

Technical and clinical assessment of oxygen concentrators

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ABSTRACT One membrane oxygen enricher (Oxygen Enrichment Company OE-4E) and four molecular sieve (MS) concentrators (Mountain Medical Econo₂, De Vilbiss MINI DeVO₂, Cryogenic Roomate III, and Mountain Medical Mini O₂) have been studied to assess technical and clinical performance. During four weeks of continuous operation at a flow rate of 2 l min⁻¹ (6 l min⁻¹ for OE-4E) consistent oxygen levels were delivered by all machines (mean >93% for MS concentrators, 36.5% for OE-4E). At flow rates of up to 21 mm⁻¹ all four MS machines delivered oxygen concentrations greater than 92%, but at 3 l min⁻¹ (Econo₂ 89.6%, MINI DeVO₂ 93.9%, Roomate III 92.0%, Mini O₂ 85.0%) and at 4 l min⁻¹ (Econo₂ 78.0%, Mini DeVO₂ 84.7%, Roomate III 83.3%, Mini O₂ 69.1%) the two newer machines gave higher oxygen concentrations. In 20 hypoxic patients the mean oxygen saturation levels achieved when they were breathing oxygen from the MS concentrators at a flow rate of 2 l min⁻¹ were similar (Econo₂ 92.6%, MINI DeVO₂ 92.5%, Roomate II 92.6%), but the level achieved when they were breathing from the OE-4E, at the equivalent flow rate of 6 l min⁻¹, was lower (91.0%, $p < 0.005$). The performance of concentrators in service (Econo₂, MINI DeVO₂, Mini O₂) was satisfactory when judged by patients' oxygen saturation levels and delivered oxygen concentrations. The OE-4E may be indicated for a small number of patients who require oxygen with high humidification. The four MS concentrators studied are all suitable for domiciliary use, but the MINI DeVO₂ and Roomate III have advantages in terms of better performance at high flow rates and reduced size and weight.

Long term domiciliary oxygen treatment for 15 or more hours daily can prolong the survival of patients with hypoxic chronic bronchitis and emphysema.^{1,2} The costs are considerable, but oxygen concentrators are the cheapest³ and probably the most convenient way to provide this form of treatment. Most modern concentrators are of the molecular sieve (MS) type, using columns of synthetic aluminium silicate (zeolite) to adsorb nitrogen from room air, so producing an inspired gas with a high concentration of oxygen (>90% at low flow rates) with small amounts of trace gases. As the flow rate is increased a greater volume of gas passes through the molecular sieve, and the time spent in contact with the aluminium silicate is less, so that adsorption of nit-

rogen is less complete and the oxygen concentration of inspired gas falls. Another type of machine, the membrane oxygen enricher (MOE), works on a different principle. This uses a semi permeable membrane that permits selective diffusion of oxygen and water, which produces gas of high humidity enriched to about 40% oxygen. This type of machine relies on a high flow rate to achieve adequate oxygenation of the patient. In an unpublished study of 23 hypoxic patients with chronic bronchitis and emphysema, the manufacturers have shown that to achieve a given arterial oxygen saturation (SaO₂) the MOE must deliver 40% oxygen at a flow rate three times greater than the flow rate of 100% oxygen that is required to produce this SaO₂.

We have studied four different MS concentrators (three of which are currently in service with the Lothian Health Board in South East Scotland) and one MOE, to assess their technical and clinical performance both in the laboratory and in the patient's home.

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Fig 1 The concentrators studied: left to right—Econo₂, MINI DeVO₂, Roomate III, Mini O₂, OE-4E.

Description of concentrators

The concentrators are shown in figure 1 and their manufacturers, distributors in the UK, weight, dimensions, and maximal flow rates in table 1.

Three of the concentrators that are currently in service (Econo₂, MINI DeVO₂, Mini O₂) are simple to operate, with a single on-off switch, an easily visible rotameter flow control, and visible or audible alarms to indicate malfunctions. The Roomate III is a recently developed machine that will be available in the UK in the near future. It is also very simple to operate, with a single, large on-off flow control dial, marked in 0.5 l min⁻¹ graduations, and audible and visible alarms to indicate malfunctions.

The OE-4E appears more complex than the other machines, and this may intimidate some patients. It has an on-off switch, a rotameter flow control, a humidity control lever, and also a vacuum pressure gauge with visible alarms to indicate power failure or malfunction of the enricher. Heated delivery tubing (7.6 m) is also necessary to reduce condensation from the humidified gas.

All machines incorporate filters to remove particulate matter from the inspired gas, and the membrane of the OE-4E is an absolute barrier to bacteria. For the MS machines the only maintenance necessary between servicing is cleaning and

replacement of the air inlet filter, which should present few problems even to the least technically minded. The OE-4E also requires the heated delivery tubing to be cleaned at weekly intervals, but this is also a simple procedure. Power consumption is similar for all machines, ranging from 275 watts for the OE-4E to 480 watts for the MINI DeVO₂. Noise levels are not quoted by all manufacturers; but we found that all machines were acceptably quiet in operation, and none of the patients visited at home complained about noise.

The newer machines (MINI DeVO₂, Roomate III) are more portable, being lighter and more compact, with a well designed carrying handle. They fit easily into a standard saloon car, should this be necessary for use away from home.

Methods

The technical performance of all the concentrators was assessed in the laboratory in two sets of tests. (1) During four weeks of continuous running at a flow rate of 2 l min⁻¹ (6 l min⁻¹ for OE-4E) we measured the oxygen concentration and humidity of the inspired gas and the temperature of the concentrator exhaust gas. In addition, the MS concentrators were run continuously for a further five days, each day the oxygen concentration of the inspired

Table 1 Details of the concentrators studied

Concentrator	Manufacturer	Distributor in UK	Weight (kg)	Size (height × weight × depth—cm)	Maximal flow rate (l min ⁻¹)
Econo ₂	Mountain Medical Equipment	Glasrock Home Health Care	52	69 × 46 × 41	7
MINI DeVO ₂	DeVilbiss Corporation	DeVilbiss Corporation	20	61 × 41 × 36	5
Roomate III	Cryogenic Associates	Planer Biomed	25	69 × 36 × 25	4
Mini O ₂	Mountain Medical Equipment	Glasrock Home Health Care	25.5	38 × 40 × 58	4
OE-4E	Oxygen Enrichment Company	Oxygen Enrichment Company	50	76 × 36 × 41	6–10

gas being measured after one hour of flow at 1, 2, 3, 4 and 5 l min⁻¹. For the rest of each 24 hour period the concentrators were run at a flow rate of 2 l min⁻¹.

The clinical performance of four concentrators (the Mini O₂ was not available at the time of the study) was assessed by measuring the rise in arterial oxygen saturation (SaO₂) produced in 20 hypoxic patients (12M, 8F; age 47–93, mean 67 years; FEV₁ 0.3–3.1, mean 0.9 l; VC 0.6–4.2, mean 1.9 l; PaO₂ 4.9–9.0, mean 7.1 kPa; PaCO₂ 3.3–8.9, mean 6.0 kPa) who inspired from each machine at 2 l min⁻¹ (6 l min⁻¹ for OE-4E) through nasal prongs. The order for the concentrators studied in the 20 patients was assigned randomly, and SaO₂ was allowed to stabilise when patients were breathing room air between each period of gas delivery.

Home visits were made to 10 patients receiving domiciliary oxygen treatment on three separate occasions. At each visit their SaO₂ was measured when they were inspiring from the concentrator through nasal prongs, and inspired gas was collected from the concentrator to measure the oxygen concentration.

Measurement of oxygen concentration was carried out with a Sybron/Taylor Servomex O₂ analyser

Table 2 Oxygen concentration and humidity of inspired gas and temperature of exhaust gas (means with standard deviations in parentheses), measured daily from five concentrators running continuously for four weeks at a flow rate of 2 l min⁻¹ (6 l min⁻¹ for OE-4E)

Concentrator	Inspired gas		Exhaust gas Temperature (°C)
	O ₂ Concentration (%)	Humidity (%)	
Econo ₂	93.2 (1.2)	57.4 (5.0)	24.6 (2.8)
MINI DeVO ₂	94.1 (0.9)	51.7 (6.8)	24.0 (2.5)
Roomate III	93.3 (1.8)	50.7 (7.6)	27.7 (2.4)
Mini O ₂	94.2 (0.7)	46.6 (6.5)	23.4 (1.0)
OE-4E	36.5 (1.7)	90.9 (3.8)	19.3 (3.9)

570A, humidity with an Ellas Instruments hygrometer, and gas temperature with a Gallenkamp total immersion nitrogen filled TJ-400 thermometer. In the laboratory study SaO₂ was measured with a Hewlett-Packard 47201A ear oximeter, and during home visits by a Biox IIA ear oximeter.

Results

TECHNICAL PERFORMANCE

(1) During four weeks of continuous running, stable readings for the oxygen concentration and humidity

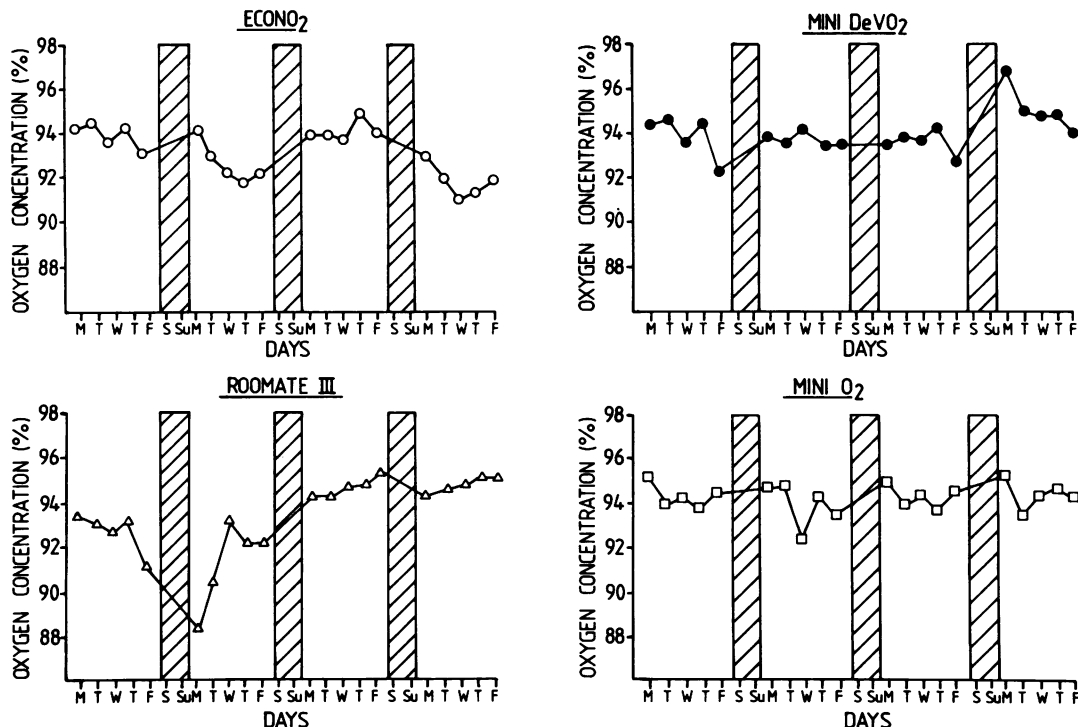


Fig 2 Oxygen concentrations delivered by the four molecular sieve concentrators running continuously for four weeks at 2 l min⁻¹.

of the inspired gas and the temperature of the exhaust gas were obtained from the MS concentrators, with minor fluctuations from day to day (fig 2, table 2). The MS concentrators achieved the following mean (SD) oxygen concentrations: Econo₂ 93.2% (1.2%); MINI DeVO₂ 94.1% (0.9%); Roomate III 93.3% (1.8%); Mini O₂ 94.2% (0.7%) at a flow rate of 2 l min⁻¹; and OE-4E 36.5% (1.7%) at a flow rate of 6 l min⁻¹. The lowest oxygen concentration recorded from an MS concentrator was 88.3% from the Roomate III; but we do not know whether this fall in the oxygen delivered will have any significant clinical effect (in the domiciliary part of this study the lowest oxygen concentration delivered by a concentrator was 89.8%, but at the same time the patient's SaO₂ was 93%).

The OE-4E delivered gas with more variable oxygen concentrations, but this machine was affected more by changes in room temperature than the others. Consistently high humidity (mean 90.9%) was achieved by the OE-4E (table 2).

(2) The oxygen concentration of inspired gas fell as flow rate increased with all the MS concentrators, but at flow rates of over 2 l min⁻¹ the two newer machines (MINI DeVO₂, Roomate III) delivered higher oxygen concentrations (fig 3). The Mini O₂ is a machine intended for use at flow rates of less than 3 l min⁻¹ and it delivers lower oxygen concentrations than the other MS concentrators at flow rates of 3 and 4 l min⁻¹.

CLINICAL PERFORMANCE

Each patient achieved a rise in SaO₂ when breathing

gas from each concentrator (fig 4), but the mean SaO₂ achieved with the OE-4E at a flow rate of 6 l min⁻¹ was significantly lower than the values achieved by the three MS concentrators studied, at a flow rate of 2 l min⁻¹ (Econo₂ 92.6%; MINI DeVO₂ 92.5%; Roomate III 92.6%; OE-4E 91.0%; *p* < 0.005, analysis of variance).

DOMICILIARY STUDIES

The oxygen concentrations delivered by concentrators installed in patients homes (MINI DeVO₂ × 4, Econo₂ × 4, Mini O₂ × 2) were consistently high and the SaO₂ levels recorded were generally acceptable (fig 5). One patient with an unacceptably low SaO₂ level (marked by an asterisk in fig 5) has been reassessed by titration of oxygen flow rate versus arterial oxygen and carbon dioxide tensions and [H⁺], and her domiciliary oxygen flow rate has been increased accordingly. The mean oxygen concentrations delivered by the home based concentrators were as follows: Econo₂ 95.6%, MINI DeVO₂ 94.85%, Mini O₂ 93.7%. Individual values are shown in figure 5.

Discussion

Previous studies⁴ have shown that concentrators are an acceptable means of providing long term domiciliary oxygen treatment. Since the time of those studies technology has advanced, today's concentrators being smaller and lighter yet having improved performance. A concentrator that is intended for long term domiciliary use must be not only reliable and able to deliver high oxygen con-

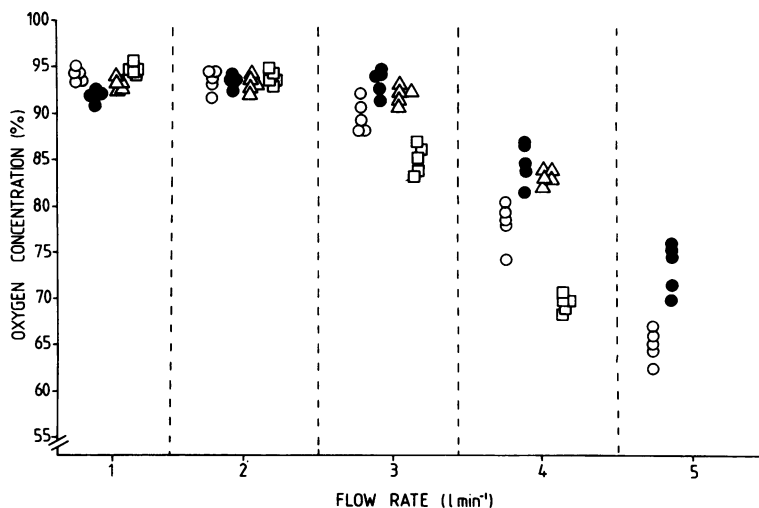


Fig 3 Oxygen concentrations delivered by the four molecular sieve concentrators at different flow rates, measured daily for five days. ○—Econo₂; ●—Mini DeVO₂; △—Roomate III; □—Mini O₂.

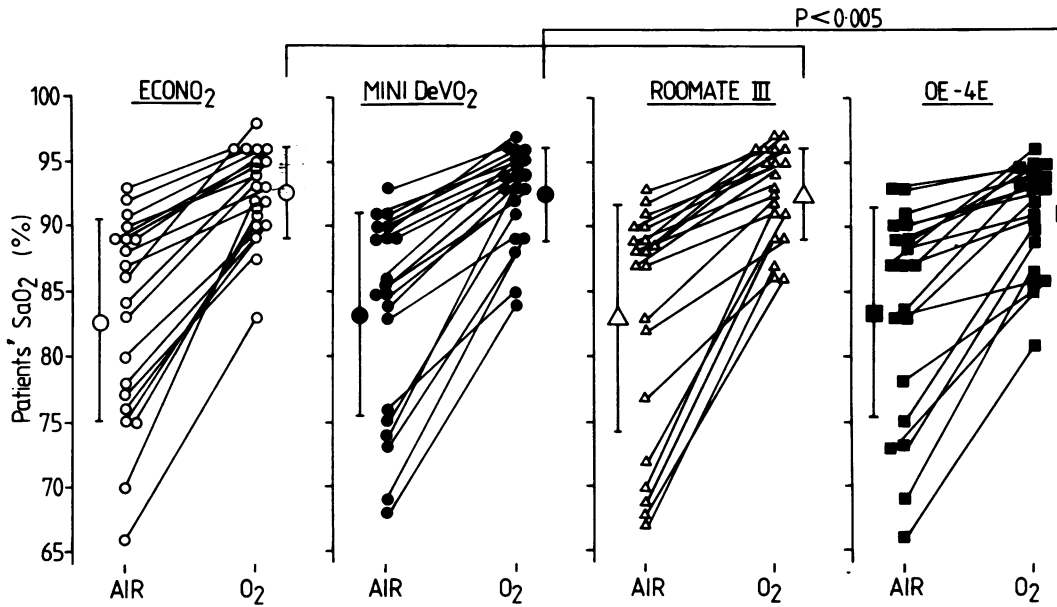


Fig 4 Arterial oxygen saturation (SaO_2) measured in 20 patients when breathing air and when breathing oxygen via nasal prongs from each of four concentrators at a flow rate of 2 l min^{-1} (6 l min^{-1} for OE-4E): individual values and mean with standard deviation for each concentrator.

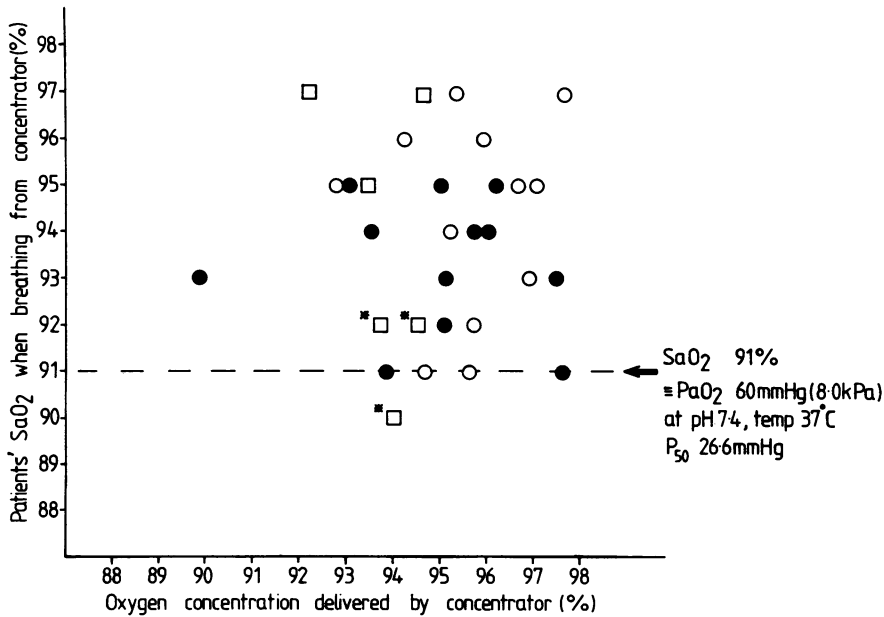


Fig 5 Arterial oxygen saturation (SaO_2) measured in 10 patients at home when they were breathing oxygen from their concentrators at a flow rate of 2 l min^{-1} and oxygen concentrations delivered by the concentrators. ○—Econo₂; ●—MINI DeV₂; □—Mini O₂. *Patient with oxygen flow rate of 1 l min^{-1} .

centrations consistently but also acceptable to the patient. Long term reliability can be assessed only from the service record in actual use, but from a study of this kind we are able to make some assessment of the other two features.

Acceptability to patients was high for the four MS concentrators studied. They are simple to operate and quiet when running, and they give out warm exhaust gas, which is unlikely to be unacceptable. The newer MS concentrators (MINI DeVO₂, Roomate III) have the added advantage of reduced size and weight, though this will be unimportant if the machine is not intended for use in more than one place. The MS concentrators all produce consistently high oxygen concentrations at flow rates of up to 2 l min⁻¹, but at flow rates of 3 and 4 l min⁻¹ the MINI DeVO₂ and Roomate III deliver higher oxygen concentrations than the Econo₂ and Mini O₂. As shown in the laboratory and domiciliary clinical studies, all patients should achieve a satisfactory level of oxygenation once the oxygen flow rate has been set appropriately.

It is probably inappropriate to compare the OE-4E directly with the MS concentrators we have studied, as it is a totally different type of machine, which works by a different principle, and is particularly intended for patients in whom humidification of inspired oxygen enriched gas is necessary. These might include patients with cystic fibrosis or bronchiectasis or those with a long term tracheostomy, but we know of no long term studies of the use of such a device in these patients.

The maximal flow rate achieved by the OE-4E is dependent on room temperature, ranging from 6 l min⁻¹ at 18°C to 10 l min⁻¹ at 35°C; but as temperature rises the concentration of oxygen in the inspired gas falls, so that the potential of this machine to improve a patient's oxygenation is relatively inflexible by comparison with a molecular sieve concentrator. The machine we studied achieved a maximal flow rate of 6 l min⁻¹, and in

several of the hypoxic patients studied a satisfactory SaO₂ was not achieved at this flow rate. Given that the objective of the OE-4E is to produce gas of high humidity that is moderately enriched in oxygen, it does achieve its aim, but owing to its flow rate limitations it would not be suitable for most hypoxic patients who are considered for long term oxygen treatment in Britain.

In summary, we have found that, although the membrane oxygen enricher that we studied, the OE-4E, may have a specific part to play in treating selected patients, it would not be suitable for most hypoxic patients, who do not require the high levels of humidity it delivers and who would be served better by a molecular sieve concentrator, particularly if they are severely hypoxic and require high flow rates of oxygen to achieve adequate oxygenation. The four molecular sieve concentrators studied are all suitable for domiciliary use, being simple to operate and consistent in performance; but the two "state of the art" machines, the MINI DeVO₂ and the Roomate III, are smaller, lighter, and more portable and also perform well, delivering high oxygen concentrations at flow rates of up to 4 l min⁻¹.

References

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