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For your interest.

David Brice.

[illegible]al oxygen analysers

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The continuous measurement of oxygen concentration in the gas coming from an anaesthetic machine is desirable in order to prevent anaesthetic disasters that result from faults in the oxygen supply (Macintosh, 1977; Thorp and Railton, 1982), faults in the oxygen rotameter flowmeter (Cole et al, 1983), and human inattention. Oxygen analysers are also commonly used in the ITU for measurement of the inspired oxygen concentration.

Monitors that are available for these applications can be divided into two types. The first type uses a polarographic electrode as the sensor. A power source is mandatory because a polarizing voltage must be applied to the electrode. The second type uses a galvanic cell which is sometimes called a microfuel cell. These cells generate a current in response to oxygen and so can drive a microammeter directly. They do not need an outside power source, unless an alarm is fitted. In practice all monitors of this type use either the C:1 or the C:2 cell made by Biomarine Industries. The difference between these is that the C:2 cell may be used in the presence of nitrous oxide but has a shorter life than the C:1 cell.

This review was undertaken to assess the accuracy, ease of use in a clinical situation, and relative cost of analysers available in the UK in December 1982.

Methods

The nine oxygen analysers studied are listed in *Table 1*. They were obtained on loan from the suppliers for the purpose of this study. Three of them use a polarographic electrode while the other six use a galvanic cell. Each analyser was subjected to the following examinations: physical characteristics, accuracy, response time, and cost.

Physical characteristics: The type of display, the power source, and the presence or absence of an alarm was noted. The ease of use in a clinical situation was recorded and battery life estimated with the assumption that normal use would be 20 h/week.

Accuracy: Each analyser was tested on at least three separate occasions. The instrument was calibrated according to the manufacturer's recommendations and then inserted into the circuit illustrated in *Fig.1*. The oxygen and nitrous oxide were delivered from standard anaesthetic cylinders while the nitrogen was delivered from a white-spot cylinder. On each occasion the analyser under test was then subjected to at least six different oxygen concentrations from 0—100 per cent using nitrogen as the second gas. At each concentration samples were taken from the three-way tap B for analysis in a Servomex paramagnetic oxygen analyser model OA 570 which was used as a standard. The readings of oxygen percentage from the Servomex were taken to one decimal point while those from the analyser under test were integer percentages.

The same tests were then performed using nitrous oxide as the second gas. Further tests were subsequently carried out over the full range of oxygen concentrations, adding 3 per cent halothane, 4 per cent enflurane, and one per cent trichloroethylene in turn to determine the effects of these vapours on the analyser. The effects of pressurizing the system to 45 mmHg were also tested over the full oxygen concentraion range. On at least two occasions calibration drift was noted over a 4-hour period.

Response time: The response time of each analyser was measured by subjecting it to sudden changes from 100 per cent nitrogen to 100 per cent oxygen and back to 100 per cent nitrogen. This was achieved by turning the three-way tap A in *Fig.1* while simultaneously turning off the oxygen supply. The 250 ml deadspace in the circuit gave a delay of approximately 1.4 seconds. The times taken to reach readings of 96 per cent oxygen and 96 per cent nitrogen were noted. The mean of these two times was taken as the 96 per cent response time.

Cost: The cost of each model exclusive of VAT was obtained from the suppliers during December 1982 together with the cost of the fuel cells or replacement membranes and electrodes.

Results

All the analysers were found to be of convenient size and could easily be fitted into an anaesthetic circuit. The sensor was a separate unit from the meter except in the Siemens-Elema 110 model which combined a T-piece, the sensor, and the meter all in.

Table 1. Data on the tested analysers (NS = not significant)

Make	Model	Galvanic cell (G) or polarograph (P)	Alarm	Analogue (A) or digital (D) display	Power source	Errors with $N_2 + O_2$ (% O_2) Mean	Errors with $N_2 + O_2$ (% O_2) Max	96% response time (seconds)	Mean N_2O bias (%)	Cost (£)	Estimated annual running cost with N_2O (£)	Estimated annual running cost without N_2O (£)
Critikon	Oxycheck	P	+	D	Battery	0.65	0.9	12	+1.9	550	48	48
Hudson	5552	G	—	A	Nil	0.6	1.9	39	NS	233	160	60
IL (Instrumentation Laboratories)	404	P	+	A	Battery	0.5	1.1	14	+2.0	420	40	40
IMI	3702	P	+	A	Mains	2.9	6.1	12	−8.3	666	50	50
Schach	—	G	+	D	Battery	0.5	1.3	33	NS	420	220	84
Siemens-Elema	110	G	—	A	Nil	1.4	3.1	> 180	NS	227	160	54
Ventronics	5525	G	—	A	Nil	1.0	2.3	32	NS	162	160	60
Vickers	T 25	G	—	A	Nil	2.5	5.1	48	NS	210	200	75
Vickers	Healthdyne	G	+	D	Rechargeable battery	0.5	1.8	50	NS	420	200	75
(Hudson)	(5550)	(G)	(+)	(D)	(Battery)	(Not tested)	(Not tested)	(Not tested)	(Not tested)	325	160	60

one unit. Model 404 from Instrument Laboratories (IL) was run continuously until battery exhaustion occurred. This happened at 3 weeks which indicated a battery life of about 6 months in normal use. The batteries of the Schach analyser were not exhausted after 3 weeks which gave support to the manufacturer's claim of an 18-month battery life. The Critikon Oxycheck gave a reading of the number of unused battery hours and this was found to be accurate. A new battery gave a reading of 280 hours indicating a life in normal use of about 3 months. The manufacturer of the Vickers Healthdyne claims a 7-hour life for the rechargeable unit. On the model we tested we were unable to obtain more than 4 hours' use from one overnight charge.

Accuracy: For each analyser, the differences between the standard reading and the test reading during the nitrogen and oxygen tests were noted and the mean of these differences was calculated. These results are shown in *Table 1* and represent the random error of the analyser. Both the Vickers T 25 and the IMI 3702 can be seen to have large random errors. With the Vickers T 25 this was caused by the needle of the ammeter intermittently sticking. Tapping on the glass only partially helped. The problem with the IMI 3702 was difficulty in maintaining calibration. The slightly high random errors seen in the Siemens-Elema 110 and the Ventronic 5525 were probably due to their small ammeters.

No errors could be attributed to the anaesthetic vapours used during these tests. However, in the polarographic analysers a systematic error attributable to nitrous oxide was found. The mean bias caused by 100 per cent nitrous oxide was calculated for each analyser and is shown in *Table 1* as the mean nitrous oxide bias. It can be seen that the IMI 3702 was very sensitive to nitrous oxide and indeed one reading showed 14 per cent oxygen with 100 per cent nitrous oxide. The other polarographic analysers, the Critikon Oxycheck and the IL 404, showed a lesser sensitivity to nitrous oxide. None of the galvanic-cell analysers showed any sensitivity to nitrous oxide.

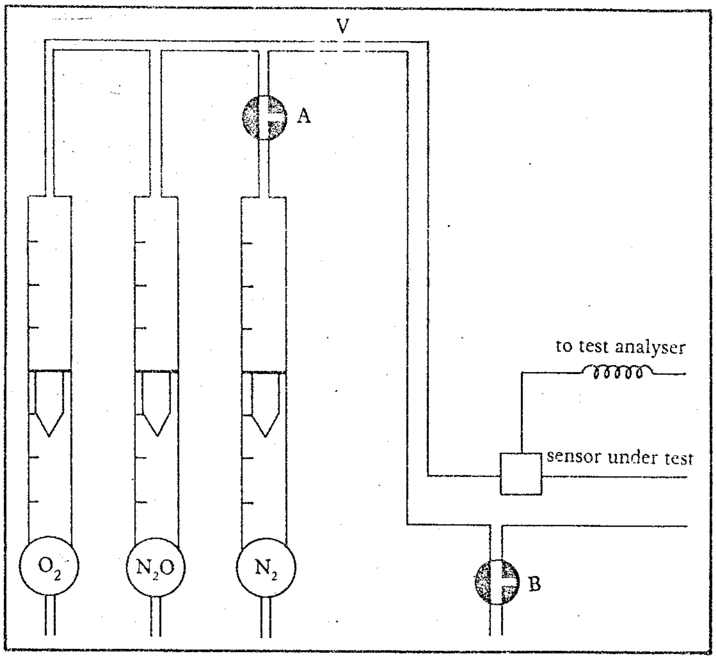

Fig. 1. Circuit used for testing the analysers. A and B are three-way taps and V is the position of the vaporizer when required.

As an example, the correlations between the Servomex measurements and those of the IL 404 and the IMI 3702 are illustrated in *Figs 2 and 3*. It can be seen that although both analysers show some nitrous oxide bias, the correlation with the IL 404 was much closer than that with the IMI 3702. With all the analysers the effect of 45 mmHg pressure was predictable in that the measured oxygen percentage increased in proportion to the partial pressure of oxygen.

The drift in calibration over 4 hours was less than one per cent oxygen in room air with all the analysers except the Vickers T 25 and the IMI 3702. The former showed a drift of 2 per cent oxygen on one occasion and the latter a drift of 2 per cent oxygen on two occasions. These drifts in calibration increased proportionately at higher oxygen concentrations.

Response time: The 96 per cent response times are shown in *Table 1*. The polarographic analysers had the fastest response times which were from between 10—15 seconds. Most of the galvanic-cell analysers had response times of 30—50 seconds but the Siemens-Elema 100 had an excessively long response time because of a bacterial filter between the sampling port and the sensor. It is designed mainly for ITU work in a ventilator circuit with rhythmical changes in pressure. Removing the filter and simulating the changes in ventilator pressure reduced the 96 per cent response time to about 2 minutes.

Cost: The initial cost of each analyser is listed in *Table 1* together with estimates of annual running costs. The latter costs have been divided on the basis of whether or not nitrous oxide is used because the C:2 galvanic cell has only 40 per cent of the life of the C:1 cell.

Discussion

The polarographic analysers were found to be slightly more expensive to buy but considerably cheaper to run than the galvanic-cell analysers. This difference could be important if analysers are to be fitted in every operating theatre in a hospital. However, all the polarographic analysers tested were sensitive to nitrous oxide. In the IMI 3702 the error was so great that it could have led to a dangerous level of hypoxia. This has been reported before (Orchard and Sykes, 1980) and was confirmed on a similar

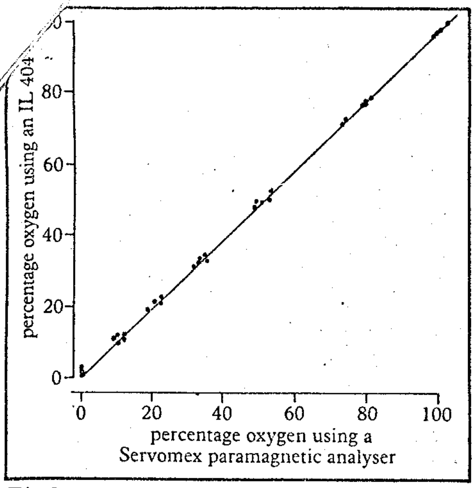

Fig.2.

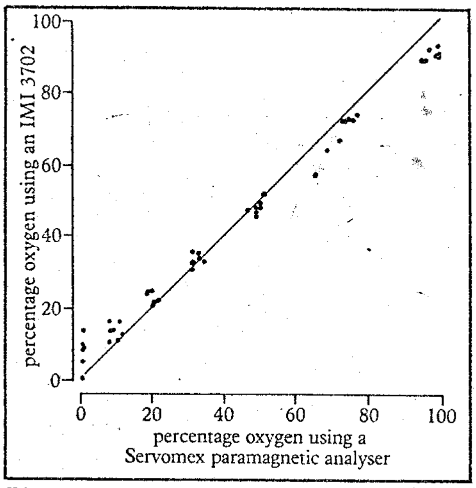

Fig.3.

Fig.2. Performance of a good analyser (IL 404) against a paramagnetic analyser (Servomex).

Fig.3. Performance of a poor analyser (IMI 3702) against a paramagnetic analyser (Servomex).

but older analyser which we had in the department. In the case of the IL 404 and the Critikon Oxycheck the sensitivity we found was unlikely to be dangerous in clinical situations. A previous report on the IL 402 (similar to the IL 404) showed an increased sensitivity to nitrous oxide as the batteries began to fail (Piernan et al, 1979). The company claims that this problem has been solved and we were unable to demonstrate this fault despite running the IL 404 until battery exhaustion. The Vickers T 25 was the only galvanic-cell analyser tested that had an inaccuracy that might lead to hazards in a clinical situation.

The long response time of the Siemens-Elema 110 might prove to be a problem clinically. The fast response times of the polarographic analysers, however, might be advantageous when calibrating an analyser and checking the anaesthetic machine.

For most clinical purposes, it was felt that an alarm was a desirable feature on an analyser. The Hudson 5552 which we tested did not have an alarm but the Hudson 5550 is the same model with an alarm fitted. Information about the Hudson 5550 is included in brackets in *Table 1*. We looked at two of these models which are in use in our hospital and found that there was difficulty in getting the maximum limit of the alarm above 95 per cent. This led to the alarm being triggered when 100 per cent oxygen was used, which might prove irritating. A battery power source was thought to be more convenient than a mains supply because many anaesthetic machines do not have a mains supply on them. The rechargeable battery on the Vickers Healthdyne analyser had a short life between charges which was felt to be a disadvantage. However, battery life and the method of battery checking were adequate on the other analysers.

For use in the operating theatre or the ITU, it was felt that the Critikon Oxycheck and the IL 404 were equally satisfactory polarographic analysers, while the Schach analyser proved a satisfactory galvanic-cell model. The Hudson 5550 was probably adequate although some doubt was cast on its alarm system.

Summary

Analysers using a polarographic electrode had a tendency to react to nitrous oxide, which was considered dangerous with one analyser. However, they had cheaper running costs and a faster response time than the galvanic-cell analysers. These latter analysers were slightly cheaper initially but their sensors were expensive and had a reduced life in the presence of nitrous oxide. Details of accuracy tests have been presented and opinions expressed with regard to the most satisfactory analysers for clinical use.

Cole, A G H, Thompson, J B, Fodor, I M, Baker, A B, Sear, J W (1983) *Anaesthesia*, 38, 175
Macintosh, R (1977) *Lancet*, ii, 307
Orchard, C H, Sykes, M K (1980) *Anaesthesia*, 35, 1100
Fiernan, S, Roizen, M F, Severinghaus, J W (1979) *Anesthesiology*, **50**, 146
Thorp, J M, Railton, R (1982) *Anaesthesia*, 37, 683

I would like to thank the suppliers for the loan of the analysers and Mrs C Walker for her secretarial assistance.

Addresses of manufacturers and suppliers
Biomarine Industry, 45 Great Valley Corporation Centre, Malvern, Pennsylvania 19355, USA
Critikon Ltd, Broadlands, Sunninghill, Ascot, Berkshire
Hudson models supplied by Viamed, 7 The Crofts, Farnhill, Keighley, Yorkshire BD20 9AG
IL (Instrumentation Laboratories), Kelvin Close, Birchwood Science Park, Warrington, Cheshire WA3 7PB
IMI model supplied by Deva Medical Electronics Ltd, 74 Brindley Road, Runcorn, Cheshire WA7 1PF
Schach model supplied by Deva Medical Electronics Ltd (see above)
Servomex model supplied by Sybron/Taylor, Taylor Instrument Analytics Ltd, Crowborough, Sussex TN6 3DU
Siemens Ltd, Siemens House, Windmill Road, Sunbury on Thames, Middlesex
Ventronic model supplied by Viamed (see above)
Vickers Medical, Priestly Road, Basingstoke, Hampshire RG24 9NP □