Evaluation of Ejectors Using the Venturi Effect for a Continuous Positive Airway Pressure System without Compressed Air

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The purpose of this study is to perform a test in the application of the existing ejectors with the continuous positive airway pressure (CPAP) system without compressed air. Four types of ejector (jet mixer, the former and new puritan nebulizer and the deluxe nebulizer) for blending oxygen and room air by the Venturi effect were tested. A decrease of mixed gas flow and an increase of oxygen concentration were observed according to the increase of positive pressure in all systems. The former puritan nebulizer and deluxe nebulizer were found to be unavailable for the CPAP system for high oxygen concentration and low mixed gas flow for the increase of positive pressure. In the system, however, with the new puritan nebulizer and jet mixer, a sufficient mixed gas flow and an appropriate oxygen concentration could be supplied at an adequate positive pressure. The CPAP system using only oxygen was judged as possibly giving availability. (Key words: Continuous positive airway pressure (CPAP), ejector, oxygen concentration, mixed gas flow)

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Wide availability of the continuous positive airway pressure (CPAP) for treatment of respiratory failure has been generally admitted since the first application of this method with patients with the idiopathic respiratory distress syndrome by Gregory et al.[1] Either oxygen blended with room air or compressed air should be necessary to supply an appropriate concentration of oxygen for setting up CPAP system. Since the existing air-oxygen blenders utilized in CPAP systems require compressed air, in the institution without a compressed air source CPAP therapy is impossible as yet. Our subject was studied to find out the possibility of a CPAP system using only oxygen gas from an oxygen-cylinder or central supply.

This paper will propose a new CPAP system using a simple and inexpensive ejector as a blender working via the venturi effect method.

Materials and Methods

Our CPAP system shown in figure 1 consists of a pressure regulating valve, an ejector, a Fleisch pneumotachograph (TV-121, Nihon Koden Kogyo, Tokyo, Japan), a zyrconia oxygen analyzer (MG-360, Minato Medical Science, Osaka, Japan), and a water box. Oxygen through the pressure regulating valve to adjust inlet pressure was blended with room air by the ejector in this system.

The positive pressure in the circuit of this system, that is CPAP, was obtained by sub-

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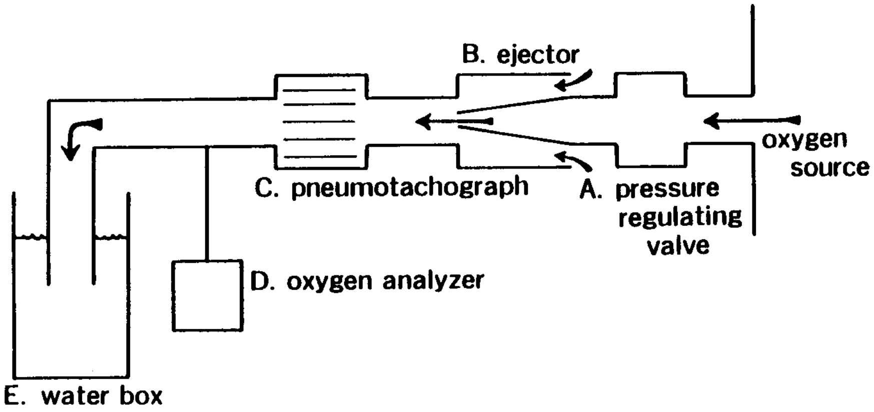

Fig. 1. The CPAP system consists of: (A) pressure regulating valve, (B) ejector, (C) pneumotachograph, (D) oxygen analyzer, (E) water box.

merging the distal limb of the system into the water. The measurements of oxygen concentration and mixed gas flow were carried out respectively by the oxygen analyzer and the pneumotachograph.

The four types of ejector to be adopted were Jet Mixer (Kimura Medical Instrument, Tokyo, Japan), the new Puritan Nebulizer (Puritan-Bennett, Lenexa, Kansas, No. 126-110), the former Puritan Nebulizer (Puritan-Bennett, No. 126-055), and Deluxe Nebulizer (Ohio Medical Products, Madison, Wisconsin). Procedures of the measurement for each type were made as follows:

Jet mixer

The inlet pressure was set at 4.0 kg/cm^2G and the setting of the oxygen concentration dial was made at 35, 40, 45, 50, 55 and 60%. Under these conditions, the measurements were made at zero, two, four, six, eight, 10, 12, 14 and 16 cm H_2O of positive pressure in the airway of the system.

The new puritan nebulizer

The inlet pressure was set at 4.0 kg/cm^2G and the flowmeter dial was set at its maximum. Under these conditions, the measurements were made at zero, two, four, six, eight and 10 cm H_2O of positive pressure in each of the oxygen dial settings at 35, 45 and 55%.

The former puritan nebulizer

The inlet pressure and the flowmeter dial setting were the same as the new puritan nebulizer. The measurements were made at zero, two and four cm H_2O of positive pressure in each of the oxygen concentration dial settings of 40 and 70%.

Deluxe nebulizer

The conditions except setting of the oxygen concentration dial at 40 and 60% were the same as with the former Puritan Nebulizer.

The student's t-test was used to determine the statistical significance.

Results

All type of ejectors we studied showed that the mixed gas flow decreased and the oxygen concentration increased in proportion as the positive pressure increased in the airway of the system. Especially with the former puritan nebulizer and Deluxe Nebulizer, the greater part of the gas flow leaked out through the suction orifice of the ejector at a positive pressure of only four cm H_2O (table 1).

The results of measurements with jet mixer are shown in table 2. The mixed gas flow increased and the oxygen concentration decreased according to the increase of inlet pressure as well as to the decrease of positive pressure. The mixed gas flow of more than 10 l/min. and the oxygen concentration of about 35 to 50% could be supplied at a positive pressure of 10 cm H_2O with this system.

Table 1. Oxygen concentration and mixed gas flow with the former puritan nebulizer and deluxe nebulizer

positive pressure (cmH_2O)	Oxygen concentration dial setting							
	the former puritan nebulizer				deluxe nebulizer			
	40%		70%		40%		60%	
	mixed gas flow (ℓ/min)	O_2 concentration (%)	mixed gas flow (ℓ/min)	O_2 concentration (%)	mixed gas flow (ℓ/min)	O_2 concentration (%)	mixed gas flow (ℓ/min)	O_2 concentration (%)
0	33.0	51.1	20.6	78.0	31.8	50.2	21.6	70.5
2	20.4	80.8	16.8	91.4	16.8	81.3	15.0	89.5
4	0	100	11.4	100	0	100	9.0	100

Inlet pressure was set at 40 kg/cm^2G and flowmeter dial was set at its maximum. Back flow through the suction orifice took place at positive pressure of only 4 cmH_2O.

Table 2. Oxygen concentration and mixed gas flow with jet mixer at inlet pressure of 4.0 kg/cm^2G

positive pressure (cmH_2O)	Oxygen concentration dial setting											
	35%		40%		45%		50%		55%		60%	
	mixed gas flow (ℓ/min)	O_2 concentration (%)	mixed gas flow (ℓ/min)	O_2 concentration (%)	mixed gas flow (ℓ/min)	O_2 concentration (%)	mixed gas flow (ℓ/min)	O_2 concentration (%)	mixed gas flow (ℓ/min)	O_2 concentration (%)	mixed gas flow (ℓ/min)	O_2 concentration (%)
0	24.0	31.7	19.2	35.1	15.6	38.8	13.2	42.7	11.4	46.5	10.2	51.3
2	23.4	32.8	19.0	36.2	15.6	39.9	13.2	43.7	11.0	47.4	9.6	52.5
4	22.6	33.7	18.0	37.2	14.4	41.0	13.0	44.8	10.8	49.0	9.6	53.2
6	20.4	34.8	16.6	38.6	14.2	42.3	12.0	46.2	10.2	50.8	9.0	55.4
8	19.2	36.0	15.1	39.7	13.2	43.8	10.8	47.8	9.6	53.2	8.4	57.4
10	17.4	37.5	13.8	41.4	11.6	45.8	10.2	49.6	9.0	53.8	7.8	59.0
12	15.6	39.0	13.2	43.1	10.8	47.3	9.6	51.2	8.4	55.7	7.2	60.1
14	13.8	41.3	12.0	45.6	9.6	50.1	8.4	54.8	7.8	59.1	6.8	63.3
16	12.0	44.5	10.2	48.8	8.4	53.6	7.8	57.6	7.1	62.3	6.0	66.5

The results of the measurements with the new puritan nebulizer are shown in table 3. The mixed gas flow of more than 20 1/min. and the oxygen concentration of about 50 to 70% could be supplied at a positive pressure of six cm H_2O, but the back-flow through the suction orifice took place at a positive pressure of 10 cm H_2O.

Discussion

An instrument, which blends two kinds of gases due to the Venturi effect, is called an ejector or jet pump. The Venturi effect is based on the Bernoulli principle which says that the lateral pressure of a gas decreases according to the velocity of flow increase. In the ejector, an oxygen flow through a constricted orifice makes the pressure below

Table 3. Oxygen concentration and mixed gas flow with the new puritan nebulizer

positive pressure (cmH_2O)	Oxygen concentration dial setting 35% mixed gas flow (ℓ/min)	35% O_2 concen-tration (%)	45% mixed gas flow (ℓ/min)	45% O_2 concen-tration (%)	55% mixed gas flow (ℓ/min)	55% O_2 concen-tration (%)
0	39.6	40.2	30.2	51.1	25.2	60.3
2	36.2	44.3	28.8	54.9	23.4	64.5
4	32.4	49.6	25.8	59.5	21.8	68.3
6	26.8	57.4	22.8	65.2	19.2	74.4
8	19.2	74.4	17.0	80.2	15.6	86.3

Inlet pressure was set at 40 kg/cm^2G and flowmeter dial was set at its maximum. Back flow through the suction orifice took place at positive pressure of 10 cmH_2O.

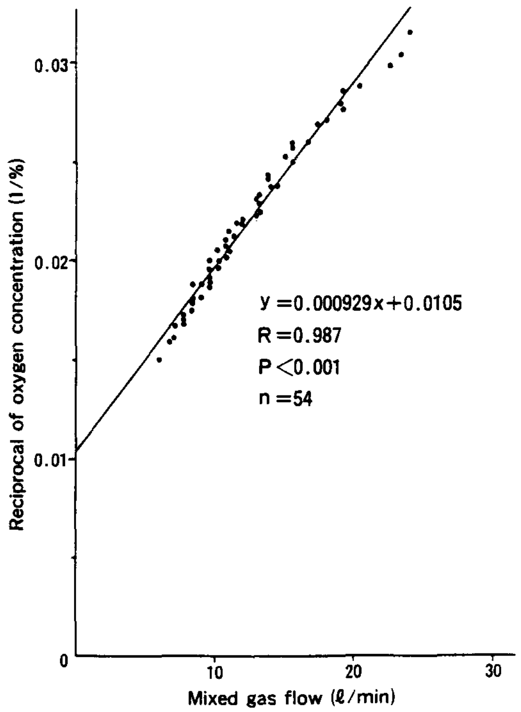

Fig. 2. Relationship between mixed gas flow (X) and reciprocal of oxygen concentration (Y) with jet mixer at inlet pressure of 4.0 kg/cm^2G.

atmospheric pressure, just after leaving the orifice of the nozzle, and then this negative pressure inspires room air through the suction orifice. The oxygen concentration can be affected by the orifice size and the oxygen flow[2]. The ejector was considered to be applied to setting up the CPAP system using only compressed oxygen from an oxygen-cylinder or central gas supply system.

In figure 2, mixed gas flow (X) has been plotted against the reciprocal of oxygen concentration (Y) not with standing positive pressure in the system for the measurements with the jet mixer. Figure 3 shows the similar data for the measurement with the new puritan nebulizer.

Relationships between X and Y are considered to give the following experimental equations:

$Y = 9.29 \times 10^{-4}X + 0.0105$ in figure 2 ($R = 0.987$, $P < 0.001$), and $Y = 5.48 \times 10^{-4}X + 0.00277$ in figure 3 ($R = 0.998$, $P < 0.001$). These linear relationships are characterized by a high degree of correlation. These findings might reach the conclusion that the oxygen concentration is decided independently of the positive pressure by the mixed gas flow. This is the most important proposal obtained from this work.

Therefore, the oxygen flow from the nozzle of an ejector can be expressed from the data of tables 2 and 3 by the equation:

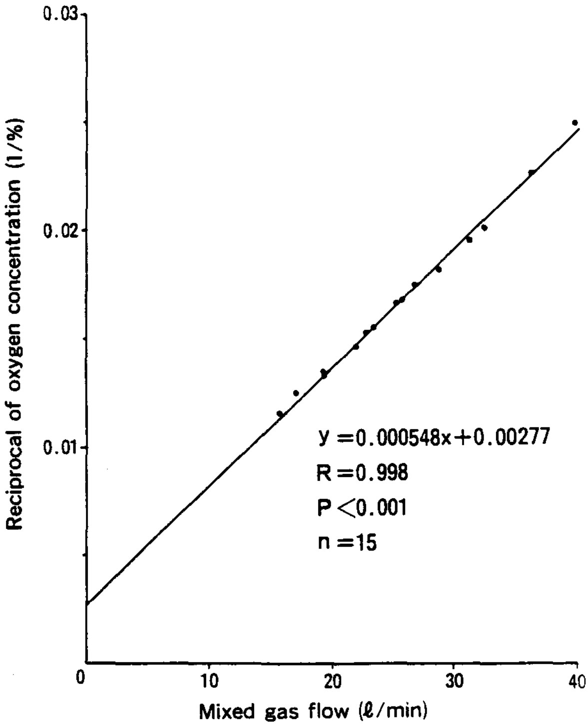

Fig. 3. Relationship between mixed gas flow (X) and reciprocal of oxygen concentration (Y) with new puritan nebulizer.

$$A = \frac{B - 20.9}{79.1} \times C$$

A: Oxygen flow from the nozzle of the ejector (1/min.)
B: Measured oxygen concentration (%)
C: Mixed gas flow (1/min)

The calculated values (Mean ± S.D.) of oxygen flow (A) are as follows:

3.7 ± 0.13 ℓ/min in table 2, and 12.1 ± 0.90 ℓ/min in table 3. It is reasonably assumed by the above results that the oxygen flow from a nozzle of an ejector is almost constant and the oxygen concentration is determined mainly by the volume of inspired room air.

The reason for the above conclusion is assumed to be the fact that a counter-pressure (positive pressure in the system) reduces principally volume of inspired room air because of much higher inlet pressure than atmospheric pressure and also counter-pressure.

The previous reports suggested that a fresh gas flow rate from two to three times the respiratory minute volume was necessary for applying a T piece technique to the spontaneously breathing patient[3–6] and twice the respiratory minute volume was necessary for applying Jackson Rees circuit[7,8]. The later circuit was used by Gregory and others in their original CPAP system[1]. In many cases, oxygen concentration over 50% isn't necessary for the CPAP to be clinically applied. In the present study, our results revealed that a sufficient fresh gas flow and an appropriate oxygen concentration could be supplied at an adequate positive pressure by the CPAP system with a jet mixer or the new puritan nebulizer. (However, the former puritan nebulizer and deluxe nebulizer seemed to be hardly applicable to the CPAP system for back flow through the suction orifice taking place at a positive pressure of only four cm H_2O.) The conclusive purpose of this work is the possible availability of easy and cheap CPAP systems using only compressed oxygen. As a matter of course, a humidifier and an elastic or weight loaded reservoir bag as a capacitance which reduces the fluctuation in the airway pressure during inspiration and expiration[9,10] should be used in this system clinically, and more detailed clinical information is expected hereafter.

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