Oxygen and carbon dioxide concentrations in oxygen tents

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In recent years there has been a growing realization that uncontrolled oxygen therapy in patients with emphysema complicated by acute chest infection may be followed by reduced ventilation and thus further elevate an already raised arterial carbon dioxide tension. Hypercapnia may give rise to headache, nausea, profuse sweats, muscular twitchings, drowsiness, and coma (CO_2 narcosis). The likelihood of hypercapnia is further increased if the inspired gases contain appreciable amounts of expired CO_2 . Hence it is desirable that apparatus for the administration of oxygen to this type of patient should have the means to supply oxygen (a) at concentrations high enough to raise the arterial O_2 tension to adequate levels, yet not so high as to depress ventilation unduly, and (b) with as low a CO_2 content as possible.

So far as masks are concerned, an attempt has been made to reduce the CO_2 content of inspired gases by increasing the oxygen flow rate; by reducing the dead-space of the mask (M.C. mask; Catterall, 1960); and by diluting the gases by entrainment of ambient air (Venturi mask; Campbell, 1960 b). The last method has the further advantage of reducing the oxygen concentration to safe levels.

Oxygen tents are liable, no less than masks, to accumulate undesirable concentrations of CO_2 , and levels of 1% to 2% are commonly reached unless means are adopted to prevent this occurring. In the Oxygenaire Mark V tent, CO_2 may be optionally washed out by the entrainment of ambient air, and the oxygen concentration is simultaneously reduced. This model was accordingly selected for a trial of its efficiency in permitting control of O_2 concentration and in maintaining a low CO_2 concentration.

MATERIAL AND METHODS

The tent was used under normal working conditions for five patients suffering from acute infective exacerbations of chronic bronchitis, and for one healthy volunteer. The mattress overlays were

covered by non-porous plastic envelopes. Gas samples were aspirated at 10-minute intervals for periods of four to five and a half hours. During this time the zipper was opened for meals, toilet, and nursing procedures. Gas samples were analysed for oxygen with a Beckman analyser, and for carbon dioxide with a modified Haldane analyser¹ which has an accuracy of $\pm 0.05\%$. After preliminary 'flushing' at 10 to 12 l./min. for 20 minutes the oxygen was run at a fixed rate until sampling showed that oxygen and carbon dioxide percentages in the tent were stable. Similarly, when any change was made, either in the oxygen flow rate or in the entrainment of air, working conditions were maintained without alteration until a new equilibrium was reached. The entrainment of air is referred to in the results as ' CO_2 wash-out on', and its absence as ' CO_2 wash-out off'. The oxygen consumption of each patient was measured with a Benedict-Roth apparatus as soon as possible after the tent analyses had been completed, and the carbon dioxide output was calculated assuming a respiratory exchange ratio of 0.8. The relative humidity within the tent was measured every 10 minutes with a hair hygrometer. Steps to humidify the oxygen were not taken.

RESULTS

As the CO_2 output of all five patients lay within close range (178 ml. to 197 ml. per minute A.T.P.D.) the results have been grouped together in the Table.

Fluctuations in O_2 and CO_2 concentration could be ascribed to the changing of cylinders, to meals, and to nursing procedures. Switching on the CO_2 wash-out produced a rapid fall in CO_2 concentration from about 1% to about 0.5% in 5 to 10 minutes, followed by a slower decline to 0.2% to 0.3% during the ensuing 20 minutes, the actual level reached being independent in practice of the oxygen flow rate.

¹Aimer Products Ltd.

TABLE

<i>CO₂ wash-out off</i>										
O ₂ flow rate (l./min.)	8									
Mean O ₂ concentration in tents (%)	54 (range 50-57)									
Mean CO ₂ concentration in tents (%)	0.96 (range 0.8-1.1)									
<i>CO₂ wash-out on</i>										
O ₂ flow rate (l./min.)	..	..	..	4	5	6	7	8	9	10
O ₂ concentration (%)	..	..	..	26	25-26	26-28	27-29	28-31	28	29-31
CO ₂ concentration (%)	..	..	..	0.25		0.25-0.3	0.2-0.35	0.25-0.45	0.3	0.2-0.4
No. of observations	..	..	..	1	2	3	3	4	1	2

The five patients were of medium build and over 50 years of age. In order to test the tent's response to a higher CO₂ output, a heavily built young male volunteer (weight 176 lb. (80 kg.), height 5 ft. 11 in. (1.79 m.)) was placed in the tent. At an oxygen flow rate of 8 l./min. the gas concentrations in the tent were as follows:—

CO₂ wash-out off:

Oxygen 56% ; carbon dioxide 1.6%

CO₂ wash-out on:

Oxygen 29.5% ; carbon dioxide 0.5%

His CO₂ output was 291 ml./min. This was 55% greater than the mean for the five patients, and the CO₂ concentrations in the tent were proportionately higher.

The relative humidity varied between 40% and 45% in the six experiments.

DISCUSSION

An analysis of the factors determining the O₂ and CO₂ content of tents, and the amount of gaseous interchange between the interior and exterior of tents, has been made by Jahn (1953).

CO₂ CONCENTRATIONS When a steady state has been reached (Jahn, 1953)

$$\text{CO}_2 \% \text{ in tent} = \frac{100 \times C (\text{O}_2 - 21)}{79 F}$$

where C is the rate of CO₂ production in l./min., O₂ is the O₂% in the tent, and F is the flow rate of O₂ into the tent in l./min.

If CO₂ production and oxygen flow rate remain constant, it follows from the formula that CO₂% in the tent varies as (O₂ - 21). Taking mean oxygen concentrations in the patients' tents,

with CO₂ wash-out off, O₂ = 53.5%, and (O₂ - 21) = 32.5

with CO₂ wash-out on, O₂ = 29.5% and (O₂ - 21) = 8.5,

when the O₂ flow rate is 8 l./min.

Whence there is a predicted fall in CO₂ concentration to about one-quarter the initial level after the wash-out is switched on. Other things

being equal, the CO₂ concentration also varies directly as the patient's CO₂ output. In practice, the carbon dioxide concentration is also slightly affected by variations in the rate of diffusion through the bedclothes, and the extent of bellows-like action of the mattress from movements of the patient. The oxygen concentration varies in like manner. For example:

(a) Case 3

CO₂ wash-out off

F = 8

C = 0.185

O₂ = 54

Predicted CO₂ concentration = 0.97%

Measured CO₂ concentration = 0.8%

CO₂ wash-out on

F = 8

C = 0.185

O₂ = 30

Predicted CO₂ concentration = 0.26%

Measured CO₂ concentration = 0.25%

(b) Volunteer

CO₂ wash-out off

F = 8

C = 0.291

O₂ = 56

Predicted CO₂ concentration = 1.6%

Measured CO₂ concentration = 1.6%

CO₂ wash-out on

F = 8

C = 0.291

O₂ = 29.5

Predicted CO₂ concentration = 0.4%

Measured CO₂ concentration = 0.5%

O₂ CONCENTRATIONS Campbell (1960a) has shown that, in patients suffering from respiratory failure due to acute chest infection, adequate arterial oxygen saturations may be achieved by administering oxygen in the range 24% to 35%. Higher oxygen concentrations can be harmful in so far as hypoventilation and a rise in arterial CO₂ tension may ensue.

It was not possible under working conditions to complete a full range of measurements for all five patients at each 1-litre increment of flow rate, but where measurements were made on three or four patients at a given flow rate, the variation in O₂ concentration was negligible.

It was found possible to obtain predictable oxygen concentrations ($\pm 1\%$) in the range 26% to 30% by using the CO₂ wash-out device in conjunction with oxygen flow rates between 4 and

10 l./min. Undoubtedly the range of oxygen concentrations could be extended in both directions by using flow rates beyond these limits.

VOLUME OF AMBIENT AIR ENTRAINED BY CO₂ WASH-OUT According to Jahn (1953),

$$E = \frac{F(100 - O_2)}{O_2 - 21}$$

where E is the diffusion exchange in l./min., F is the maintenance oxygen flow rate in l./min., and O₂ is the oxygen percentage in the tent.

The term 'diffusion exchange' is here defined as the exchange of gases between the interior of the tent and the ambient air, whether by diffusion through the bedclothes, or bellows action resulting from the patient's movements, or the entrainment of air via the CO₂ wash-out.

Applying this formula to average measurements given in the Table, it may be calculated that, with an oxygen flow rate of 8 l./min., 'diffusion exchange' with CO₂ wash-out off is 11.4 l./min.; and with CO₂ wash-out on it is 66.4 l./min. The difference between these rates represents the volume of air entrained by the wash-out mechanism, which is 55 l./min. A similar calculation shows that in the volunteer's tent air entrainment was 56.3 l./min.

THE PLACE OF THE TENT IN OXYGEN THERAPY

It might be thought that recent improvements in the design of masks for the administration of oxygen, previously referred to in the Introduction, have reduced the tent's field of applicability. Objections that have been raised to the use of tents (Ball, 1961; Miller, 1962) are expense, trouble of maintenance, and difficulties of access to the patient for feeding, nursing procedures, and physiotherapy. Some patients feel oppressed, hot, and sweaty despite adequate control of temperature and humidity.

Undoubtedly, a suitable mask is the first choice, if its design will eliminate rebreathing, and if it will give predictable oxygen concentrations.

It cannot be denied, however, that some patients are so restless, fidgety, confused or intolerant of masks that this method of administration becomes impracticable. With these patients the mask (or intra-nasal catheter) soon becomes displaced, thus losing efficiency, or it may even be thrown aside. There is also the occasional male patient who tinkers with his giving-set, turning the flow high or low, on or off, as and when he fancies, regard-

less of requirements. For all these patients a properly set-up tent offers a degree of reliability in the maintenance of suitable gas concentrations that is unobtainable with masks. When this is paramount, the trouble and expense are a small price to pay. The discomfort experienced by some patients in tents is usually due to a high (1% to 2%) CO₂ content, and the feeling of stuffiness, sweating, headache, and restlessness, wrongly ascribed to heat and humidity, are due to the ensuing hypercapnia. In fact, the temperature and relative humidity within the tent may be demonstrably the same as that in the ambient air, or even cooler and drier. All these distressing symptoms are eliminated by the CO₂ wash-out.

SUMMARY

Patients with respiratory failure due to emphysema complicated by acute chest infection may suffer from CO₂ retention. In these circumstances inhalation of expired CO₂ in the course of oxygen therapy aggravates the CO₂ retention. CO₂ concentrations of 1% to 2% may be encountered in oxygen tents unless means are adopted to effect a reduction. High oxygen concentrations may depress ventilation and further aggravate CO₂ retention.

The Oxygenaire Mark V tent, which incorporates a CO₂ 'wash-out' device, was tested for efficiency in reducing CO₂ concentrations: a reduction to about one-quarter of pre-existing levels was found. Predictable O₂ concentrations between 26% and 30% were obtained using the washout in conjunction with various O₂ flow-rates.

The place of the tent in oxygen therapy is discussed.

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