REVIEW

Non-invasive ventilation in acute cardiogenic pulmonary oedema

R Agarwal, A N Aggarwal, D Gupta, S K Jindal

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Non-invasive ventilation (NIV) is the delivery of assisted mechanical ventilation to the lungs, without the use of an invasive endotracheal airway. NIV has revolutionised the management of patients with various forms of respiratory failure. It has decreased the need for invasive mechanical ventilation and its attendant complications. Cardiogenic pulmonary oedema (CPO) is a common medical emergency, and NIV has been shown to improve both physiological and clinical outcomes. From the data presented herein, it is clear that there is sufficiently high level evidence to favour the use of continuous positive airway pressure (CPAP), and that the use of CPAP in patients with CPO decreases intubation rate and improves survival (number needed to treat seven and eight respectively). However, there is insufficient evidence to recommend the use of bilevel positive airway pressure (BiPAP), probably the exception being patients with hypercapnic CPO. More trials are required to conclusively define the role of BiPAP in CPO.

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Non-invasive ventilation (NIV) is the provision of ventilatory support to the lungs without the use of an endotracheal airway. It has emerged as an important tool in the treatment of diverse forms of acute respiratory failure. It not only reduces the need for invasive mechanical ventilation and its associated complications, but also reduces the complications associated with stay in the intensive care unit, length of hospital stay, and mortality in selected patients.[1] Cardiogenic pulmonary oedema (CPO) is a common medical emergency[2] and NIV in addition to conventional medical treatment is beneficial for patients with CPO as it augments cardiac output,[3] results in rapid improvement in gas exchange,[4–13] decreases the need for endotracheal intubation,[6 7 9 10 14] and there is a trend towards decreased in-hospital mortality.[7 12 13 15]

PHYSIOLOGY AND PATHOPHYSIOLOGY OF CPO

CPO is defined as an episode of acute heart failure accompanied by severe respiratory distress and oxygen saturation <90% on room air before all treatment.[16] The pathogenesis of CPO is related to a critical interaction between progressive decrease in left ventricular systolic function and acute increase in systemic vascular resistance with resultant exudation of fluid from the intravascular compartment into the lung interstitium and alveoli. This leads to a vicious cycle amplified by three important processes. Firstly, as pulmonary congestion increases, oxygen saturation decreases, resulting in decreased myocardial oxygen supply. This leads to ischaemia in regions with already borderline blood supply, further impairing cardiac performance. Secondly, hypoxemia and increased fluid content in the lungs induces pulmonary vasoconstriction increasing the right ventricular pressure. This compromises left ventricular function through the ventricular interdependence mechanism.[17] Finally, profound circulatory insufficiency results in metabolic acidosis, which further jeopardises cardiac performance.

CPO is characterised by an increase in extravascular lung water, which causes a decrease in respiratory system compliance, increased airway resistance, air trapping, arterial hypoxaemia, and decreased diffusing capacity.[18–20] Retention of carbon dioxide not previously associated with chronic obstructive pulmonary disease is a common finding in patients presenting with CPO[6 11 20–22] and is associated with a poor prognosis.[22] This hypercapnia is probably attributable to respiratory muscle fatigue as a result of increased work of breathing from both reduced lung compliance and increased airway resistance secondary to interstitial and bronchial oedema.[23–25] Moreover, the respiratory muscles have to generate large negative swings in pleural pressure to start inspiratory flow and maintain adequate tidal volumes.[26] This increase in negative intrathoracic pressure aggravates pulmonary oedema by increasing both preload and afterload.[27 28] Another important point to remember while managing these patients is that respiratory distress and dyspnea are not directly related to hypoxaemia, and thus cannot be reversed with oxygen administration alone.[29]

HOW DOES CONTINUOUS POSITIVE AIRWAY PRESSURE (CPAP) WORK?

The immediate goals in the treatment of acute CPO are to improve systemic oxygen saturation by giving oxygen with a high flow facemask, reduction of preload and afterload of both the ventricles by a combination of morphine, diuretics, and nitrates.[30] As early as 1936, CPAP had

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Table 1 Randomised controlled trials of non-invasive ventilation in patients with acute cardiogenic pulmonary oedema

Study	Patients (n)			Intubation rate n (%)			Mortality n (%)		
	BiPAP	CPAP	Control	BiPAP	CPAP	Control	BiPAP	CPAP	Control
Rasanen et al[4]	–	20	20	–	6 (30)	12 (60)	–	3 (15)	6 (30)
Lin et al[5]	–	25	30	–	7	17	–	2	4
Bersten et al[6]	–	19	20	–	0	7 (35)	–	2 (10.5)	4 (20)
Lin et al[14]	–	50	50	–	3 (6)	4 (8)	–	4 (8)	6 (12)
Mehta et al[50]	14	13	–	1 (7)	1 (8)	–	1 (7)	2 (15)	–
Takeda et al[8]	–	11	11	–	2 (18)	8 (73)	–	1 (9)	7 (64)
Sharon et al[49]	20	–	20	16 (80)	–	4 (20)	2 (10)	–	0
Masip et al[9]	19	–	18	1 (5)	–	6 (33)	0	–	2 (10.5)
Levitt et al[48]	21	–	17	5 (23.8)	–	7 (41.2)	3 (15)	–	3 (21.4)
Park et al[10]	7	9	10	0	3 (33.3)	4 (40)	0	1 (11.1)	0
Kelly et al[39]	–	31	27	–	2 (6.5)	7 (25.9)	–	2 (6.5)	7 (25.9)
Nava et al[11]	65	–	65	13 (20)	–	16 (25)	6 (8)	–	9 (14)
Crane et al[12]	20	20	20	1 (5)	1 (5)	0	5 (25)	0	6 (30)
L'Her et al[13]	–	43	46	–	2 (4.3)	4 (9.3)	–	2 (6.5)	7 (25.9)
Bellone et al[51]	24	22	–	2(8.3)	1 (4.5)	–	0	2 (9.1)	–
Park et al[45]	27	27	26	2 (7)	2 (7)	11 (42)	2 (7)	1 (4)	6 (23)

been shown to be an effective therapy for CPO unresponsive to medical treatment.[31]

CPAP therapy in patients with CPO is associated with immediate and pronounced improvements in respiratory[3–13] and haemodynamic[3 14 27 28 32 33] variables. CPAP augments the inspiratory and expiratory flow and pressure thereby increasing the tidal volume and unloading the inspiratory muscles.[34] It decreases dead space ventilation and improves alveolar ventilation, re-expands flooded alveoli, and counteracts intrinsic PEEP.[35 36] CPAP prevents microatelectasis and places the respiratory pressure volume characteristics in a more favourable position.[35 36]
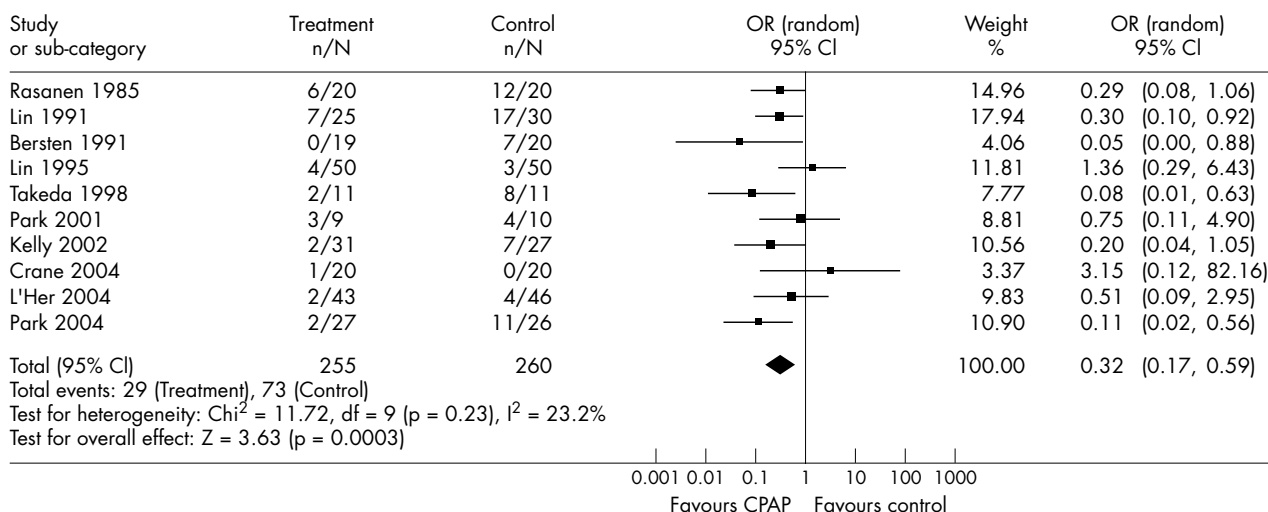
The effective filling and emptying of the heart is determined in part by the pressure difference between the inside of the heart and the intrathoracic pressure, known as the cardiac transmural pressure (P_{TM}). The amplitude of inspiratory swings is greater in patients with CPO and leads to an increase in P_{TM} in patients with CPO.[28] The more positive the P_{TM} is during diastole, the greater the filling of the heart (preload). The more positive the P_{TM} is during systole, the higher the workload is for the heart (afterload). During systole, CPAP induced increase in intrathoracic pressure reduces the venous return, decreasing the right and left ventricular preload, thereby improving mechanics in an overloaded ventricle, whereas in diastole, CPAP increases

pericardial pressure, reduces transmural pressure, and thus decreases afterload.[37] Although CPAP can decrease cardiac index in normal people,[38] it increases cardiac index in patients with CPO.[3 36] CPAP also causes a significant decrease in the heart rate,[4–8 13 39] resulting from increased parasympathetic tone in response to CPAP induced lung inflation.[40]

However, treatment with NIV in CPO is beneficial only in patients who have systolic dysfunction. In patients with diastolic dysfunction who require a comparatively high filling pressure, the effects of positive pressure therapy compromises venous return, resulting in deterioration of haemodynamics.

HOW DOES BILEVEL POSITIVE AIRWAY PRESSURE (BiPAP) WORK?

BiPAP in contrast with CPAP delivers two different pressures, inspiratory positive airway pressure (IPAP) and expiratory positive airway pressure (EPAP). BiPAP decreases inspiratory work of breathing, and can improve diaphragmatic function better than CPAP alone.[41–44] Recently it has been shown that BiPAP has similar cardiac and haemodynamic benefits as CPAP in patients with CPO. In addition, BiPAP unloads the respiratory muscles, reduces respiratory effort, and increases tidal volume before any changes in pulmonary mechanics. This is in contrast with CPAP, which requires the pulmonary

Study or sub-category	Treatment n/N	Control n/N	OR (random) 95% CI	Weight %	OR (random) 95% CI
Rasanen 1985	6/20	12/20		14.96	0.29 (0.08, 1.06)
Lin 1991	7/25	17/30		17.94	0.30 (0.10, 0.92)
Bersten 1991	0/19	7/20		4.06	0.05 (0.00, 0.88)
Lin 1995	4/50	3/50		11.81	1.36 (0.29, 6.43)
Takeda 1998	2/11	8/11		7.77	0.08 (0.01, 0.63)
Park 2001	3/9	4/10		8.81	0.75 (0.11, 4.90)
Kelly 2002	2/31	7/27		10.56	0.20 (0.04, 1.05)
Crane 2004	1/20	0/20		3.37	3.15 (0.12, 82.16)
L'Her 2004	2/43	4/46		9.83	0.51 (0.09, 2.95)
Park 2004	2/27	11/26		10.90	0.11 (0.02, 0.56)
Total (95% CI)	**255**	**260**		**100.00**	**0.32 (0.17, 0.59)**

Total events: 29 (Treatment), 73 (Control)
Test for heterogeneity: Chi^2 = 11.72, df = 9 (p = 0.23), I^2 = 23.2%
Test for overall effect: Z = 3.63 (p = 0.0003)

0.001 0.01 0.1 1 10 100 1000
Favours CPAP   Favours control

Figure 1 Intubation rates: CPAP compared with standard medical therapy (odds ratio with 95% confidence intervals, random effects model).
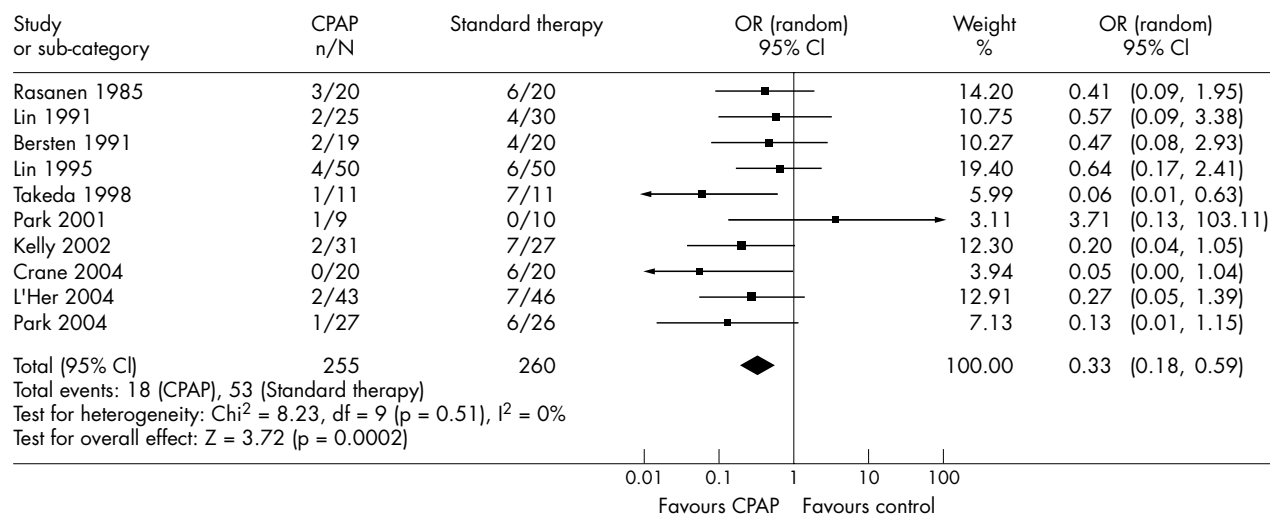
Study or sub-category	CPAP n/N	Standard therapy	OR (random) 95% CI	Weight %	OR (random) 95% CI
Rasanen 1985	3/20	6/20		14.20	0.41 (0.09, 1.95)
Lin 1991	2/25	4/30		10.75	0.57 (0.09, 3.38)
Bersten 1991	2/19	4/20		10.27	0.47 (0.08, 2.93)
Lin 1995	4/50	6/50		19.40	0.64 (0.17, 2.41)
Takeda 1998	1/11	7/11		5.99	0.06 (0.01, 0.63)
Park 2001	1/9	0/10		3.11	3.71 (0.13, 103.11)
Kelly 2002	2/31	7/27		12.30	0.20 (0.04, 1.05)
Crane 2004	0/20	6/20		3.94	0.05 (0.00, 1.04)
L'Her 2004	2/43	7/46		12.91	0.27 (0.05, 1.39)
Park 2004	1/27	6/26		7.13	0.13 (0.01, 1.15)
Total (95% CI)	255	260		100.00	0.33 (0.18, 0.59)

Total events: 18 (CPAP), 53 (Standard therapy)
Test for heterogeneity: $Chi^2 = 8.23$, df = 9 (p = 0.51), $I^2 = 0\%$
Test for overall effect: Z = 3.72 (p = 0.0002)

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0.01   0.1    1    10   100
Favours CPAP   Favours control
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Figure 2 Death rates: CPAP compared with standard medical therapy (odds ratio with 95% confidence intervals, random effects model).

mechanics to change before any benefits of respiratory muscle unloading are seen.[3]

CLINICAL EVIDENCE FOR THE ROLE OF NIV
For the evidence, all the authors independently searched the National Library of Medicine's Medline database for relevant studies published from 1966 to September 2004 using the keywords: noninvasive ventilation OR continuous positive airway pressure OR bilevel positive airway pressure AND pulmonary edema AND randomized controlled trials (publication type) or controlled clinical trials or clinical trials, randomized. Bibliographies of all selected articles and review articles that included information on NIV in CPO were reviewed for other relevant articles. In addition, we reviewed our personal files. Our search produced 16 citations (table 1), which were randomised controlled trials (blinded or unblinded). We discuss the clinical evidence under the following headings—CPAP compared with conventional medical therapy, BiPAP compared with conventional medical therapy, and CPAP compared with BiPAP. Apart from the potential weaknesses of all meta-analysis like publication bias (negative studies less likely to be submitted or accepted for publication) and heterogeneity (different interventions, different clinical circumstances), the main limitation of this meta-analysis is that the studies have not been adequately blinded and the individual studies have included small

number of patients. Thus the results of this analysis need to be confirmed by a larger randomised controlled trial.

CPAP COMPARED WITH CONVENTIONAL MEDICAL THERAPY
Almost six decades ago, Poulton and Oxon[31] described the use of CPAP delivered by the ''pulmonary plus pressure machine'' through a facemask to patients with ''cardiac asthma.'' Several studies have shown that CPAP is effective in patients with CPO as it rapidly improves gas exchange and cardiac haemodynamics, and can decrease intubation rates and in-hospital mortality.[7 10 12 39] However, most studies on CPO have not been adequately powered to detect these differences.

Rasanen et al[4] randomised 40 patients with CPO to either facemask CPAP (10 cm H_2O) or standard medical therapy, and showed improvement in gas exchange, decrease in respiratory work, and reduced need for intubation. Lin et al[5] randomised 55 patients to CPAP or high flow oxygen therapy, and showed significant decrease in the intubation rates in the CPAP group compared with controls (28% v 60% respectively). Bersten et al[6] compared the efficacy of CPAP (10 cm H_2O) with that of conventional treatment in 39 patients with CPO and found a significant and rapid improvement in arterial oxygen tension and a significant decrease in arterial carbon dioxide tension in patients treated with CPAP
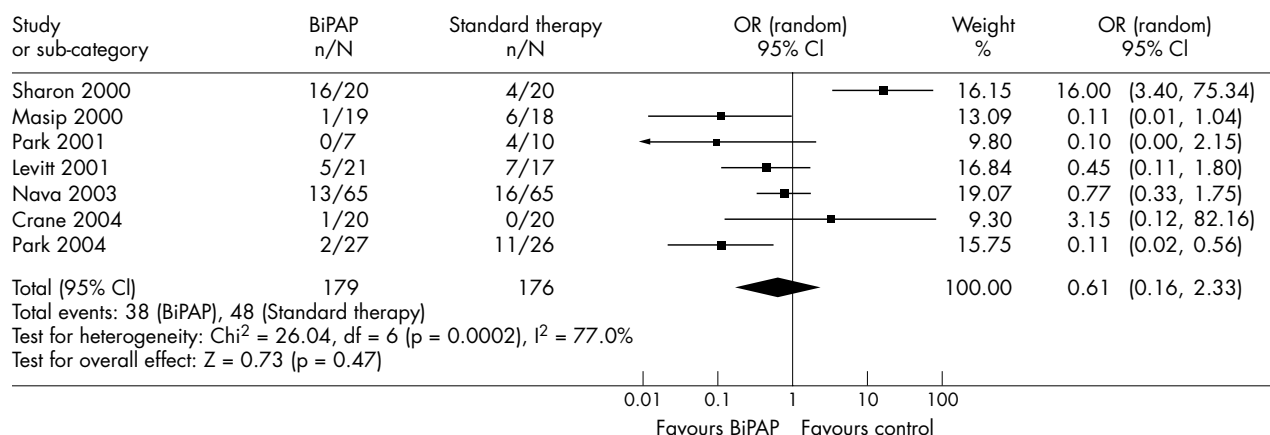
Study or sub-category	BiPAP n/N	Standard therapy n/N	OR (random) 95% CI	Weight %	OR (random) 95% CI
Sharon 2000	16/20	4/20		16.15	16.00 (3.40, 75.34)
Masip 2000	1/19	6/18		13.09	0.11 (0.01, 1.04)
Park 2001	0/7	4/10		9.80	0.10 (0.00, 2.15)
Levitt 2001	5/21	7/17		16.84	0.45 (0.11, 1.80)
Nava 2003	13/65	16/65		19.07	0.77 (0.33, 1.75)
Crane 2004	1/20	0/20		9.30	3.15 (0.12, 82.16)
Park 2004	2/27	11/26		15.75	0.11 (0.02, 0.56)
Total (95% CI)	179	176		100.00	0.61 (0.16, 2.33)

Total events: 38 (BiPAP), 48 (Standard therapy)
Test for heterogeneity: $Chi^2 = 26.04$, df = 6 (p = 0.0002), $I^2 = 77.0\%$
Test for overall effect: Z = 0.73 (p = 0.47)

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0.01   0.1    1    10   100
Favours BiPAP   Favours control
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Figure 3 Intubation rates: BiPAP compared with standard medical therapy (odds ratio with 95% confidence intervals, random effects model).

compared with those treated conventionally. Whereas no patient required endotracheal intubation in the CPAP group, 35% of the patients in the oxygen group were intubated within three hours of study entry. Although the final death rate was similar in both groups, patients receiving CPAP showed a significant reduction in ICU length of stay. Lin et al[14] in another study randomised 100 patients with CPO, and showed favourable effects of incremental CPAP (2.5–12.5 cm H_2O) on oxygenation, respiratory rates, and the need for intubation. Although statistically not significant, the study showed trend towards improved hospital survival. Takeda et al showed beneficial results of CPAP in CPO in the setting of acute myocardial infarction.[8] Recently L'Her et al[13] randomised 89 elderly patients with CPO to standard medical therapy or CPAP (7.5 cm H_2O) plus standard medical therapy, and showed that CPAP decreased intubation rates, and promoted early clinical improvement in patients attending emergency departments for severe pulmonary oedema. However, only the early 48 hour mortality was reduced and no sustained benefits were seen during the overall hospital stay.

Figures 1 and 2 shows the combined data of all randomised trials of CPAP compared with standard medical therapy in CPO, and pooled data (515 patients) suggest that CPAP significantly decreases intubation rates (odds ratio (OR) 0.32; 95% confidence intervals (CI) 0.17 to 0.59) and hospital mortality ((OR 0.33; 95% CI 0.18 to 0.59)). Also seven patients with CPO need to be treated with CPAP to prevent one intubation whereas the number needed to treat (NNT) to prevent one death is eight.

BiPAP COMPARED WITH CONVENTIONAL MEDICAL THERAPY

Fewer controlled trials have been performed to see if BiPAP is an effective therapy for patients with CPO. Physiological studies have shown that BiPAP is more effective at unloading the respiratory muscles than CPAP alone in patients with COPD[41–44] and in patients with acute CPO.[3] Several open clinical studies have reported rapid improvements in gas exchange in patients with CPO treated with BiPAP.[46–48] Rusterholtz et al[48] applied BiPAP (IPAP 20.5 (4.7) cm H_2O, EPAP 3.5 (2.3) cm H_2O) in 26 patients with CPO and found improvement in gas exchange with only five patients requiring endotracheal intubation. In a randomised, prospective trial of 40 patients, Masip et al[9] found a significantly lower rate of intubation in patients treated with BiPAP (IPAP 15.2 (2.4) cm H_2O, EPAP 5 cm H_2O) compared with oxygen treated control subjects (5% v 33% respectively; p<0.037). Although resolution time (oxygen saturation ⩾96% and

respiratory rate ⩽30 breaths/min) was significantly shorter in the BiPAP group (p<0.002), hospital lengths of stay and death rates were similar in the two groups. Importantly, four of the six patients (66%) requiring intubation in the conventional therapy group were hypercapnic, whereas no hypercapnic patients in the BiPAP group required intubation. The small sample size however did not permit a subgroup analysis of the impact of hypercapnia on the outcome. Three other randomised trials have also described improvement in physiological parameters but no decrease in intubation rates or mortality.[10 12 49] On the other hand, Sharon et al[50] in a randomised trial of BiPAP (IPAP 8–12 cm H_2O, EPAP 3–5 cm H_2O) plus low dose nitroglycerin compared with high dose nitroglycerin in 40 patients with acute pulmonary oedema showed that patients treated with BiPAP had a higher rates of intubation, myocardial infarction, and death compared with control subjects. The combined primary end point (death, mechanical ventilation, or myocardial infarction) was seen in 85% of BiPAP group compared with 25% of control (p<0.0003). However, the findings of this study are controversial and the 80% intubation rate in the BiPAP group is inordinately high, and may reflect the use of low inspired oxygen concentration and low airway pressures. Moreover, the classification of myocardial infarction cannot be taken as a valid end point and can probably be the cause of the emergency presentation with pulmonary oedema. On the other hand, Nava et al[11] in a multicentre study randomised 130 patients to medical therapy or BIPAP (IPAP 14.5 (21.1) cm H_2O, EPAP 6.1 (3.2) cm H_2O). BiPAP improved hypoxaemia, respiratory rate, and dyspnea significantly faster than did oxygen therapy but the intubation rate, hospital mortality, and the duration of hospital stay were similar in the two groups. However, in the subgroup of hypercapnic patients, intubation rates were lower in the BiPAP group than oxygen therapy (2 of 33 compared with 9 of 31; p <0.015). Adverse events, including myocardial infarction, were equally distributed in the two groups. Recently Park et al[46] randomly assigned 80 patients with acute CPO to oxygen, CPAP, and BiPAP. Treatment with CPAP or BiPAP resulted in significant improvement in the PaO_2/FiO_2 ratio, subjective dyspnea score, and respiratory and heart rates compared with oxygen therapy. Endotracheal intubation was necessary in 11 of 26 patients (42%) in the oxygen group but only in two of 27 patients (7%) in each NIV group (p = 0.001). There was no increase in the incidence of acute myocardial infarction in the CPAP or BiPAP groups. Mortality at 15 days was higher in the oxygen than in the NIV groups (p<0.05).

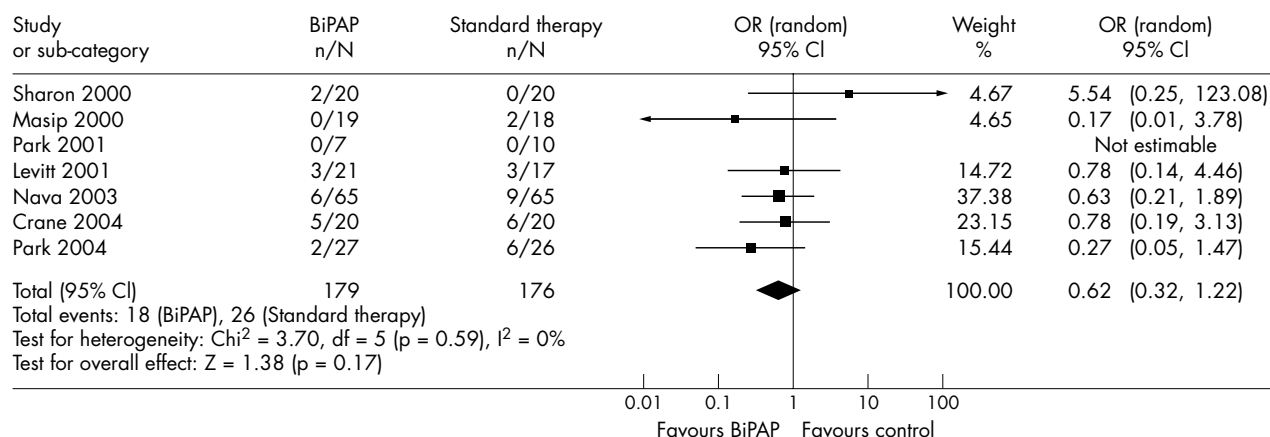Figures 3 and 4 show the combined data of all randomised trials of BiPAP compared with standard medical therapy in

Study or sub-category	BiPAP n/N	Standard therapy n/N	OR (random) 95% CI	Weight %	OR (random) 95% CI
Sharon 2000	2/20	0/20		4.67	5.54 (0.25, 123.08)
Masip 2000	0/19	2/18		4.65	0.17 (0.01, 3.78)
Park 2001	0/7	0/10			Not estimable
Levitt 2001	3/21	3/17		14.72	0.78 (0.14, 4.46)
Nava 2003	6/65	9/65		37.38	0.63 (0.21, 1.89)
Crane 2004	5/20	6/20		23.15	0.78 (0.19, 3.13)
Park 2004	2/27	6/26		15.44	0.27 (0.05, 1.47)
Total (95% CI)	179	176		100.00	0.62 (0.32, 1.22)

Total events: 18 (BiPAP), 26 (Standard therapy)
Test for heterogeneity: Chi^2 = 3.70, df = 5 (p = 0.59), I^2 = 0%
Test for overall effect: Z = 1.38 (p = 0.17)

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            0.01   0.1    1    10    100
         Favours BiPAP    Favours control
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Figure 4 Death rates: BiPAP compared with standard medical therapy (odds ratio with 95% confidence intervals, random effects model).
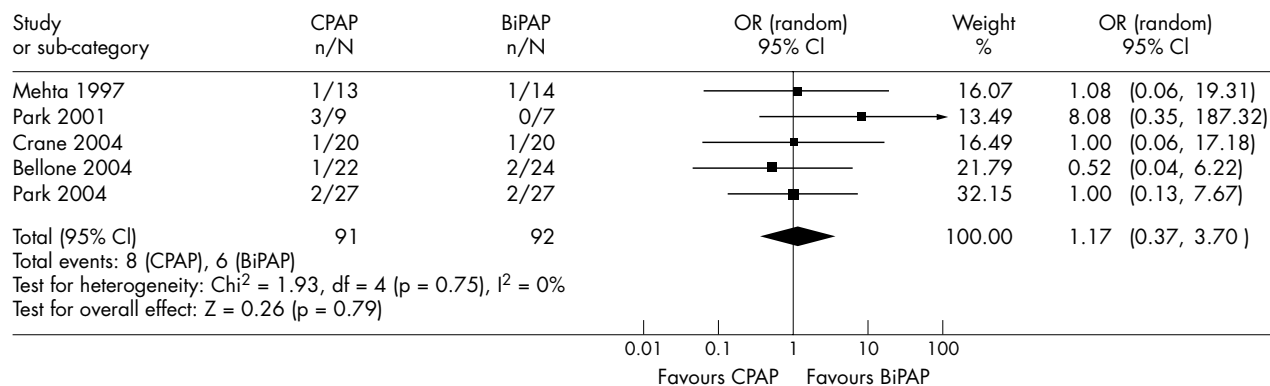
Study or sub-category	CPAP n/N	BiPAP n/N	OR (random) 95% CI	Weight %	OR (random) 95% CI
Mehta 1997	1/13	1/14		16.07	1.08 (0.06, 19.31)
Park 2001	3/9	0/7		13.49	8.08 (0.35, 187.32)
Crane 2004	1/20	1/20		16.49	1.00 (0.06, 17.18)
Bellone 2004	1/22	2/24		21.79	0.52 (0.04, 6.22)
Park 2004	2/27	2/27		32.15	1.00 (0.13, 7.67)
Total (95% CI)	**91**	**92**		**100.00**	**1.17 (0.37, 3.70)**

Total events: 8 (CPAP), 6 (BiPAP)
Test for heterogeneity: Chi^2 = 1.93, df = 4 (p = 0.75), I^2 = 0%
Test for overall effect: Z = 0.26 (p = 0.79)

0.01　0.1　1　10　100
Favours CPAP　Favours BiPAP

Figure 5 Intubation rates: CPAP compared with BiPAP (odds ratio with 95% confidence intervals, random effects model).

CPO, and pooled data (355 patients) suggest that BiPAP shows a trend towards decreased intubation rates (OR 0.61; 95% CI 0.16 to 2.33) and hospital mortality (OR 0.62; 95% CI 0.32 to 1.22). However, this is not statistically significant, and more studies are required to settle this issue.

CPAP COMPARED WITH BiPAP

The superiority of BiPAP over standard therapy for acute CPO is not surprising, but the question of interest is whether BiPAP is superior to CPAP alone. There have been four randomised trials that have attempted to answer this question. Mehta et al[51] randomised patients to receive either nasal CPAP (10 cm H_2O) or BiPAP (IPAP 15 cm $H2O$/EPAP 5 cm H_2O). Although the BiPAP group had greater reductions in $PaCO_2$, systolic blood pressure, mean arterial pressure, and hypercapnia than did the CPAP group, myocardial infarction rates were higher in the BiPAP group (71%) than in the CPAP group (31%) and the study was stopped prematurely after the enrolment of 27 patients. While this difference could have been attributable to unequal randomisation as more patients in the BiPAP group presented with chest pain, the results none the less raised concerns about the safety of the ventilatory techniques used to treat CPO. On the other hand, Park et al[10 45] and Bellone et al[52] showed that BiPAP was as effective as CPAP in the treatment of CPO and both methods improved ventilation and vital signs in patients with acute CPO. No significant differences were found in hospital mortality and acute myocardial infarction rates in patients with acute CPO in comparison with CPAP alone. Recently, Crane et al[12] randomised 60 patients presenting with acute CPO to receive conventional oxygen therapy, CPAP (10 cm H_2O), or bilevel ventilation (IPAP 15 cm H_2O, EPAP 5 cm H_2O). Although treatment success (respiratory rate <23 bpm, oxygen saturation >90%, pH>7.35 occurred in three patients in the control group, seven in the CPAP group, and nine in the BiPAP group (p = 0.116), 14 of the control group patients survived to hospital discharge, compared with 20 in the CPAP group and 15 in the bilevel group (p = 0.029).

Figures 5 and 6 show the combined data of all randomised trials of CPAP compared with BiPAP in CPO, and pooled data (183 patients) suggest that BiPAP increases intubation rates (OR 1.17; 95% CI 0.37 to 3.7) and probably hospital mortality (OR 0.99; 95% CI 0.22 to 4.48). However, again like BiPAP compared with standard medical therapy group, this is not statistically significant, and more studies are required to settle this issue.

PRACTICAL ASPECTS OF NIV IN CPO
Where are these patients best treated?
While most patients with CPO present to the emergency department, practical issues, including hospital setup and

staff determine where NIV is actually performed. It is important to realise that the workload in the first six to eight hours may be greater than that required for a conventionally managed patient.[15] Consequently, patients with severe CPO requiring NIV need to be triaged to an environment with round the clock medical care, adequate nurse-patient ratio, and continuous electrocardiographic and pulse oximetry monitoring facilities. We like many other investigators manage such patients in intensive care units. Many patients with CPO would be as a consequence of myocardial infarction and unlike many investigators who have excluded such patients; many centres (including our centre) concurrently provide support with NIV while proceeding to thrombolysis or percutaneous revascularisation.

Do all patients with CPO require NIV?
Not all patients with CPO require NIV. In fact, a large number of patients rapidly respond to medical treatment and do not need additional intervention. NIV is likely to be beneficial in patients with more severe forms of CPO, especially those who present with a pH<7.25 or systolic blood pressure<180 mm Hg.[22] A potential use for NIV is to support patients who are not candidates for intubation, either because of a previous directive or as a result of poor prognosis related to an underlying disease. Another approach is to give a trial of NIV in all patients with CPO who do not respond to initial medical therapy. However, patients should be carefully monitored and failure to improve after 30 minutes on NIV should be an indication for its withdrawal, with facilities for immediate endotracheal intubation and mechanical ventilation being readily available.[53]

How should NIV be applied initially?
The application of NIV is an art of medicine. All physicians using NIV should personally apply NIV to actually understand what the patient is experiencing. You should not order a specific pressure level for a given patient without first applying NIV and assessing the patient's tolerance to the device. Initial application of NIV requires careful instruction of the patient, with a goal to gain the patient's confidence and acceptance of NIV. You must start with low pressures and the mask should be held and not strapped to the patient's face. As the patient accepts the NIV, pressures are increased to reach the gas exchange goal, but generally should not exceed 20–25 cm H_2O to minimise gastric distension and the risk of vomiting.[34] Although time consuming, the cost savings are large compared with the alternative—that is, invasive ventilation.

What should be the interface?
The masks most commonly used for short term applications of NIV include nasal or oronasal (also called full face) masks.
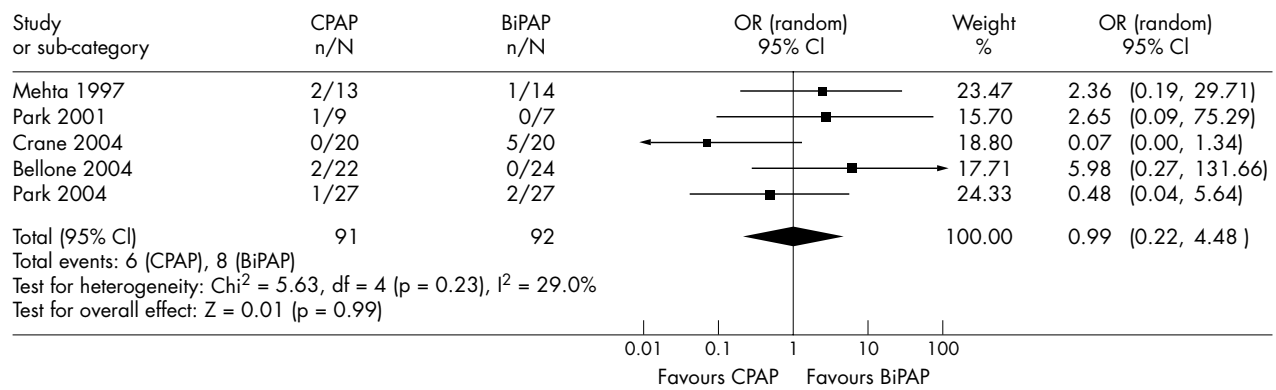
Study or sub-category	CPAP n/N	BiPAP n/N	OR (random) 95% CI	Weight %	OR (random) 95% CI
Mehta 1997	2/13	1/14		23.47	2.36 (0.19, 29.71)
Park 2001	1/9	0/7		15.70	2.65 (0.09, 75.29)
Crane 2004	0/20	5/20		18.80	0.07 (0.00, 1.34)
Bellone 2004	2/22	0/24		17.71	5.98 (0.27, 131.66)
Park 2004	1/27	2/27		24.33	0.48 (0.04, 5.64)
Total (95% CI)	91	92		100.00	0.99 (0.22, 4.48)

Total events: 6 (CPAP), 8 (BiPAP)
Test for heterogeneity: $Chi^2 = 5.63$, df = 4 (p = 0.23), $I^2 = 29.0\%$
Test for overall effect: Z = 0.01 (p = 0.99)

0.01 0.1 1 10 100
Favours CPAP   Favours BiPAP

Figure 6 Death rates: CPAP compared with BiPAP (odds ratio with 95% confidence intervals, random effects model).

Although the nasal mask is theoretically more comfortable for the patient as it is less claustrophobic, has lower dead space volume, permits speech and eating, and better mobilisation of secretions; oronasal masks achieve better control of mouth leak in mouth breathers (common feature during acute respiratory failure) and result in better quality of ventilation, in terms of improved minute ventilation and blood gas pressures.[54] In a study of 70 patients with acute respiratory failure randomised to receive a nasal or oronasal mask, both the masks performed similarly with regard to improvements in gas exchange and avoidance of intubation, however the nasal mask was less well tolerated because of excessive mouth leaks[55]; probably because mouth leaks with nasal CPAP lead to high unidirectional nasal airflow and increased nasal resistance.[56] In another study, however, no significant differences were noted irrespective of the type of mask used.[57] From the available evidence it cannot be said that any interface is clearly superior to another in terms of important outcomes such as intubation rate or mortality. An oronasal interface may be more effective and better tolerated than the nasal interface for patients with acute respiratory failure. Thus, a sensible approach would be to start with an oronasal mask for most patients with acute respiratory failure, and switch to a nasal mask if prolonged use is contemplated. Whichever mask is chosen, a comfortable fit is of paramount importance, and thus using a mask of proper size, not strapping the headgear too tightly, and using wound care tape on the bridge of the nose are important considerations to avoid pressure ulcers.[34]

Does the type of ventilator make any difference?

NIV can be delivered through ventilators designed for invasive mechanical ventilation ("critical care ventilators"), and portable devices. Critical care ventilators are less leak tolerant and are thus likely to sound alarms more inappropriately. But the monitoring capabilities and presence of oxygen blenders make it superior to portable devices. On the other hand, the portable ventilators are more leak tolerant and less likely to sound alarms inappropriately than the critical care ventilators. However, they may promote rebreathing by virtue of their single inspiratory and expiratory tubing (minimised by assuring adequate expiratory pressure[58 59] and expiratory ports over the nasal bridge[60]) Also, most of the portable ventilators do not have an oxygen blender and supplemental oxygen is usually given by adding it into the mask or the circuit. Thus continuous pulse oximetry is required to monitor oxygenation when using this device in patients with CPO.[61] However, comparisons of the two devices show that the portable device performs as well as the critical care ventilators.[34] Recently, ventilators that deliver either invasive ventilation or NIV have been designed. When in the non-invasive mode, they are more leak tolerant and use only the alarms essential for the operation of NIV. On the other hand, newer portable devices with graphic monitors, oxygen blenders, and sophisticated alarms have also become available for use in the acute setting.

CONCLUSIONS

There is a strong evidence for the use of CPAP by facemask in patients with CPO, and CPAP decreases the need for endotracheal intubation and improves survival. However, there is insufficient evidence to recommend the use of BiPAP, probably the exception being patients with hypercapnic CPO.[9 11 45 46] Although evidence suggests that patients presenting with CPO are more likely to survive to hospital discharge if treated with CPAP, rather than with BiPAP, and probably there is no relation between early physiological changes and hospital survival, the evidence is not strong so as to completely exclude BiPAP, and more studies are required to elucidate the role of BiPAP in CPO.[62]

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