

Use of jet mixing devices with an oxygen concentrator

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Abstract

Jet mixing devices ("Venturi" devices) can be used in conjunction with domiciliary oxygen concentrators and provide delivered oxygen concentrations similar to those obtained with medical oxygen, though with the devices delivering higher concentrations (above 30% oxygen) the total flow is substantially reduced. A jet mixing device driven by a domiciliary concentrator would be valuable in various circumstances, especially in developing countries and also for infants and for patients with upper respiratory tract infections who are breathing through the mouth.

(Thorax 1992;47:1060-1062)

Fixed performance oxygen-air jet mixing devices provide a simple, reliable, and robust means of supplying preset concentrations of oxygen to patients. They are incorrectly referred to as Venturi devices, because they function by the principle of jet mixing of two viscous fluids (air and oxygen) rather than by means of the Venturi or Bernoulli principles, in which a subatmospheric pressure is generated by flow acceleration.^{1,2} They are often incorporated into facemasks and other oxygen delivery devices to produce a controlled concentration of oxygen. Such a system is often used to deliver controlled oxygen therapy to patients with respiratory failure, in whom high and uncontrolled concentrations might have adverse effects on hypoxic respiratory drive.

Oxygen concentrators have been widely used for domiciliary oxygen therapy for patients with chronic respiratory failure, but because of the relatively low flows they produce (usually 2-4 litres/min) they have normally been used in conjunction with a low flow delivery system such as nasal prongs or a nasopharyngeal catheter. This generally provides adequate oxygen delivery, but the delivered concentration may be altered by changes in minute ventilation, mouth breathing, or minor displacement of the device.

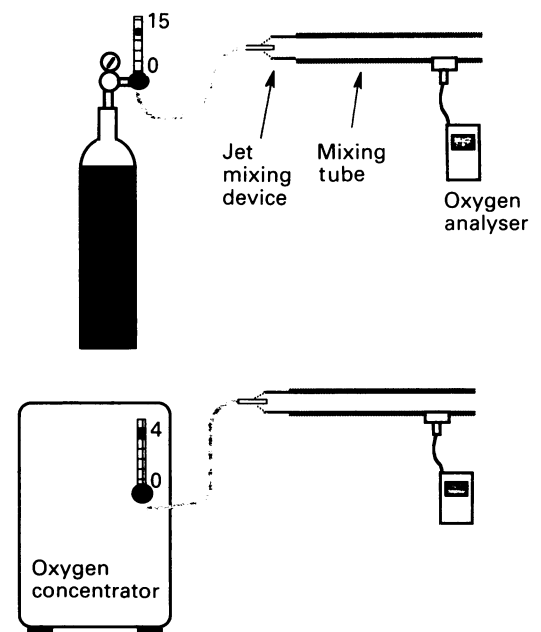
The performance of jet mixing devices driven by the flow of gas from a domiciliary oxygen concentrator has not previously been evaluated. Differences in performance might be expected because of (a) the limitation of driving gas flow to the maximum available from the concentrator (typically 4 l/min) and (b) the composition of the concentrator product gas, which normally contains oxygen 95% and

argon 5% (oxygen concentrators adsorb nitrogen from room air, leaving oxygen and argon in the product gas in a ratio of about 20 : 1).

Methods

The jet devices used, normally part of oxygen facemasks (Intersurgical), were those that deliver nominal inspired concentrations of 60%, 40%, 35%, and 28% oxygen. Their performance was tested (figure) with the prescribed driving flows from a cylinder of oxygen (15 l/min for 60%, 10 l/min for 40%, 8 l/min for 35%, 2 l/min for 28%), and a calibrated polarographic oxygen analyser (Critikon Oxychek) was used to determine delivered concentrations at the downstream end of a wide bore (22 mm) mixing tube 60 cm in length.

A domiciliary oxygen concentrator (Puritan Bennett 492a, World Health Organisation standard model) was then substituted as the source of driving gas. A flow of 4 l/min was set on the concentrator outlet flowmeter and the product gas concentration of 95% oxygen was checked. The product gas was then fed to the jet mixing device, and the resulting flow of oxygen enriched air was directed down 60 cm of breathing hose as described above.



The jet mixing device used with an oxygen concentrator.

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As the driving flow and concentration, the concentration of oxygen in air, and the final output concentrations were known, the total gas flow could be calculated from the equation $C_c \times DF + C_a \times V_a = C_t \times V_t$, where C_c = concentration of oxygen in the driving gas (100% or 95%), DF = flow per minute of driving gas, C_a = fractional concentration of oxygen in air (0.21), V_a = volume of air entrained per minute, C_t = measured fractional output concentration of mixing device, and V_t = total flow produced by mixing device. The total flow is the sum of the driving flow and the air entrained. It can be calculated by rearranging the above equation and substituting the fractional concentrations of oxygen in cylinder gas (1.0) and room air (0.21):

$$V_t = \frac{DF \times (C_c - C_a)}{C_t - C_a} = \frac{DF \times (1.0 - 0.21)}{C_t - 0.21}$$

In the case of the concentrator with flow set at 4 l/min $V_t = V_a + 4$, and with the fractional oxygen concentration of the driving gas 0.95 the equation now becomes

$$V_t = \frac{DF \times (C_c - C_a)}{C_t - C_a} = \frac{4(0.95 - 0.21)}{C_t - 0.21}$$

This method of deriving the total flow generated from measured concentrations avoids the technical difficulties of measuring a relatively high flow of gas flowing down a very small pressure gradient—such a measurement would be subject to inaccuracy because of the resistance to flow of any measuring instrument.

Results

Using cylinder oxygen, the devices all produced clinically acceptable flows at concentrations at or close to their stated concentration, though the "28%" jet when driven by the prescribed flow of 2 l/min produced a total flow of only 22.6 l/min (table). When the "28%" jet was driven by the fixed flow of 4 l/min of concentrator product gas the concentrations were only slightly lower, but the total flows delivered by the "60%" and "40%" devices were below 20 l/min.

Discussion

The results for the cylinder driven devices

confirm the findings of Canet and Sanchis³ that a driving flow of 2 l/min of oxygen may produce an insufficient flow, allowing further dilution of the oxygen during inspiration. Jones *et al*⁴ found a mean inspiratory flow rate of 0.37 l/s (22.2 l/min) in a group of patients using Ventimasks; this would suggest that the total flow generated by such a mask needs to be 22 l/min or more to prevent further dilution of the inspired mixture by air. In this respect the performance of the "28%" jet with only 2 l/min of driving gas is borderline, as is that of the "35%" jet with the concentrator. The concentrator system performs well with the "28%" jet.

Although the driving flow from domiciliary concentrators is limited, the final concentrations obtained lie within a useful clinical range. These results accord with those of Johns *et al*⁵ and the claim of Intersurgical Ltd (personal communication) that prescribed flows of driving gas affect the total flow generated but not the final concentration of oxygen. The presence of 5% argon in the driving gas does not appear to make any clinically important difference to the performance of the device.

The above suggests that domiciliary concentrators can be used in conjunction with jet mixing devices producing lower concentrations of oxygen (below 30%). Many patients prefer the comfort of nasal prongs or a nasopharyngeal catheter, so what application have these results?

The use of nasal prongs or a catheter depends on a patent nasal airway and the absence of any appreciable mouth breathing; in a patient with an upper respiratory infection mouth breathing often occurs, especially in sleep, and such a patient using a domiciliary concentrator might be well advised to use facemask oxygen during the night. As most such patients require 28% oxygen or less, an oxygen concentrator can safely be used with a mask in these circumstances.

In many developing countries childhood pneumonia is a major cause of death,⁶ resulting in an estimated 4.3 million deaths each year in children under 5 years; oxygen supplies are scarce—for example, in Tanzania an informal study in 1991 showed that three quarters of district hospitals have cylinder oxygen supplies for less than a quarter of the year (E Egan, personal communication). In such circumstances the use of concentrators is increasing, and is supported by the World Health Organisation.

Results of using jet mixing devices with different concentrations of oxygen with an oxygen cylinder and an oxygen concentrator

Mixing device (initial % of oxygen)	60%	40%	35%	28%	28%
CYLINDER					
Prescribed oxygen flow (l/min)	15	10	8	4	2
Delivered concentration (jet driven at prescribed flow by 100% oxygen)	57%	40%	35%	28%	28%
Calculated delivered flow (l/min)	32.9	41.6	45.1	45.1	22.6
CONCENTRATOR					
Driving flow (l/min)	4	4	4	4	
Delivered concentration (driven by concentrator gas)	54%	38%	35%	27%	
Total flow delivered (l/min)	8.9	17.4	21.1	49.3	

This study suggests that a jet mixing device might be used to drive a fixed concentration head box to provide oxygen therapy for infants, though clinical studies are needed to confirm this.

- 1 Scacci R. Air entrainment masks: jet mixing is how they work; the Venturi and Bernoulli principles are how they don't. *Respir Care* 1979;24:928-31.
- 2 Kittredge P. Neither Venturi nor Bernoulli. *Lancet* 1983;

i:182.

- 3 Canet J, Sanchis J. Performance of a low flow oxygen Venturi mask: diluting effects of the breathing pattern. *Eur J Respir Dis* 1984;65:68-73.
- 4 Jones HA, Turner SL, Hughes JM. Performance of the large reservoir oxygen mask (Ventimask). *Lancet* 1984;i:1427-31.
- 5 Johns DP, Streeton JA, Rochford PD. An air entrainment device for preparing precision gas mixtures. *J Med Engr Technol* 1983;7:140-3.
- 6 Director General of the World Health Organisation. *Biennial report 1990-1*. Geneva: World Health Organisation, 1992:97.

Adventitia

Confessional

In the biological nature of things, as I enter my 80s my crucial and tricky viva voce with St Peter cannot be too long delayed. I therefore thought that it might be, in the current jargon, cost effective prophylaxis to take advantage of the Editor's proffered confessional and shrive off some of the accumulated backlog in my personal "sindrome." I am hoping, without all that much confidence, that it may prove prophylactic to confess now that the crucial appointments in my career were obtained by methods that might, according to the taste or prejudice of the commentator, be variously described as modern free market headhunting, the Old Boy System, mafoid technology, or just plain corruption.

Like hundreds of other young doctors, in late 1945 I was booted out of the army into a cold, competitive world. The shock was mitigated by a benign government with the offer of a year's rehabilitation job at an annual salary of £650. But after five months I was informed that, owing to the tidal wave of discharges on to the market, my job would be for six months, not a year.

Thereafter the first suitable post to be advertised was at the Central Middlesex Hospital, at that time by far the most outstanding, and most academic, of the then (pre-NHS) municipal hospitals. As the interviews were to be in July, my wife and I cancelled our previously booked holiday in Ireland. I believe that there were 100 applicants. I wasn't short listed. No holiday. No job.

As well as my rehabilitation post at St Thomas's Hospital I had had two sessions a week as an (unpaid) clinical assistant to Guy Scadding at the Brompton Hospital. Guy had for a year been my OC medical division in a large military hospital in Egypt. He had taught me an enormous amount and we had become very good friends. After six weeks' unemployment, during which I finished off my MD thesis—rather exotically and pot boilingly on typhus as I had run a typhus ward in Egypt—the government agreed to fund several registrarships at the Brompton Hospital. I was slid into one of these without, so far as I can remember, any competition or interview. Three months later the famous Medical Research Council (MRC) controlled trials of streptomycin started. I was asked to be the half time MRC coordinator for the Brompton

Hospital. At the same time Guy Scadding had become the dean of the new university institute at the Brompton. Consequently he had less time to give to the other part of his work, at the then Postgraduate (now Royal Postgraduate) Medical School at Hammersmith Hospital. It was therefore suggested that he should have a half time lecturer to help him. My interview at the Postgraduate School consisted of having lunch in the canteen with the professor of medicine, John (later Sir John) McMichael, Scadding, and Sharpey-Schafer, later to be professor of medicine at St Thomas's Hospital. I have no memory of any plumbing of the academic depths or heights over lunch. I only recall Sharpey-Schafer mischievously discussing the influence of red meat on hypertension. At any rate, perhaps because I was observed to stand up successfully to the postwar Postgraduate School canteen menu, I found myself appointed to the lectureship.

Five years later I was asked to go up to Edinburgh to be interviewed for the vacant chair of tuberculosis (later to be converted at my request to "tuberculosis and respiratory diseases"). Unconventionally by present standards, before the interview I was taken out to lunch at the New Club ("new" in about 1780) by two of the interviewing panel, Sir Stanley Davidson and Sir Derick Dunlop. I was presented with the largest pre-lunch sherry I had ever encountered, and later sailed into the interview under full spinnaker. The powerful Iberian catalyst had a logarithmic effect on my intrinsic Hibernian garrulity and perhaps induced a minor torrent of mRNA from some normally recessive lyrical sequence in the DNA. I gave an enthusiastic and largely imaginative account of my previous career and achievements. Somehow this must have overwhelmed, or bluffed, the fundamental Calvinistic constraints, and the usual and proper academic caution, on the other side of the table. In a fit of absence of mind they must have overlooked my acrid critique of the tuberculosis services in Edinburgh, outlined in a previous, more pedestrian, memorandum. At any rate, they changed my life. They gave me the job.

At least I was too poor to have crossed anybody's palm with silver. I hope St Peter will remember that!

JOHN CROFTON