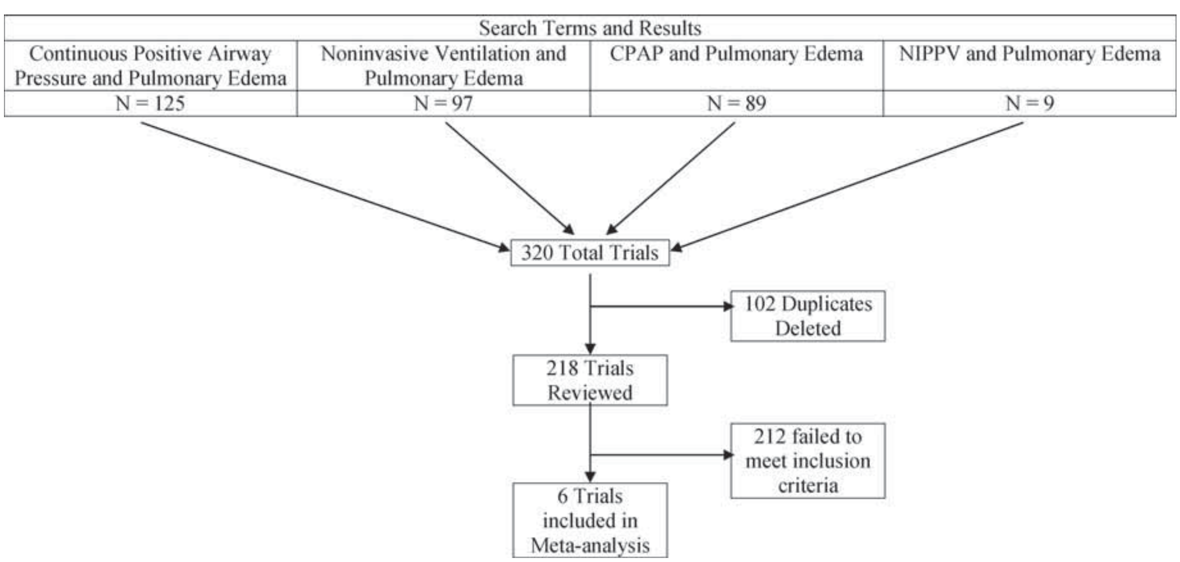

FIGURE 1. Flow diagram of selection process for identifying articles chosen for meta-analysis.

Table 3. Summary of Publications Included in Meta-Analysis

Source	Country	Inclusion Criteria	Exclusion Criteria	Sample Size	Interventions	Outcome
Bersten et al., 1991[20]	Australia	Emergency department patients presenting with rales, respiratory distress, PaO2 < 70 mm Hg or PaCO2 >45 mm Hg, chest radiograph consistent with APE	Myocardial infarction with shock, SBP <90 mm Hg, severe stenotic valvular disease, COPD	39	CPAP @ 10 cm H_2O vs. standard treatment	Need for intubation, overall hospital mortality, overall hospital length of stay, ICU length of stay, complications
Crane et al., 2004[21]	England	Emergency department patients with clinical evidence of APE, RR >23/min, chest radiograph consistent with APE, arterial pH <7.35	SBP <90 mm Hg, temperature >38°C, patients requiring immediate thrombolysis for MI, patients requiring dialysis, impaired consciousness, or dementia	60	CPAP @ 10 cm H_2O vs. NPPV (15/5 cm H_2O) vs. standard treatment	Treatment success at 2 hours and overall hospital mortality
Hubble et al., 2006[4]	USA	All patients presenting with clinical evidence of APE in the prehospital setting.	SBP <90 mm Hg, hypotension, face mask intolerance, deterioration in mental status changes	215	CPAP @ 10 cm H_2O vs. standard treatment	Need for intubation, overall hospital mortality, overall hospital length of stay
Kelly et al., 2002[22]	Scotland	Emergency department patients with dyspnea <6 hours, RR >20/min, bilateral rales, chest radiograph consistent with APE	Evidence of pneumonia or pneumothorax on chest radiograph, prehospital treatment with interventions other than oxygen, diuretics or opiates	58	CPAP @ 7.5 cm H_2O vs. standard treatment	Change in symptoms and lab values, hospital length of stay, ICU length of stay, complications
L'Her et al., 2004[23]	France	Emergency department patients aged ≥75 years, PaO_2/F_iO_2 ≤300 despite ≥8 lpm oxygen, RR ≥25/min, clinical evidence of APE, chest radiograph consistent with APE	GCS ≤ 7, SpO2 ≤ 85% despite oxygen, SBP ≤90 mm Hg, COPD	89	CPAP @ 7.5 cm H_2O vs. standard treatment	48 hour mortality, in-hospital mortality, need for ventilatory support, change in physiologic parameters, overall hospital length of stay
Park et al., 2004[24]	Brazil	Emergency department patients aged ≥16 years, RR >25/min, tachycardia, diaphoresis, chest radiograph consistent with APE	Impaired consciousness, intractable vomiting, myocardial infarction, SBP <90, other decompensated pulmonary disease	83	CPAP @ 10 cm H_2O vs. NPPV (10/15 to 16/21 cm H_2O) vs. standard treatment	Intubation rate, overall hospital length of stay, hospital mortality, complications

Meta Analysis of CPAP Intubation Risk Difference

Study name	Risk difference	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Bersten, et al 1991	-0.350	0.110	0.012	-0.566	-0.134	-3.175	0.001	11.90
Crane, et al 2004	0.050	0.065	0.004	-0.078	0.178	0.766	0.444	17.23
Hubble, et al. 2006	-0.169	0.051	0.003	-0.270	-0.069	-3.305	0.001	19.01
Kelly, et al 2002	0.000	0.033	0.001	-0.065	0.065	0.000	1.000	21.01
L'Her, et al 2004	-0.040	0.053	0.003	-0.143	0.062	-0.770	0.441	18.85
Park, et al 2004	-0.349	0.109	0.012	-0.563	-0.135	-3.196	0.001	12.00
	-0.115	0.055	0.003	-0.223	-0.007	-2.084	0.037	

Statistics for each study

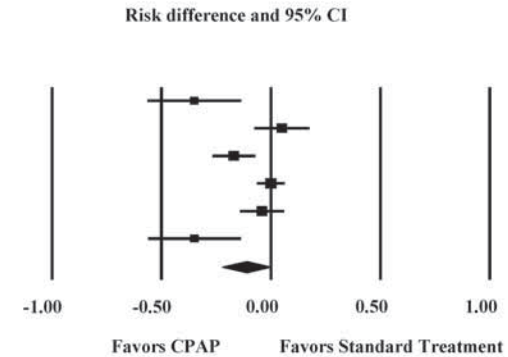

FIGURE 2. Pooled risk difference for eventual intubation: CPAP versus standard treatment.

Meta Analysis of CPAP Mortality Risk Difference

Study name	Risk difference	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Events / Total Group-A	Events / Total Group-B	Relative weight
Bersten, et al 1991	-0.095	0.114	0.013	-0.318	0.128	-0.832	0.405	2/19	4/20	8.05
Crane, et al 2004	-0.300	0.106	0.011	-0.508	-0.092	-2.824	0.005	0/20	6/20	9.24
Hubble, et al. 2006	-0.182	0.048	0.002	-0.275	-0.088	-3.812	0.000	6/120	22/95	45.94
Kelly, et al 2002	-0.152	0.090	0.008	-0.329	0.026	-1.678	0.093	2/27	7/31	12.75
L'Her, et al 2004	-0.025	0.096	0.009	-0.214	0.164	-0.262	0.793	12/43	14/46	11.23
Park, et al 2004	-0.194	0.090	0.008	-0.371	-0.017	-2.146	0.032	1/27	6/26	12.79
	-0.166	0.032	0.001	-0.229	-0.102	-5.133	0.000			

Statistics for each study

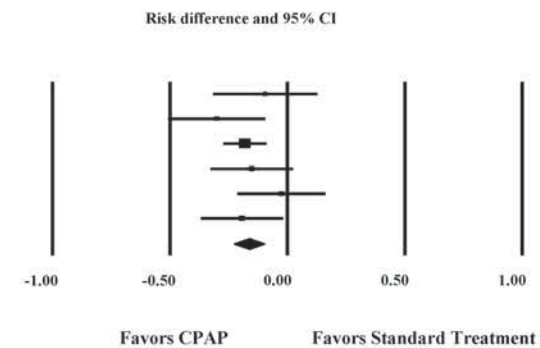

FIGURE 3. Pooled risk difference for mortality: CPAP versus standard treatment.

Table 4. Multivariate Sensitivity Analysis of Selected CPAP Intubation Rates and Mechanical Ventilation Days on Reduction in Hospitalization Costs

		Mechanical Ventilation Days		
		1.25	5.00	8.72
Intubation Rate of CPAP Group	2.96%	$211,030	$666,605	$1,118,050
	7.46%	$169,971	$541,181	$909,024
	11.96%	$120,701	$390,672	$658,194
	16.46%	$79,643	$265,247	$449,169
	20.96%	$30,372	$114,738	$198,339
	24.56%	−$2,474	$14,399	$31,119

Discussion

Reports of short term mortality for CHF-related acute pulmonary edema vary between 20% and 30%.[8,9] While many patients with APE respond to oxygen, nitrates, morphine and furosemide, others do not and develop progressive respiratory failure requiring ventilatory support.[9,10] Traditionally, this has been provided by endotracheal intubation and mechanical ventilation. Mechanical ventilation has been shown to decrease the work of breathing, decrease cardiac afterload, and enhance alveolar recruitment, thereby decreasing shunt and improving oxygenation.[11] Despite these clinical benefits, mechanical ventilation and intensive care unit admission are among the most significant independent predictors of hospital costs for these patients.[12]

Ideally, cost-effective treatment strategies for APE are needed that avert the need for intubation and mechanical ventilation. However, cost-effectiveness analysis in medicine is complex, and as a result, many medical procedures have been adopted without a full evaluation of their economic implications. Unfortunately, even treatments with unambiguous clinical benefits may not compare favorably with alternative treatments once their economic impacts are considered. Consequently, new procedures and treatments should be evaluated for both clinical benefit as well as cost-effectiveness prior to widespread adoption. The purpose of this study was to evaluate the cost-effectiveness of prehospital CPAP in the management of APE secondary to heart failure.

Hospital charges account for the vast majority of the high costs of heart failure care,[13] and have resulted in widespread efforts to decrease the costs of treating this disease by preventing hospital admissions and reducing lengths of stay.[14] Although not specific to pulmonary edema, 80% of emergency department presentations for heart failure are admitted to the hospital,[15] and the average U.S. hospital lost $1,288 per admission in 2001.[2] One of the greatest cost drivers of in-hospital stays is the intensive care unit, accounting for nearly a third of total inpatient costs.[16,17] ICU stays are estimated to cost 3–5 times more than stays on a general medical/surgical floor and much of this increased cost may be due to mechanical ventilation.[6,13,16] A length of stay greater than 5 days for a heart failure admission is the point at which most hospitals begin to lose money.[2] Our data revealed a mean length of stay of 5.84 days for patients who avoided intubation, compared with 10.82 days for those who required intubation and mechanical ventilation, suggesting that circumventing intubation may result in considerable cost-savings for hospitals and society.

Cost-effectiveness analysis may be conducted from the perspective of the payer, patient, provider or society. Of these, the societal perspective is the broadest and most commonly used. The societal perspective represents the public interest rather than that of any particular group, and incorporates all costs and health benefits regardless of who bears those costs and who receives the clinical or financial benefits. From a societal perspective, our analysis suggests that CPAP is more effective and less costly than non-CPAP approaches to the management of pulmonary edema. In the base case scenario, the cost per life saved using prehospital CPAP was exceedingly low at $490, and remained low ($387–$874) after altering our assumptions through a series of univariate sensitivity analyses. To place these estimated costs in perspective, any treatment that costs less than $50,000 per quality-adjusted life year (QALY) is generally considered to be cost-effective, although some evidence suggests this threshold should be higher.[18]

The main area of cost savings derived through CPAP is in reducing the number of intubations and the associated number of ICU days with mechanical ventilation, which is consistent with previous reports.[6,19] In our original study, on average prehospital CPAP was applied roughly 16 minutes prior to hospital arrival and was associated with decreased intubation rates and reduced mortality.[4] Based on these data, for every 120 CPAP applications there is a reduction in hospitalization costs in the base-case scenario of $499,717 per year by preventing 20 intubations and reducing the ICU length of stay. One-way sensitivity analyses showed

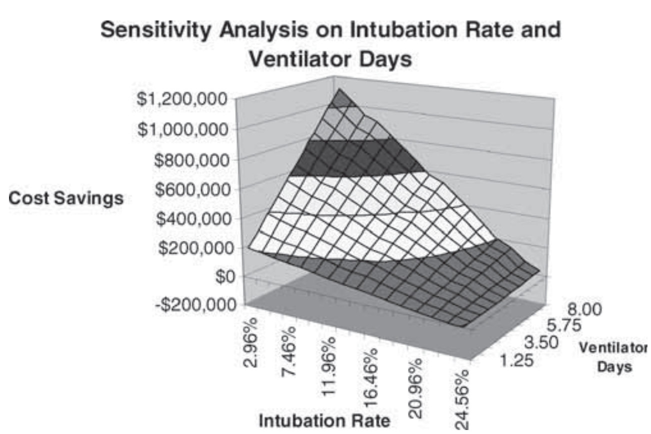

Figure 4. Surface plot of multivariate sensitivity analysis of intubation rate and ventilator days on reduction in hospitalization costs.

that the cost reduction estimates were robust to many alternative input assumptions, with the most influential input variables being intubation rate and hospital length of stay. However, there is a cost savings throughout the entire range of values for both of these variables in the univariate sensitivity analyses (Table 2). Only at the most unfavorable extremes in the multivariate sensitivity analysis did the cost savings of prehospital CPAP disappear. (Table 4) (Figure 4).

LIMITATIONS

First, much of the cost benefit we attribute to CPAP is inextricably linked to its ability to reduce intubation rates and the need for mechanical ventilation. We based our estimates of reduced intubation primarily on one prehospital study, supplemented by additional studies conducted among emergency department patients. The lack of adequate numbers of prehospital studies reduces our confidence of the feasible range used in the sensitivity analyses. In addition, mechanical ventilation costs are based on estimates of medical patients and may lack precision in estimating the costs for cardiogenic pulmonary edema patients specifically. Furthermore, we assumed that all additional hospital days attributed to intubation and mechanical ventilation were ICU days. Although this assumption is supported by previous studies, it is plausible that there may be a mixture of ICU and non-ICU days.

In evaluating the benefits of CPAP, we only evaluated the number of additional lives saved. We did not consider more sophisticated estimates of benefits such as QALYs, years of productive life, etc., nor did we analyze hospital costs other than length of stay. We also assumed that CPAP initiated in the prehospital setting is more advantageous than awaiting hospital arrival to initiate this treatment. While an advantage was demonstrated in our original study, these outcomes have not been confirmed by other investigators.[4]

Our results are conservative and the benefits of CPAP are likely greater, as we did not consider other potential benefits of CPAP, such as its use in chronic obstructive pulmonary disease (COPD). Furthermore, we expensed all training costs in one year which likely exaggerates the true costs of training. These methodological issues likely overstate the true costs and understate the true benefits of CPAP. Moreover, our analysis uses the societal approach which obscures the true relationship between costs and benefits. Presumably, in implementing a CPAP program, the EMS system would bear the financial burden while hospitals would receive the benefits through reduced costs of hospitalization due to shorter lengths of stay.

Presumably, there is an interaction between mortality costs and hospitalization costs. By preventing some deaths, patients would be expected to consume additional hospital resources, and consequently, increase the cost of their care. However, because of insufficient data in the published literature describing this interaction, we were unable to incorporate this interaction in our model. Consequently, the cost per life saved and reduction in hospitalization costs were modeled independently.

Finally, our calculations are largely theoretical and based, in part, upon previously published data, limited to one model of CPAP unit, and limited to a single EMS service. The accuracy of our cost-effectiveness estimates is limited by the precision of our input variables drawn from these reports.

CONCLUSION

Previous studies have demonstrated the clinical effectiveness of CPAP in the management of APE. Based upon a theoretical cost-effectiveness analysis which models the costs and clinical benefits of implementing CPAP in an urban EMS system, prehospital CPAP appears to be a cost-effective treatment. The cost per additional life saved is minimal, while the cost savings realized through reducing the need for intubation and mechanical ventilation are substantial. Ultimately, an actual cost-effectiveness analysis should be conducted as an extension of a future randomized controlled trial of CPAP where costs and benefits can be measured directly.

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