Should we judge a mask by its cover?

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Abstract

Background **A table of the approximate ranges of inspired oxygen delivered at given oxygen flow rates is often given on the packaging of oxygen masks. A study was carried out to check the inspired oxygen concentration given by one of the new masks, which has been designed to be used with or without the Venturi attachment as a result of the proposal to use it without the Venturi attachment as a general purpose mask for emergency use.**

Methods **Measurements were made at resting respiratory rate and 26 breaths/min in 12 normal subjects. Continuous oxygen and carbon dioxide concentrations were recorded at the lips with a mass spectrometer, and inspired oxygen concentrations were calculated from end tidal values by means of the alveolar gas equation. Measurements were made at oxygen flow rates of 2, 4, and 6 l/min for the mask alone and at 2 and 4 l/min with both the 24% and the 28% Venturi attachments.**

Results **Without the Venturi attachment the mask gave average inspired oxygen concentrations 8–10% greater than are stated on the packaging at oxygen flow rates of 2, 4, and 6 l/min at resting respiratory rates of 8–20 breaths/min, some individuals receiving 30% more than expected. Addition of the interchangeable Venturi attachments designed to give 24% and 28% inspired oxygen delivered average concentrations within 2% of the expected concentrations, no individual receiving more than 5% above the expected concentrations.**

Conclusions **The labelling on the packaging of oxygen masks may lead to inappropriate use by those not expert in prescribing oxygen therapy. Caution is still needed when a single multipurpose mask is being selected for emergency use, where accurate delivery of low concentrations of oxygen is vital for some patients.**

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Many conditions may require the administration of supplementary oxygen in an emergency, such as in ambulances, to prevent the development of life threatening tissue hypoxaemia. In most cases the exact concentration of oxygen delivered is not critical provided that arterial oxygen tension (Pao_2) is raised adequately. It has, however, been well documented over many years[1,2] that controlled low flow oxygen therapy is essential for patients with type II respiratory failure (hypoxaemia and carbon dioxide retention) due to chronic obstructive lung disease. High concentrations of oxygen in these patients may depress the hypoxic drive to breathe resulting in a worsening of the carbon dioxide retention[2] and lethal respiratory acidosis.[3]

For many years the choice of delivery device for such supplemental oxygen therapy lay between nasal cannulae; the soft plastic medium concentration masks, such as the MC mask; and masks incorporating the Venturi principle, which reliably provide low inspired oxygen concentrations.[4] More recently the choice has widened to include mask "systems" that can be provided with or without interchangeable Venturi attachments. These Venturi devices come, quite reasonably, at extra cost above that of the basic mask.

The work described in this article was stimulated by a proposal to use one such mask, without the Venturi device, as a general purpose mask for use in emergencies. This proposal was based on the observation that the packaging, in keeping with that of its competitors from other companies, stated that the approximate range of inspired oxygen concentrations delivered by the mask was from 29% at an oxygen flow rate of 2 l/min to 46% at 6 l/min. The lower figure was considered reasonable for short term use even in patients with type II respiratory failure.

There were no published data on the in vivo performance of this particular mask, the Lifecare Duo Mask, though previous studies on the performance of similar devices, such as the MC and Hudson masks,[5–7] have indicated that this type of mask does not reliably deliver predictable inspired oxygen concentrations. As volume, shape, rigidity, and the size and placement of the air holes all affect the performance of a mask, we decided to compare the performance of this mask with that of the same mask supplied with interchangeable Venturi attachments, the Lifecare Tru-flow mask, in normal volunteers. The Tru-flow mask is designed to supply inspired oxygen concentrations of 24% or 28%. As oxygen flow rates are often inaccurately set,[8] and as the inspired oxygen fraction is also known to be dependent on breathing pattern in the MC mask,[5] we tested both masks in normal subjects at two respiratory frequencies using various oxygen flow rates.

Methods

We studied six healthy subjects (2 M, 4 F; 23–38 years) using the Duo-mask and a further six healthy subjects (3 M, 3 F; 21–38 years)

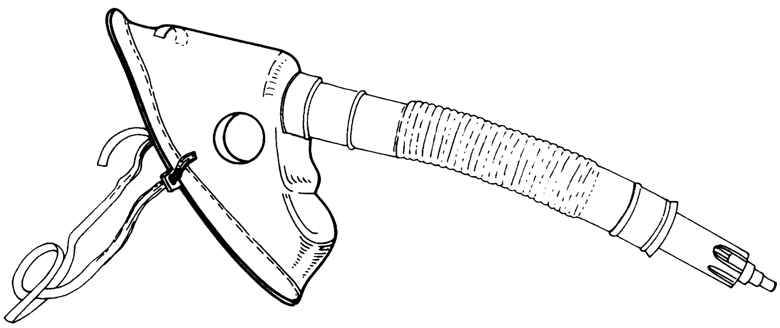

Figure 1 The Tru-flow mask with the interchangeable Venturi attachment.

using the Tru-flow Venturi principle mask (fig 1). All subjects had normal lung function (forced expiratory volume in one second (FEV_1) 2·5–4·5 l, 88–110% predicted), were free of respiratory symptoms at the time of study, and gave no history of respiratory disease.

Measurements were made with the subjects seated at rest. Oxygen consumption and carbon dioxide output were initially measured from duplicate two minute mixed expired gas collections[9] and the respiratory quotient (R) was calculated. The performance of the masks was then studied. Continuous oxygen and carbon dioxide concentrations were recorded with a mass spectrometer (VG Spectrolab-M) previously calibrated with five gas mixtures of known oxygen and carbon dioxide concentrations, and the output was displayed on a chart recorder at a paper speed of 10 mm/s. The mass spectrometer probe was inserted into a short cannula sealed into the mask, with the aperture between the subject's front teeth. Measurements were made at oxygen flow rates of 2, 4, and 6 l/min for the Duo-mask alone and at 2 l and 4 l/min for the Tru-flow mask when both the 24% and the 28% Venturi attachments were being used. At each flow rate subjects initially breathed for seven minutes at their own resting respiratory rate, with measurements made during the last 30 seconds or during a minimum of six breaths. They then breathed at 26 breaths/min in time with a metronome for one minute, with measurements made during the last 30 seconds. The oxygen and carbon dioxide concentrations were measured from the chart for each breath, with end tidal values for both oxygen and carbon dioxide taken at the time of highest expired carbon dioxide in each breath cycle (fig 2), and inspired carbon dioxide concentration taken as the lowest value during inspiration. Inspired oxygen concentration for each breath was derived from the simplified form of the alveolar gas equation:

$$F_{AO_2} = F_{IO_2} - \frac{F_{ACO_2}}{R},$$

where F_{IO_2} is the inspired fractional oxygen concentration, F_{AO_2} and F_{AO_2} are the fractional alveolar oxygen and carbon dioxide concentrations (taken as equal to end tidal fractional concentrations), and R is the measured respiratory quotient.[10] The mean value for the inspired oxygen and carbon dioxide of all recorded breaths was calculated at each flow and respiratory rate for each subject.

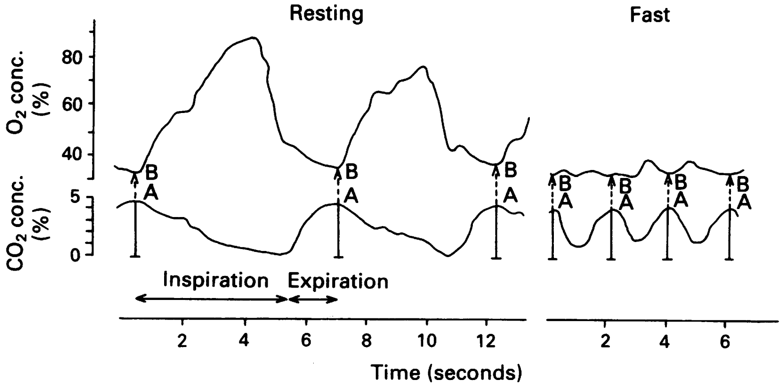

Figure 2 Continuous recording of oxygen and carbon dioxide concentrations measured in one subject while he was breathing through the Duo-mask at both resting and fast (26 breaths/min) respiratory rates, with an oxygen flow rate of 2 l/min. End tidal oxygen (B) and carbon dioxide (A) concentrations were measured for each breath at the time of the highest expired carbon dioxide concentration (A).

Results

PERFORMANCE OF THE DUO-MASK

The measured inspired oxygen concentration increased with the oxygen flow rate, but at each flow rate was lower at a respiratory rate of 26 breaths/min than at the subject's resting respiratory rate (range 8–20 breaths/min—table 1). At all three flow rates the mask gave an oxygen concentration on average 8–10% greater than expected at the subject's resting respiratory rate, and 2–4% greater than expected at a respiratory rate of 26 breaths/min. There was, however, wide individual variation in the concentration produced, some subjects receiving 10% less than expected whereas others received up to 30% more.

On average the inspired carbon dioxide concentration was raised only slightly, though there was individual variation, with a value of almost 2% in one subject (table 1).

PERFORMANCE OF THE TRU-FLOW MASK

The mean inspiratory oxygen concentration was not affected by the oxygen flow rate or the respiratory rate, and was within 2% of the expected concentration with both Venturi attachments (table 2). The actual inspired oxygen concentration again varied between individuals, but less than with the Duo-mask, with maximum deviations from the expected ranging from 3% less to 5% more than expected (table 2).

Discussion

With the Duo-mask the inspired oxygen concentration was usually considerably higher than predicted, being up to 20% more than expected in some subjects even at 2 l/min, with a wide variation between subjects. In comparison, the interchangeable Venturi units performed well, yielding inspired oxygen con-

Table 1 Inspired oxygen and carbon dioxide concentrations with the Duo-mask (means and ranges for the six subjects)

O_2 flow rate (l/min)	Estimated inspired O_2 (%)*	Respiratory rate (breaths/min)	Mean inspired O_2 (%)	Mean inspired CO_2 (%)
2	29	13·5 (8–20)	37 (32–50)	0·4 (0·1–1·3)
		26	33 (27–44)	0·5 (0·3–0·8)
4	38	12·5 (8–16)	47 (36–67)	0·5 (0–1·3)
		26	40 (32–55)	0·6 (0·3–1·3)
6	46	13·2 (8–18)	56 (41–70)	0·5 (0–1·5)
		26	49 (36–77)	0·8 (0·3–1·8)

*As quoted by the manufacturers on the packaging.

Table 2 Inspired oxygen and carbon dioxide concentrations with the Tru-Flow mask with 24% and 28% Venturi attachments (means and ranges for the six subjects)

O_2 flow rate (l/min)	Respiratory rate (breaths/min)	Mean inspired O_2 (%)	Mean inspired CO_2 (%)
24% VENTURI ATTACHMENT			
2*	12·6 (8–22)	24 (21–27)	0·2 (0·2–0·2)
	26	25 (22–26)	0·4 (0·3–0·8)
4	14·6 (9–24)	25 (22–26)	0·2 (0·2–0·3)
	26	26 (23–27)	0·3 (0·2–0·5)
28% VENTURI ATTACHMENT			
2	14·6 (8–20)	28 (25–30)	0·3 (0·3–0·5)
	26	29 (25–31)	0·8 (0·3–2·0)
4*	16·0 (8–24)	29 (25–33)	0·2 (0·2–0·3)
	26	29 (26–31)	0·5 (0·3–0·8)

*Manufacturer's recommended flow rate.

centrations on average within 2% of that expected when the appropriate recommended flow rate was used.

Oxygen flow rates, especially the low ones, are sometimes difficult to set accurately on standard cylinder or ward regulators. We therefore assessed both Venturi attachments at the two recommended flow rates of 2 and 4 l/min as these are most commonly used with devices that provide low dose controlled oxygen therapy, and therefore are the most likely to be confused. In our subjects changes from 2 to 4 l/min made only a 1% difference in inspired oxygen concentration on average, which would be of questionable clinical importance.

Overall, the degree of rebreathing in both systems, as reflected by the inspired carbon dioxide, was acceptably low and should be of little clinical consequence, though one individual had an inspired carbon doxide concentration of almost 2% with both the Duo-mask (table 1) and the Tru-flow mask (table 2).

It is well established clinically that masks of simple design can deliver medium concentrations of oxygen to patients when accurate control is not vital. Our present results, however, confirm previous findings that masks of this type are not suitable for use in those patients critically dependent on a particular oxygen dose.[5 6] The table of delivered oxygen concentrations printed on the packaging of this mask was derived from theoretical calculations (personal communication from the manufacturer). The fact that these figures did not accurately reflect its performance in vivo emphasises that such tables should be verified empirically before use as a guide for treatment.

We have undertaken this study using healthy volunteers in circumstances necessarily different from those encountered in clinical practice. By studying the performance of the masks at two different respiratory rates in each subject we have attempted to mimic one of the sources of variation found in real life, but we accept that there are other variables in clinical practice that we have not studied. We have therefore probably underestimated the variability in performance of these devices, which strengthens our argument that the delivery of oxygen in vivo should be confirmed.

The Lifecare Tru-Flow mask incorporating the Venturi attachments generally provided reliable controlled low dose oxygen in all subjects. This is in keeping with the results reported for similar masks, such as the Vickers Ventimask and Inspiron Accurox,[11] in which a consistent F_{IO_2} is also delivered over a range of oxygen flow rates. Intersubject variability in the inspired oxygen concentration delivered, however, still occurred in the small sample of normal subjects we studied, and such variation is likely to be greater in patients with respiratory disorders, where breathing patterns are abnormal. Davies and Hopkin[12] have suggested that Venturi masks should be used to administer controlled low flow oxygen in exacerbations of chronic obstructive lung disease as nasal cannulae can give excessively high, and therefore dangerous, inspired oxygen concentrations. The between subject variability in the inspired oxygen concentration with the Tru-flow masks serves as a reminder that the only way to give low dose oxygen effectively and safely, irrespective of the method of administration, is to repeat measurements of arterial blood gas tensions at frequent intervals after the start of treatment.[3]

We would like to emphasise that the performance of the masks reported in this study is not unique to the Lifecare masks but merely reflects the behaviour of the different basic designs. Irrespective of the manufacturer, all medium concentration masks will deliver widely differing inspired oxygen concentrations that depend on the patient's breathing pattern. Most of the studies on the performance of the various designs of oxygen mask were reported over 20 years ago.[1 2 4 6 7] This study emphasises the continuing necessity for caution in the selection of an oxygen mask for general purposes in ambulances and accident and emergency departments where accurate delivery of low concentrations of oxygen is needed for patients suffering from an acute exacerbation of chronic obstructive lung disease.

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