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Fixed performance oxygen masks: an evaluation

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Abstract

Fixed performance oxygen masks operate by supplying mixtures of oxygen and air at rates exceeding the inspiratory flow rate of the patient. In this study the oxygen concentration delivered by three fixed performance oxygen masks was determined non-invasively at various inspiratory flow rates. At low inspiratory flow rates all the masks studied acted as fixed performance devices. When the peak inspiratory rate increased the performance of all the masks showed some variability. The change from fixed to variable performance depended on the relation between inspiratory flow rate and the total gas flow delivered by the mask and was independent of the volume of the mask.

Hence the use of low volume masks and high oxygen flow rates should produce more consistent results than high volume masks and lower flow rates.

Introduction

Oxygen masks that operate on the Bernoulli principle deliver accurate mixtures of oxygen and air at high flow rates. Leigh found that these masks deliver a constant percentage of oxygen throughout the respiratory cycle and called them fixed performance devices.[1] For these masks to act as fixed performance devices the flow of gas mixture delivered by the mask must be equal to, or greater than, the peak inspiratory flow rate of the patient.[1] If the peak inspiratory flow rate of the patient exceeds the rate at which gas is supplied by the mask room air will be drawn into some part of the mask. This effect is greater with masks that deliver a high concentration of oxygen as they supply the gas at a lower rate. Campbell and Minty stated that a 60% oxygen mask should have a volume of over 300 ml to serve as a reservoir to prevent a fall in inspired oxygen during high peak inspiratory flow.[2] Campbell also suggested that the newer low volume masks may allow the patient to inhale room air from the large holes near the patient's face.[3] A recent bench study showed that the low volume Inspiron Accurox masks (Bard) perform less well than the high volume Ventimask (Vickers)[4]; the authors attributed this to the different volumes.

The experimental methods used in these previous studies did not explore the relation between inspiratory flow rate and mask function. We undertook the present study to examine the relative performance of three types of oxygen masks at various inspiratory flow rates and to establish whether a high volume mask acts as an efficient reservoir.

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Method

The masks used in this study were the high volume Ventimask Mk 2 and Mk 3 (nominal oxygen concentrations 24%, 28%, 35%, 40%, and 60%) and the low volume Inspiron Accurox (nominal oxygen concentrations 24%, 28%, 31%, 35%, and 40%). These 15 masks were tested on six volunteers. The oxygen supply to the jet in the masks was set to the level recommended by the manufacturer.

Oxygen and carbon dioxide concentrations were measured continuously with a mass spectrometer (Centronic MGA 200). The probe from the spectrometer, a fine nylon catheter, was placed in the external nares of the subject. The response time of this system was 250 ms. The subjects were supine and were instructed to breathe through their noses and to keep their mouths closed.

Respiratory flow was measured non-invasively with an inductance pneumograph. This consists of two zigzag coils stitched to elastic belts placed around the chest and abdomen of the subject. Respiratory movements cause a change in the cross sectional area of the coils. The resulting changes in inductance are detected by oscillators mounted on the belts. Signals from the oscillators are demodulated, filtered, and summed to produce a tidal volume trace. This is then differentiated electrically to give respiratory flow. The device was calibrated against a dry spirometer of known accuracy (Ohio). This method of measuring respiratory gas flow rate is accurate at flow rates of up to 3·0 l/s.[5]

The masks were applied to the subjects in random order, and measurements were made after 10 minutes had elapsed. The subjects were instructed to breathe as quietly as possible for five minutes and then to increase the depth and frequency of ventilation. During these manoeuvres the inspiratory flow rate and oxygen and carbon dioxide concentrations were continuously recorded on an eight channel recorder (Hewlett Packard) and on magnetic tape.

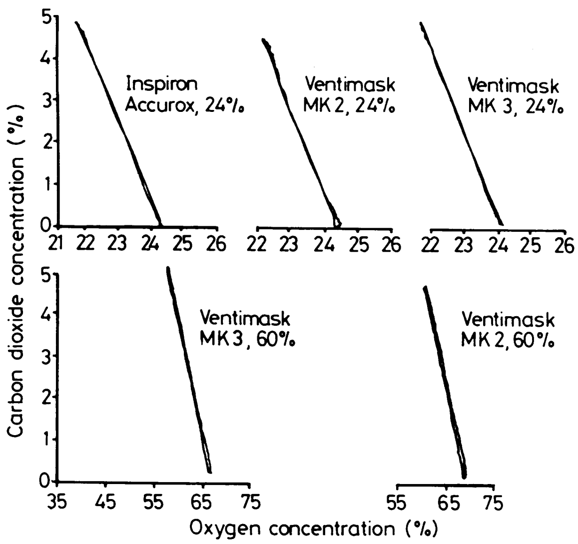

FIG 1—Gas R lines at peak inspiratory flow rate of 0·2 l/s.

The performance of each mask on a breath to breath basis was analysed with a modification of the technique originally used by Leigh.[1] This entails plotting gas R lines on single breaths while the subject breathes from the mask. The gas R line is a graphical plot of the partial pressure of oxygen in respiratory gases against the partial pressure of carbon dioxide. Inspired gas contains no carbon dioxide and a high oxygen concentration. Alveolar gas contains a high carbon dioxide concentration and a lower oxygen concentration. The amount of carbon dioxide produced is in a fixed proportion to the uptake of oxygen. If the partial pressures (or concentrations) of oxygen and carbon dioxide are plotted against each other continuously throughout the respiratory cycle a straight line is produced. This is the gas R line, and it runs from the point indicating alveolar gas concentrations to intercept the oxygen axis (zero carbon dioxide) at a point which represents the inspired oxygen concentration. If the inspired oxygen concentration is constant the inspiratory and expiratory limbs of the gas R line are superimposed. If the inspired oxygen concentration varies during inspiration then the inspiratory limb of the gas R line becomes curved; because the expiratory limb remains straight the R line forms an open loop. A change in the R line from a straight line to an open loop indicates that the mask is no longer acting as a fixed performance device. As the performance of the mask deteriorates, with increasing inspiratory flow the loop becomes wider and the intercept moves down the oxygen axis.

The gas R lines were produced by plotting oxygen and carbon dioxide concentrations of single breaths on an X/Y chart recorder (Bryans). We did not follow the convention of plotting the gas R line on equal axes in units of partial pressure: both axes were calibrated in percentage concentration, and the oxygen axis was condensed for greater clarity.

Results

When the subjects breathed at a peak inspiratory flow rate of 0·2 l/s or less all the masks behaved as fixed performance devices. Figure 1 shows the gas R lines for the 24% and 60% masks. The table shows the oxygen concentrations delivered by the masks when the inspiratory flow rate was 0·2 l/s. At this inspiratory flow rate the oxygen concentration delivered was determined by the point at which the R line intercepted the oxygen axis. When the peak inspiratory flow rate was increased the oxygen concentration delivered by all the masks fell. The inspired oxygen concentration was determined at various inspiratory flow rates for individual subjects and for each of the masks (fig 2). When the gas R line no longer formed a straight line the oxygen concentration was taken as the point at which the cursor came to rest on the oxygen axis. (For simplicity the individual measurements were replaced by bands representing the overall scatter of results.)

The inspiratory flow rate that brought about the transition from fixed to variable performances depended on the concentration of oxygen delivered by the mask and hence the total gas flow rate. The

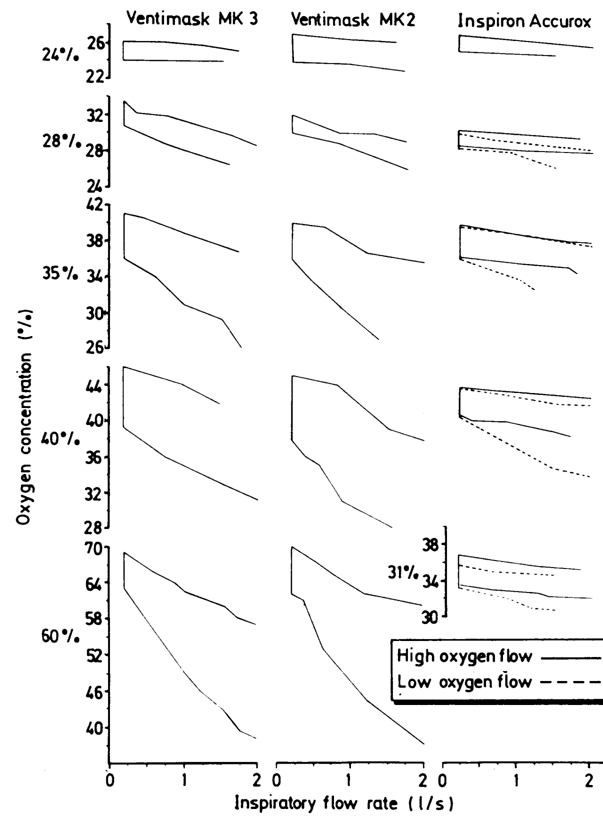

FIG 2—Inspired oxygen concentrations at various inspiratory flow rates (envelope diagrams showing data obtained in all subjects).

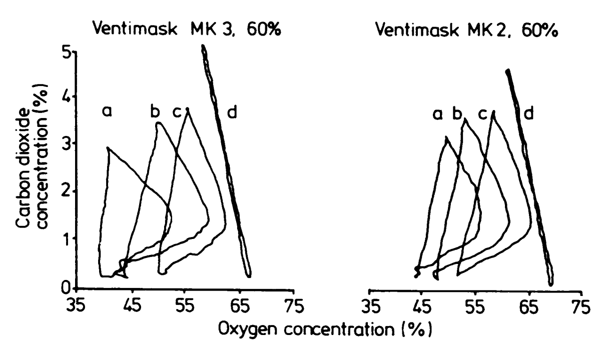

FIG 3—Gas R lines at varying peak inspiratory flow rates: a=1·2 l/s, b=0·8 l/s, c=0·4 l/s, d=0·2 l/s.

24% masks became variable performance devices only when the inspiratory flow rate exceeded 1·9 l/s. The 60% masks became variable performance devices when the inspiratory flow rate lay between 0·2 and 0·3 l/s (fig 3).

Inspiron Accurox masks have two suggested oxygen priming flows. Figure 4 shows two matched pairs of breaths at low and medium inspiratory flow rates. At the lower supply rate the R line formed an open loop during the more rapid inspiration. A similar breath when the higher oxygen flow rate was used produced a narrower loop, which intercepted the oxygen axis at a higher concentration. Thus increasing the rates of flow of oxygen and air from the mask resulted in the mask becoming very nearly a fixed performance device again. Moreover, the areas of scatter were smaller at high oxygen flow rates than at low oxygen flow rates (fig 2).

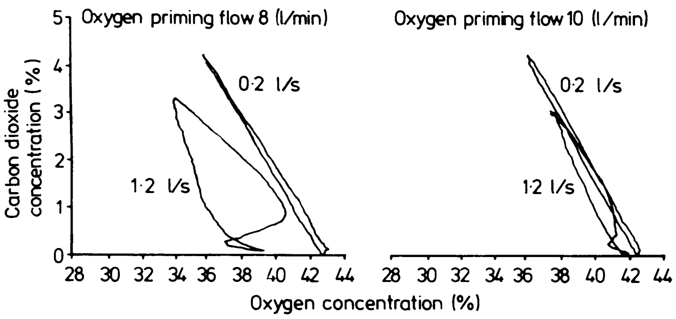

FIG 4—Gas R lines for Inspiron Accurox mask, 40%, at different inspiratory flow rates and oxygen priming flows.

Discussion

To investigate the effect of inspiratory flow rate on the function of a fixed performance oxygen mask volunteers and non-invasive techniques are necessary. The use of mass spectrometry and inductance pneumography in this study yielded a dynamic analysis of each mask's function throughout the respiratory cycle. This is a refinement of the approach used by Leigh.[1] Other workers have concentrated on static bench testing,[6] the use of invasive techniques,[7] or patient models with simulated respiration.[4] A model cannot fully reproduce the interactions that occur between the mask and the subject.

We found that at low inspiratory flow rates all the masks behaved as fixed performance devices, though the accuracy of the oxygen mixture varied (table). When the peak inspiratory flow was high all the masks exhibited variable performance. This did not occur with the masks delivering low concentrations until the inspiratory flow exceeded the normal physiological range; this is because the total gas flow rate delivered by these masks is high. Variable performance may occur at fairly low inspiratory flow rates when masks delivering high concentrations are used; this is because the total gas flow rate delivered by these masks is low.

When the peak inspiratory flow rate of the subject approached the rate of delivery of the oxygen and air mixture from the masks both Inspiron Accurox masks and the Ventimasks showed similar decreases in the oxygen concentration delivered to the subject. The fact that Ventimasks have a large volume compared with Inspiron Accurox masks did not appear to influence the change from fixed to variable performance (fig 2). The Inspiron Accurox masks retained their fixed performance characteristics better than the Ventimasks when peak inspiratory flow rate was high, particularly when the higher recommended flow rates were being used.

The fall in the oxygen concentration during inspiration when the peak inspiratory flow rate was high may have been due to entrainment of room air around the edges of the mask as the rate of inspiration approached the rate of supply of the oxygen and air mixture. Campbell and Minty predicted that this might occur in the 60% Ventimask.[2] They suggested that the volume of the mask should exceed 300 ml, so that a reservoir of gas is available to limit the fall in oxygen concentration during rapid inspiration. Cox and Gillbe attributed the relatively poor performance of the Inspiron Accurox mask in their study to the fact that it has a low internal volume and does not act as a reservoir.[4] Our findings do not agree with those of Cox and Gillbe, which is probably due to the different methods of study used. When an oxygen mask starts to malfunction the change in inspired oxygen concentration is extremely rapid. It is questionable whether such changes could be adequately followed by the method used by Cox and Gillbe. In our study we found that all the masks started to deliver a reduced oxygen concentration when the peak inspiratory flow rate was less than the rate of supply of fresh gas from the mask. The possible reason for this was suggested by Leigh.[8] He predicted that the negative pressure caused by inspiration would affect the entrainment ratio of the Venturi jet and thereby reduce the inspired oxygen concentration. Inspiron Accurox masks may perform better than the Ventimasks because the entrainment device is situated at the end of a short tubular extension. This might isolate it from the changes in downstream pressure caused by inspiration.

We conclude that the major determinant of function of oxygen masks using the Bernoulli principle is the relation between the peak inspiratory flow of the patient and the total gas flow rate delivered by the mask. We found that the volume of the mask is relatively unimportant. In clinical practice use of low volume masks combined with high oxygen flow rates should produce more consistent results than use of large volume masks using less oxygen. Whether inspiration can change the entrainment ratios of the Venturi jets requires further study.

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Oxygen concentration (%) received by subjects when peak inspiratory flow rate was 0·2 l/s, compared with nominal concentration

Case No	Nominal concentration: Ventimask Mk 2 24%	28%	35%	40%	60%	Ventimask Mk 3 24%	28%	35%	40%	60%	Inspiron Accurox 24%	28%	31%	35%	40%
1	24	25·5	31·5	38	58	24·5	30·5	36	39·5	61·5	24·5	28·5	33	36	40·5
2	25·5	30	38·5	44	67	24·5	31	38·5	42·5	68	25·5	29	35	38·5	42
3	26	31·5	40	44·5	70	26	32	39·5	45·5	70	25·5	29	35	39	43
4	27	32·5	40·5	46	70	26	33	42	46·5	70	26	29	36	39	43·5
5	26·5	31·0	39	41	67·5	25·2	32·5	36·5	42	67	25·5	30·2	36	39·5	44
6	24	31	36·2	39	67	25	31·5	38·5	41·5	67·5	25·5	29·5	36·5	39·2	42·5

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