Original Article

Continuous Positive Airway Pressure *Versus* Continuous Negative Pressure Around the Chest for Patients with Acute Exacerbation of Chronic Obstructive Pulmonary Disease in the Intensive Care Unit: A Pilot Study

Rakesh K. Chaturvedi[1] and Arnold Zidulka[2]

Divisions of Cardiac Surgery and Critical Care, Royal Victoria Hospital[1]; and Respiratory Medicine and Intensive Care Medicine, Montreal General Hospital and Montreal Chest Institute[2], McGill University Health Center, Montreal, Canada

ABSTRACT

Introduction. With chronic obstructive pulmonary disease (COPD) exacerbations, continuous positive airway pressure (CPAP) has been used to overcome the threshold load provided by intrinsic positive end expiratory pressure and decrease the inspiratory work of breathing. In this pilot study, we observed whether a continuous negative pressure (CNP) around the thorax and upper abdomen with a shell and wrap would provide a similar level of relief in dyspnoea.

Methods. In eight patients with COPD in the intensive care unit receiving CPAP, CNP was alternated twice with CPAP (30 minutes each time). We measured heart rate, respiratory rate, blood pressure, arterial oxygen tension (PaO_2), arterial carbon dioxide tension ($PaCO_2$), pH and dyspnoea score, and asked each patient which system was more comfortable.

Results. Comparing CPAP with CNP, we found no significant difference in all measured parameters except $PaCO_2$ which was lower with CNP. Seven out of eight patients found that CNP was more comfortable.

Conclusions. The CNP was similar to CPAP except CNP was more comfortable. **[Indian J Chest Dis Allied Sci 2011;53:141-144]**

Key words: Chronic obstructive pulmonary disease exacerbations; Continuous positive airway pressure; Continuous negative pressure; Dyspnoea; Comfort and Intensive care unit

INTRODUCTION

A large portion of the work of breathing in acute exacerbation of chronic obstructive pulmonary disease (AECOPD) is a result of intrinsic positive end expiratory pressure (PEEPi).[1-3] We wanted to test the hypothesis that reducing PEEPi by a continuous negative pressure (CNP) around the chest and upper part of the abdomen would result in the same relief of dyspnoea as by a continuous positive airway pressure (CPAP) at the airway opening.

We did not wish to compare CNP with a negative swing in pressure *versus* bi-level airway pressure (BiPAP) at the airway opening,[4] as it has been previously shown that it was difficult to ventilate patients with COPD with the former system.[5]

Of note, the negative pressure with CNP is applied only around the chest and upper abdomen. This is unlike an iron lung where the entire body (except for the head and part of the neck) is surrounded by the negative pressure. We have shown in dogs that a negative pressure localised to the chest and upper abdomen is different from the negative pressure of the iron lung. The iron lung had the same haemodynamic effects of reducing cardiac output in dogs as with positive pressure ventilation (PPV). This did not occur with more localised negative pressure ventilation.[6] Furthermore, in immediate post-operative cardiac surgery patients, we have recently shown that CNP localised to the chest and upper abdomen, while receiving PPV resulted in an increased cardiac output compared to PPV alone.[7]

For the above reasons, we studied the use of CNP localised to the thorax with CPAP. Because a negative pressure around the thorax leaves the patient's face free to eat, speak, read, cough and raise sputum, the potential exists that CNP is more comfortable than CPAP. Therefore, we compared a

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Correspondence and reprint requests: Dr Arnold Zidulka, Montreal General Hospital, Division of Respiratory Medicine and Intensive Care Medicine, 1650 Cedar Ave., LH 10- 412, Montreal, Quebec, Canada H3G 1A4; Phone: 514 934 1934 Extn: 48014; Fax: 514 934 8226; E-mail: arnold.zidulka@muhc.mcgill.ca

pilot study of CNP *versus* CPAP in patients in the intensive care unit (ICU) with an AECOPD. We wished to see if CNP was equivalent to CPAP in terms of relief of dyspnoea, yet was preferred by the patients in terms of comfort.

MATERIAL AND METHODS

After obtaining ethics committee approval and securing informed consent from the patients, we studied eight adult patients with AECOPD who were receiving CPAP in the ICU of the Montreal Chest Institute. The CPAP was provided by a full face mask (Resmed full face CPAP mask, Agile Medical, 701B Moore Station Industrial Park, Prospect Park, PA 19076).

To create a negative pressure around the chest, we constructed a light weight hard shell with a front door (to allow the patient into the shell). The shell surrounded the chest (front and back) from just under the axilla to the upper abdomen and was held up by shoulder straps. To create an airtight seal we used a commercially available nylon jacket which went over the shell. A hole in front of the jacket and shell allowed connection to a suction port so that a negative pressure could be created under the shell. As the suction was applied, the nylon jacket was sucked against the body to make the shell air tight at the neck, waist and arms. The CNP was produced by a Thompson Maxivent Ventilator (Model MV, Puriton-Bennett corporation, Boulder, Co.). It was modified so that it provided a CNP.

During the application of CNP, the suction pressure was measured under the shell. Patients were initially tested with different levels of negative pressure to find out which level was most comfortable for breathing. This ranged from zero to $-40cmH_2O$ (in steps of $5cmH_2O$) and from –40 to 0 cmH_2O. Approximately four breaths were allowed at each negative pressure level. The negative pressure used was the one with which the patient felt the most comfortable.

All patients were receiving intravenous corticosteroids and inhaled brochodilators. However, none of these medications were given for at least one hour before or during the study period. Patients were assigned to continue to receive their standard treatment with CPAP using a full face mask alternating with CNP using the shell and wrap. Which mode started first was randomised. The CNP and CPAP were alternated twice, remaining in each mode for 30 minutes. The CPAP level and the fraction of inspired oxygen (FIO_2) used was that which had been selected by the treating ICU physician. At the end of the experiment the patients continued with their regular CPAP therapy. The FIO_2 was attempted to be matched during CNP compared to CPAP by using a high-flow system venturi mask.

At the end of each 30 minutes we measured arterial blood gases, heart rate (HR), systolic and diastolic blood pressure (BP), respiratory rate (RR) as well as a dyspnoea level on a modified Borg's scale.[8] In addition, each patient was asked as to which system (CPAP or CNP) was more comfortable.

We excluded patients who were unstable haemodynamically or who had cardiogenic pulmonary oedema, known obstructive sleep apnoea or chest wall deformities which would not allow easy use of the shell and vest, e.g. scoliosis or kyphosis.

Statistical Analysis

Being a pilot study we have not calculated the number of patients for sufficient power. We averaged the two values of the CPAP and CNP modes on each patient and these mean values were used for statistical analysis. As the patients served as their own control, paired 't' test was used for statistical purposes (InStat, GraphPad Software, Inc., San Diego, CA, USA**).** Group data are presented in the form of mean $\pm$ standard deviation.

RESULTS

Table 1 lists the patients' age, gender, FIO_2 and the pressures used with CPAP and CNP. On comparing CPAP with CNP, we found no difference in RR, HR, systolic and diastolic BP, PaO_2 and pH (Table 2). Arterial carbon dioxide tension was lower with CNP than with CPAP (p=.0254). The modified Borg's scale for dyspnoea was similar for CPAP and CNP. However, seven out of eight patients found CNP more comfortable than CPAP. The eighth patient was unable to judge that one system was more comfortable than the other. The theoretical mechanism of action of CPAP and CNP is shown in the figure.

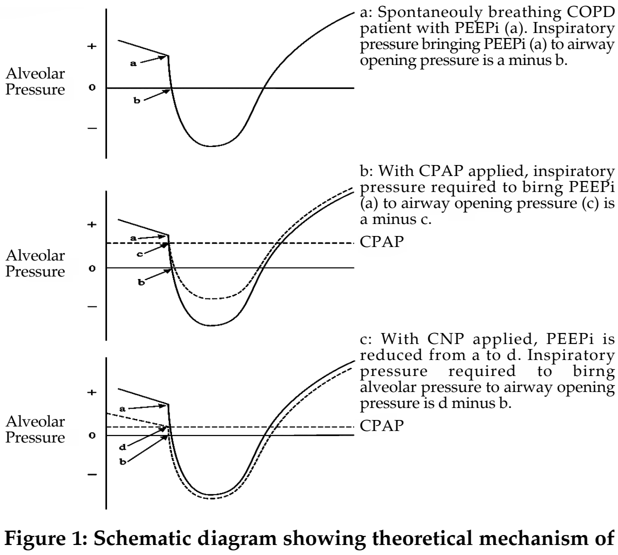

Figure 1: Schematic diagram showing theoretical mechanism of action of CPAP and CNP.

Table 1. Patient demographics, values on admission and mode applied

Patient No.	Patient's Demographics			Blood Gas Values on Admission				Mode Applied	
	Age (in years)	Gender	FIO_2 (%)	PaO_2 (mmHg)	$PaCO_2$ (mmHg)	pH	HCO_3	CPAP (cmH_2O)	CNP (cmH_2O)
1	70	M	24	73	79	7.31	40	7.5	-34
2	67	F	31	70	41	7.43	28	5.0	-18
3	69	F	24	95	50	7.36	28	7.5	-18
4	64	F	28	102	84	7.26	38	3.0	-14
5	65	M	32	102	58	7.30	34	5.0	-42
6	83	M	26	85	61	7.33	32	7.5	-20
7	65	M	30	68	58	7.38	34	5.0	-40
8	57	M	28	107	82	7.36	46	7.5	-26

CNP=Continuous negative pressure; CPAP=Continuous positive airway pressure; M=Male; F=Female; FIO_2=Fraction of inspired oxygen; PaO_2=Arterial oxygen tension; $PaCO_2$=Arterial carbon dioxide tension

Table 2. Parameters at end of each mode of ventilation

Parameter	CPAP Mean±SD	CNP Mean±SD	p value Paired 't' Test
Respiratory rate (breaths/min)	21.2±2.9	21.6±2.0	0.6957
Heart rate (beats/min)	90.3±19.7	89.3±19.3	0.6744
PaO_2	79.0±5.7	87.2±29	0.4183
$PaCO_2$	57.2±17.9	54.5±18.3	0.0254*
HCO_3	33.4±6.6	32.9±7.6	0.4061
pH	*7.4±.06*	*7.4±.07*	*0.3579*
Systolic arterial blood pressure	149.7±39.6	152.2±43.4	0.4726
Diastolic arterial blood pressure	72.8±14.1	69.4±11.1	0.0611
Borg scale for dyspnoea	2.14±.9	1.8±1.3	0.2534

*PaO_2=Arterial oxygen tension; $PaCO_2$=Arterial carbon-dioxide tension; HCO_3=Hydrogen bicarbonate; *=p<0.05*

DISCUSSION

With respect to RR, HR, BP and dyspnoea level, the results with CNP were not different from CPAP. We have hypothesised that this may be a result of CNP reducing the threshold load by making the PEEPi closer to atmospheric pressure with a resulting reduction in the inspiratory work of breathing. This might be similar to CPAP reducing the threshold load and reducing the inspiratory work of breathing. The $PaCO_2$ was mildly reduced with CNP relative to CPAP. This might be because of a better reduction in the inspiratory work of breathing, perhaps because the patients were questioned as to which level of pressure was most comfortable with CNP. This question was not posed with the application of CPAP, as the level of CPAP was selected by the treating physician.

In seven of eight cases CNP was more comfortable than CPAP. This was most likely because the face was now not enclosed by a tight fitting full face mask. The patients were able to converse freely while receiving supplemental oxygen. One patient felt he was able to cough more effectively with CNP than CPAP and was able to raise sputum easier. In addition, with the face not enclosed, patients would be able to read while they received supplemental oxygen via a nasal cannula or a loosely fitted mask. They would be able to eat their regular meals without stopping their CPAP. If it was not possible to temporarily discontinue CPAP, these patients would have to be fed by a nasogastric or nasoduodenal tube—a condition that would not apply with CNP.

We have shown that COPD exacerbations in patients who are close to being discharged from hospital can walk further in a 6-minute walk test using CNP, compared with sham negative pressure or with the patient not wearing the shell and jacket.[9] This further supports the hypothesis of CNP causing a reduction of the threshold load.

A "grid and wrap" or "shell and jacket" differs from an iron-lung in the following fashion: when the entire body is enclosed in a sub-atmospheric chamber with the airway opening exposed to atmospheric pressure, this is equivalent to a positive pressure at the airway opening. In an iron-lung with negative pressure, only the head with the airway opening are exposed to atmospheric pressure. This situation is closer to a positive airway pressure than in the situation where negative pressure surrounds only the chest wall and upper abdomen as with a shell and jacket.

In support of this concept, we have previously shown that PPV with positive end expiratory pressure (PEEP) depressed cardiac output in dogs similar to iron-lung negative pressure ventilation with negative end expiratory pressure (NEEP), but not with "grid and wrap" negative pressure ventilation with NEEP.[6]

The present study has some limitations as described below:

1. As the number of patients was small and the study time was short, these results would require verification by a larger randomised study.
2. Many patients admitted to the ICU with a COPD exacerbation receive non-invasive PPV via a full face mask. Not only does this system tend to overcome the threshold load provided by PEEPi but it also provide a ventilatory assist, thereby better ensuring a reduction in the $PaCO_2$. As CNP does not provide a ventilatory assist, CNP might, therefore, perhaps be better used in the less severe COPD exacerbation where elevation of the $PaCO_2$ does not cause severe respiratory acidosis.
3. PEEPi is generally not measured with the application of CPAP for COPD exacerbation. It is presumed that PEEPi is elevated in COPD exacerbation and negated by CPAP.[3,4] In this pilot study PEEPi was also not measured.
4. Had there been a change in respiratory rate with CNP relative to CPAP, this could have changed the PEEPi.[10,11] No change in respiratory rate was observed in the present study.
5. Another limitation of the study is that the Borg's scale for dyspnoea was not compared with the patients receiving neither CPAP nor CNP. In a future study, this would be important to ensure that the patient was indeed benefitting from either CPAP or CNP. In the current study, we can only conclude that CNP was no different than CPAP.
6. Patients with left ventricular heart failure were excluded in this present study because of the concern that more negative intra-thoracic pressure would enhance venous return and cause increased pulmonary oedema
7. As the patients were started on CNP only after stabilisation in the ICU, it is probable that the current population studied was less ill than a population immediately arriving in the ICU.
8. It is uncertain whether CNP would impede expiration. To the extent that during expiration dynamic collapse of the airways might occur in COPD exacerbation, this would minimise any effect of the CNP impeding expiration.[12]

In the present study, we postulate that with the continuous negative pressure provided by the "shell and jacket", that the threshold load of PEEPi is reduced by having the alveolar pressure brought closer to the atmospheric pressure, a mechanism that is different from PEEP or CPAP. In this pilot study, CNP was found to be equivalent to CPAP in patients with COPD exacerbation requiring ICU admission. CNP, however, was found to be more comfortable. This mode might potentially be used in easing a patient's work of breathing. It also could possibly allow a patient to be treated on a regular hospital ward, rather than requiring admission to an ICU with a tight fitting full face mask.

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