PAPERS AND ORIGINALS

Measurement and reduction of occupational exposure to inhaled anaesthetics

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Summary

The occupational exposure of hospital staff to inhaled anaesthetics was investigated using a personal sampling device that provides a measure of the average concentrations breathed by a person over a period of time, as distinct from the spot sampling in the general environment. The anaesthetist's average exposure to nitrous oxide and halothane during complete operating sessions was twice that expected from simple dilution of the escaping gases by the operating room ventilation. The sampling technique was also used to evaluate the effect of (1) redirection of the waste gas outflow; (2) active scavenging connected to the piped vacuum system. Short-period studies under controlled conditions in the operating theatres and anaesthesia induction rooms showed that the anaesthetist's exposure could be reduced two- to fourfold by redirecting the outflow and another four- to sixfold by active scavenging. Exposures during complete operating sessions were reduced two- to sevenfold by scavenging.

Introduction

Despite the continuing discussion about the possible hazards to operating theatre staff of long-continued inhalation of low concentrations of anaesthetic agents there is little or no information available about the real exposures of the people concerned. Several studies have been made of spot concentrations in various parts of operating suites,¹ and threshold-limit values have been suggested,² but there is no satisfactory evidence about the

relation between the concentrations in the general environment and the exposure of individuals. This lack of information makes it extremely difficult if not impossible to evaluate methods of reducing exposure.

Integrated personal sampling (IPS), using a continuous sampler carried on the person and sampling from the breathing zone, is a recognised³ but uncommon method of measuring exposure to gases and vapours. Only occasional attempts have been made to use it in the anaesthetic field^{4, 5} for short periods. The major obstacle has been the rather cumbersome and expensive apparatus, but the replacement of chemical analysis with physical methods, such as gas chromatography and mass spectrometry, means that smaller and simpler samplers can now be used.

The main advantage of IPS is that it gives a simple and reliable measure of the average exposure of the person, integrated over time. The technique is also much less laborious than collecting, analysing, weighting, and averaging many spot samples. Except for some preliminary studies with spot samples, which are included for comparison, all our observations were therefore based on IPS.

The environment

When measuring atmospheric contamination it is essential to take account of the volumetric ventilation flow rate in the environment. Room air changes per hour are unhelpful as they give no clue to the dilution factor unless the volume of the room is specified. If this information is not available comparison of results with those of others is almost meaningless.

In Northwick Park Hospital, which was opened in 1970, each main operating room is supplied with plenum ventilation at about 45 000 l/min to control wound contamination, the air escaping through low-level vents into the various surrounding rooms, including the anaesthesia induction room. With a flow of about 9 l/min from a Magill circuit or Manley ventilator the gases would be expected to be diluted 1/5000 in the operating room when complete mixing has taken place. With expired concentrations of, for example, 60% nitrous oxide and 1% halothane the expected concentrations would be 120 ppm and 2 ppm respectively.*

*We have used the convention of expressing anaesthetic concentration as a percentage or parts per million (ppm v/v). SI units have not yet been agreed on for this purpose.

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On the other hand, concentrations in the anaesthesia induction room may be higher because of a lower ventilation rate and because the concentrations used and the escape of anaesthetics to the atmosphere are usually greater during induction of anaesthesia.

Another factor affecting the anaesthetist's exposure is the high concentration close to the Heidbrink valve,¹ which is often close to the anaesthetist's face. Unless measurements are made in the breathing zone and appropriately weighted the real exposure can be seriously misjudged.

Measuring exposure

METHODS

Spot sampling

In preliminary experiments spot samples were taken in glass syringes with nylon taps after flushing three times with the sample gas. Control tests showed that this technique avoided any cross-contamination between samples and that there was no significant loss before analysis.

Integrated personal sampling

Samples were taken into evacuated 250-ml glass bottles fitted with special stoppers containing a spring-loaded valve. The bottles could be evacuated through the valve and would hold their vacuum indefinitely. An evacuated bottle has the great advantage of being both a store of energy for drawing the sample and a compact and durable storage container for it.⁶ A simple vacuum regulator was screwed into the stopper to reduce the vacuum to about 0.9 atmosphere, so that constant flow could be obtained until the pressure in the bottle rose to this level. The regulator was fitted with a needle valve with which the flow could be adjusted from a few μ l to several ml per minute. The rate was adjusted so that the bottle would not quite fill over the expected period of exposure.

The subject carried the bottle in a pocket and a length of 1-mm nylon tubing was fitted with its open end attached to the outside of the face mask.

Sampling was started by screwing in the regulator at the beginning of exposure and stopped at the end by unscrewing it. The single sample in the bottle could then be repeatedly analysed to obtain any desired precision.

Control tests in a chamber with a constantly monitored homogeneous anaesthetic atmosphere showed that the apparatus was reliable and accurate and not subject to anaesthetic losses during 12 hours of storage before analysis.

Analysis

The pressure in each bottle was measured with an aneroid manometer to check that it was not more than 0.9 atmosphere, and so ensure that its sampling period had not been exceeded. To avoid having to draw a sample against a partial vacuum, with the danger of leakage, an all-glass matched-barrel syringe filled with clean air was inserted, with an adaptor plug, into the stopper. Air was then allowed to enter the bottle until the syringe piston came to rest and the volume entering was noted. The volume of each bottle was accurately known so the dilution factor could be calculated. After adequate mixing a specimen was withdrawn for analysis on a Pye 104 gas chromatograph.

Halothane concentrations from 0.3 to 2500 ppm were measured with a flame ionisation detector held at 250°C after separation on a 2.13-m glass column with an internal diameter of 3.18 mm held at 80°C filled with 100/120-mesh Chromosorb W treated with 10% OV-101 silicon oil. The carrier gas was helium at 20-50 ml/min, and the nominal sampling loop volume was 0.1 ml.

Nitrous oxide concentrations from 25 to 1500 ppm were measured with a ⁶³Ni electron-capture (150 μ s pulse space) held at 250°C after separation on a 3 m $\times$ 3.2 mm glass column held at 80°C, filled with 80/100 mesh Porpac Q. The carrier gas was argon at 25 ml/min and the nominal sampling loop volume was 0.5 ml. The linear range of the electron-capture response could be varied by altering the detector oven temperature,⁷ and higher concentrations were measured by sample dilution.

For halothane each sample was measured in duplicate, and when there was a discrepancy of >5% a third measurement was made.

Preliminary studies with nitrous oxide showed such excellent reproducibility that each sample was normally analysed only once.

Calibration graphs were obtained from standards prepared by vaporising a known volume of liquid halothane in a known volume of clean air. Nitrous oxide standard concentrations were prepared by volume dilution of medical-grade nitrous oxide. The sample concentrations measured with the gas chromatograph were subsequently corrected for any initial dilution before analysis.

RESULTS AND COMMENT

Spot sampling—Table I shows the results in the operating room with halothane as an indicator. We found that (a) as expected, concentrations fell off with distance from the Heidbrink valve; (b) concentrations varied greatly in the anaesthetist's breathing zone; (c) the peripheral concentration was similar to that predicted by the dilution factor; (d) the peripheral concentration did not change significantly with time—that is, the level was a balance between contamination and ventilation.

TABLE I—Halothane levels (ppm) in operating room on spot sampling

Position	Mask	Intubated
Close to Heidbrink valve	1000-2500	1000-2500
Anaesthetist's breathing zone	20-550	10-100
Edge of theatre:	0.71-2.1	1.0-3.0
after 1 hour's anaesthesia	0.7-2.4	
after 4 hours' anaesthesia	1.8-10	
after 6 hours' anaesthesia	0.8-2.0	

Integrated personal sampling—IPS proved to be invaluable. The saving of time and labour compared with taking and analysing the spot samples recorded in table I was enormous. Results in the form of a single figure for a period of exposure seemed both meaningful and a sound basis for evaluating precautions against exposure.

The subjects were anaesthetists and anaesthesia and recovery-room nurses, but only the exposure of anaesthetists will be detailed here. Figures for the mean exposure of anaesthetists to nitrous oxide and halothane over three-hour operating sessions are given in the first part of table II. Figures for 10-minute periods in the anaesthetic induction room and operating room separately are given in table III.

Exposure of anaesthetists—The figures in table II for the exposure of anaesthetists during three-hour sessions with no precautions show that in spite of high exposure in the induction room and proximity to

TABLE II—Results of integrated personal sampling: exposure of anaesthetists over three-hour operating session. Various techniques and agents. Results are means (and ranges)

	Nitrous oxide (ppm)	Halothane (ppm)
No precautions (n=8)	269.0 (108-430)	3.6 (1.0-8.0)
Banjo fitting (n=11)	243.0 (73-400)	1.1 (0.3-4)
Scavenging (n=13)	127 (67.5-225)	0.57 (0.1-6)

TABLE III—Exposure of one anaesthetist over 10-minute periods: Magill circuit and spontaneous respiration (N₂O:O₂ 6:3 L/min, halothane 2%)

	Anaesthesia Induction room		Operating room	
	Nitrous oxide (ppm)	Halothane (ppm)	Nitrous oxide (ppm)	Halothane (ppm)
No precautions:				
No of samples	8	8	5	4
Mean (and range)	3038 (600-5380)	52.1 (12.5-115.0)	453 (301-630)	5.3 (4.0-6.3)
Banjo fitting:				
No of samples	8	8	10	10
Mean (and range)	887 (450-1323)	12.7 (8.1-17.1)	250 (25-464)	2.45 (0.4-3)
Scavenging:				
No of samples	6	6	12	12
Mean (and range)	152 (67.5-235)	3.1 (0.75-8.5)	62.0 (0-147)	0.46 (0.1-2.5)

an unshrouded Heidbrink valve the nitrous oxide concentration* was only about twice the general level in the operating room. This can be accounted for by the fact that the anaesthetist may leave the room to attend patients in the recovery room or if working with a trainee, during which time his exposure is negligible. Also, for over half the time, patients are artificially ventilated with a ventilator discharging near the floor, when the anaesthetist's exposure in the operating room is no higher than the general level. The mean exposure of anaesthesia nurses was found to be very near the general level in the operating room—namely, 121 ppm nitrous oxide (range 52-260) and 2.1 ppm halothane (range 0.8-0). The mean exposure of recovery room nurses was negligible: 18 ppm nitrous oxide (range 15-25) and 0.1 ppm halothane (range 0-0.5). This, however, may not be true in recovery rooms with little or no ventilation or close to the operating rooms.⁸ The anaesthetist's exposure therefore seems to be the main problem. We have not made observations on surgeons, but they can be near the Heidbrink valve and may spend more time continuously at the patient's side and so sometimes have a comparable exposure.

Reducing exposure

METHOD

Reducing exposure was conducted in two stages. Firstly we stopped the anaesthetist and others directly breathing the outflow from the Heidbrink valve by fitting a device over the holes in the valve to duct the gases through a single nozzle. As can be seen from fig 1 this "banjo" fitting does not interfere with the adjustment of the valve. The nozzle can also be turned to point in any direction.

FIG 1—Banjo fitting on a Heidbrink valve.

Additional resistance to breathing is negligible compared with that of the Heidbrink valve, which has minimum loading of 1 cm H₂O.⁹ We have chosen to use this fitting on our present Heidbrink valves rather than replace them with new ones because the new ducted valves are more expensive and cumbersome.

The second stage was active scavenging, which was done by fitting a hood with six 3.5-mm bore bypass holes to the banjo and connecting it via a length of flexible tubing to piped vacuum (fig 2). The bypass holes prevent a suction head of more than 1 cm H₂O being exerted

FIG 2—Perforated hood on a banjo fitting for connection to piped vacuum.

*Nitrous oxide levels are a better index than halothane levels because nitrous oxide is nearly always used and the concentration given is fairly constant. Halothane levels are included for comparison with the figures of others.

at a flow of 40 l/min so that the Heidbrink valve is not lifted, even at its lightest setting. It was not found necessary to introduce a reservoir into the extraction system provided that the suction flow was at least 30 l/min. Although higher peak expiratory flows than this may occur they are absorbed by the bag in the Magill circuit.

Scavenging from ventilators—Although our ventilators produced no special hazard to anaesthetists, we fitted them with scavenging devices to bring down the general level of gases. Because they produce higher peak flows the scavenging flow of 40 l/min is insufficient and a reservoir is required. The suction hood was therefore fitted by means of an adaptor into a T-piece and bag inserted in the outlet of the ventilator.

RESULTS AND COMMENT

The effect of these measures is shown in tables II and III. It is difficult to show clearly the effect on sessional exposures because they are relatively slight and variable, for reasons already discussed. We therefore decided to make 10-minute studies in the anaesthesia induction room and operating room separately on one anaesthetist who stayed by the patient's head and controlled the anaesthetic method and agents rigorously. Table III shows that the anaesthetist's exposure in the induction room can be much higher and was reduced over threefold by the banjo fitting and another sixfold by scavenging.

The exposure in the operating room was also higher in short-term measurement than for a whole session because it was continuous and because a ventilator was not used. The effect of the banjo was relatively small because of the high ventilation flow in the operating room. Scavenging, however, produced a nearly eightfold reduction.

Acceptability of precautions—We have found that these simple precautions are readily accepted and require no change in anaesthetic methods. Banjos have been fitted to all Heidbrink valves by the instrument curator and the addition of scavenging hoods has been welcomed because they improve the operating room atmosphere while retaining an intermittent sound of the patient's ventilation. Measurement of exposure is not essential for monitoring scavenging because agents such as methoxyflurane can be smelt all over the theatre in spite of the high ventilation flow, which would be expected to dilute the methoxyflurane concentration to below 1 ppm. As soon as the scavenging is turned on, however, the smell disappears, even in the immediate vicinity of the extraction hood, where any escape would lead to very high local concentrations.

Sampling device

The sampling equipment we used was developed specially for this project. Because it would have many other useful applications, especially in industry, arrangements have been made for its commercial production and a full description will be published elsewhere. When it is generally available those with access to analytical facilities will be able to monitor the exposure of operating room staff with little trouble and expense and compare results with others using the same technique. The commercial version of the equipment will use an aerosol can as a container, which can be sent by post for analysis at a central laboratory.

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