OBJECTIVE
A simple, inexpensive device for the continuous low-flow sampling of air was devised to permit monitoring of pollution by gaseous anaesthetics. The device consisted of a water-filled Perspex cylinder in which a double-walled flexible-film gas sample collection bag was suspended. Air samples could be aspirated into the collection bag at flow rates of as low as 1 ml min⁻¹ by allowing the water to drain from the cylinder at a controlled rate. The maintenance of sample integrity with aspiration and storage of samples of nitrous oxide in air at concentrations of 1000, 100 and 30 p.p.m. v/v was examined using gas chromatography. The sample bags retained a mean 94% of the nitrous oxide in air samples containing nitrous oxide 25 p.p.m. over a 72-h storage period.

Measures for decreasing occupational exposure to inhalation anaesthetics should be supported by the monitoring of air pollution to ensure that such measures are effective, and to enable an accidental leak of gas or malfunction in either scavenging equipment or ventilation system to be detected and corrected.

Ideally, monitoring should be carried out with air sampling devices which collect air samples on a continuous basis during the period of exposure. Intermittent snatch sampling is not suitable for routine monitoring purposes because the concentration of anaesthetic agent in the breathing zone of health personnel tends to fluctuate widely during induction and maintenance of anaesthesia. The continuous collection of the air sample enables the concentrations of pollutants in the sample to be expressed as a time-weighted average.

Several air sampling systems have been devised for collecting air samples on a continuous basis (Hallen, Ehrner-Samuel and Thomason, 1970; Corbett, 1973; Davenport et al., 1976; Whitcher and Piziali, 1977). Factors such as cost, convenience and sample volume have limited the adoption of these systems for general use.

Ideally, the equipment used to monitor air pollution should be inexpensive, simple, reliable and easy to operate. It should allow collection of air samples from the breathing zone of the anaesthetist or surgeon for periods extending over several hours. Air samples should be of relatively low volume for convenience of handling and carriage by post to a laboratory for analysis. Sample integrity should be maintained with minimal losses or extraneous contamination until analysis has been carried out (American Dental Association Council on Dental Materials and Devices, 1977).

The purpose of this paper is to report on the development and evaluation of a simple method for collecting air samples on a continuous basis to allow monitoring of nitrous oxide pollution in operating theatres and dental surgeries.

METHODS

Design considerations

To comply with the specifications for an ideal air sampling system, two criteria have to be met. First, restriction of the sample volume which is collected over periods extending up to 6 h and second, the maintenance of a consistent air sampling rate over the period of collection.

A previous study on snatch sampling techniques indicated that flexible nylon film gas sample bags retained air samples containing nitrous oxide with minimal losses for periods of up to 24 h after collection (Austin et al., 1978). These bags were used as prospective air sample containers for the development and testing of the equipment used in this study.

Sample collection can be carried out either by pumping or by aspirating air into these sample
Since mechanical pumps which will pump air at the required low flow rates of 1–5 ml min⁻¹ are complicated and expensive to construct it was decided to collect air by means of an aspiration technique. Evacuated nylon sample bags were suspended in a rigid-walled water-filled container and by allowing the water to drain from the sealed container at the required rate an air sample was obtained. The air sample collection bag was provided with a nozzle which passed through the wall of the chamber. The end of the nozzle was provided with a silicone rubber septum seal. Air was aspirated into the bag by means of a hypodermic needle which was passed through the nozzle septum when air sampling was in progress (fig. 1).

Pilot studies were carried out on the system of sampling using a 0.5-litre nylon bag. However, it was found that the nylon bag alone was unsuitable; the nylon film, being hygroscopic, absorbed water. After several hours of immersion gas chromatography showed that the water vapour concentration had increased in air samples collected in the bags, indicating that the nylon film was pervious to water vapour. This problem was overcome by enclosing the nylon sampling bag in an outer protective sleeve of high density polyethylene. This measure prevented water from coming into direct contact with the nylon sampling bag.

Construction of gas sample bags

The inner nylon bags were made of 150 mm wide × 0.05 mm thick tubular nylon film (Nylon 6—fusion point 218 °C, Portex, Hythe, Kent). The tubular film was cut into 190 mm lengths to construct sample bags with a capacity of approximately 650 ml of air when the open ends had been sealed. The outer sleeves of the sample bags were made of 210 mm lengths of 162 mm wide × 0.125 mm thickness tubular high density polyethylene (HDPE) film (Allied 3204, Keagrams (Pty) Ltd, Aeroton, South Africa). One end of the tubular nylon and HDPE film was heat-sealed and the nylon film was inserted inside the HDPE sleeve thus formed. A 12 mm diameter hole was punched through the two layers of film to make provision for the insertion of a specially constructed brass nozzle, the lumen of which provided a connection between the inner nylon gas sampling bag and the environment to be sampled. The brass nozzle was turned from 19 mm hexagon brass, and consisted of a 12 mm diameter threaded stem with a hexagonal head at one end. An axially positioned hole was bored through the nozzle and the threaded end was counterbored and tapped to provide a recess for accommodating a 3 mm thick silicone rubber septum which was held in position with a grub screw (fig. 2).
securing nut had “O” rings positioned in recesses in both its upper and lower face to prevent water leaking from the chamber along the threaded nozzle stem or at the point at which the nozzle passed through the chamber wall (fig. 2).

After the nozzle had been fixed in position, the remaining open ends of the nylon and HDPE films were in turn heat-sealed to form the inner sample bag and outer protective bag. The silicone rubber septum was positioned in the recess at the end of the sampling nozzle, the inner bag was inflated with approximately 250 ml of air and the whole unit was submerged in water for several hours to test for air and water leaks. Leaking bags were discarded. Bags which did not leak were evacuated by aspirating residual air from the bags with a hypodermic needle connected to a high vacuum pump (Speedivac, Edwards, Crawley, Sussex) and stored until they were required for use.

Construction of the water chamber

The water chamber was constructed of clear acrylic (Perspex AECI, Johannesburg). The body of the chamber was made of a 210 mm length of 150 mm diameter acrylic tubing and the ends of 175 mm diameter discs of 12 mm thick acrylic sheet. The ends of the tube were accurately faced on a lathe and fitted into stepped circular recesses machined in one face of the end plates. These recesses were provided with an “O” ring seal (fig. 3). The end-plates were held on to the body of the chamber with four tie rods. The upper end-plate of the chamber was fitted with a dual-purpose filling and draining nozzle and an air vent to allow air to escape during filling. Provision was made for the sampling bag nozzle to pass through an opening in the side wall of the chamber. An acrylic collar was cemented in the curved wall of the chamber to provide a flat face for seating the “O” ring seal in the upper face of the nut positioned on the nozzle of the sample collection bags.

Preparation of the chamber for air sampling

The sample bag was placed in the body of the chamber and the nozzle was passed through the collar in the chamber wall and secured with a nut. The ends of the chamber were seated on the body and fastened by means of wing nuts which were screwed onto the tie rods. The chamber was inverted and filled with water via the filling and drainage nozzle. All air was vented from the chamber via a vent hole positioned on the periphery of the junction between the body and base of the chamber. The filling nozzle was then sealed with a silicone rubber septum which was held in position with a threaded septum cap.

Sampling procedure

The chamber was suspended from an i.v. fluid stand and an i.v. infusion set with its drip chamber and plastic tubing primed with water connected to the lower drainage nozzle (figs 4, 5). A gas
it remained constant for the period of sampling without further adjustment being necessary. The drip chamber provides a visual means of monitoring the rate of sample collection during the period of gas sampling. Adhesion between the opposed walls of the evacuated nylon sample bag during atmospheric sampling was not found to be a problem because, in spite of vacuum aspiration, the nylon film adjacent to the nozzle was always kept slightly parted by the protrusion of the base flange of the metal nozzle into the bag. Cleavage of the opposed nylon surfaces began as soon as the gas sampling needle was inserted through the sample bag septum and drainage of water from the chamber commenced.

**Evaluation of the air sampling system**

The air sampling system was tested to determine if it would reliably aspirate air samples at a constant flow for several hours and to determine if losses of nitrous oxide occurred when air containing trace concentrations of nitrous oxide was aspirated into the sample bag using the water displacement method and the bag removed from the chamber and stored for up to 72 h.

The first part of the evaluation was confined to estimating the constancy of the sampling rate and the losses of nitrous oxide which occurred when air with a known concentration of nitrous oxide was transferred from stock sample bags to the sample collection bags using the aspiration technique. Stock samples of nitrous oxide in air were prepared in 3.5-litre capacity nylon film bags (Austin et al., 1978). The nylon bags were inflated with dry air from a compressed air cylinder (Afrox, Germiston, South Africa). Medical grade nitrous oxide was added to the bags in volumes of approximately 3.5 ml, 0.35 ml and 0.11 ml to give concentrations of approximately 1000 p.p.m., 100 p.p.m. and 30 p.p.m. (v/v) respectively. These concentrations were selected on the basis of a previous study on nitrous oxide pollution in dental surgeries, in which this range of concentrations was shown to occur (Cleaton-Jones et al., 1978).

After each stock sample had been prepared, the concentrations of nitrous oxide in air were determined with a Pye Unicam Model GCV gas chromatograph. Nitrous oxide was separated using a 2 m × 4 mm borosilicate glass column packed with 80–100 mesh Poropak Type Q (Waters Assoc., Milford, Massachusetts, U.S.A.) at a column temperature of 80 °C. Helium was used as a carrier gas at a flow rate of 25 ml min⁻¹. Nitrous oxide was detected with a katharometer, the filament temperature being 180 °C and the detector oven temperature set at 100 °C. The injection port temperature was 150 °C. Peak areas were integrated with a Pye DP88 integrating computer and compared with the peak areas obtained with commercially prepared 1000-p.p.m. and 100-p.p.m. (v/v) nitrous oxide in nitrogen standards (Altec Associates Calibration Gas, Arlington Heights, Illinois, U.S.A.). All the concentration-prepared bulk samples were within 10% of the desired 1000-p.p.m. and 100-p.p.m. (v/v) nitrous oxide in nitrogen standards. Ten prepared bulk samples of nitrous oxide in air at concentrations of ±10% of 1000 p.p.m., 100 p.p.m. and 25% of 30 p.p.m. (v/v) were, in turn, suspended next to the sampling chamber and connected to the collecting bags in the acrylic chambers by means of a 21-gauge stainless steel cannula. Approximately 0.5 litre of air was
aspirated from the bulk sample bags into the nylon collection bags by the water displacement collection technique using a flow rate of 4 ml min⁻¹ over a 2-h period of collection.

The concentrations of nitrous oxide in air in the bulk sample bags prepared at the three different concentrations were determined by gas chromatography just before sampling was begun and 24 h thereafter. The concentration of nitrous oxide in air in the sample collection bags was similarly determined immediately after the 2-h sample collection period and 24 h later. The concentrations of nitrous oxide in the aspirated air sample at the end of the sampling procedure and 24 h later were expressed as percentages of the original concentrations of nitrous oxide in the bulk samples from which they originated. This provided a measure of nitrous oxide losses associated with the aspiration and storage phases of the exercise. Differences in mean concentrations of nitrous oxide in air between the three groups of bulk sample bags and their corresponding sample collection bags immediately after collection and 24 h later were examined statistically using the paired t test.

To determine the retention of nitrous oxide in the sampling bags over a 72-h period, eight bulk samples of nitrous oxide in air were prepared by adding nitrous oxide 0.09 ml to approximately 3.4 litre of air to provide air samples containing approximately 25 p.p.m. (v/v) of nitrous oxide in air. The concentrations of nitrous oxide were determined by gas chromatography and adjusted, if necessary, so that they were between 20 and 30 p.p.m.

Eight loose gas sampling bags were then, in turn, connected directly to these eight bulk sample bags by means of 21-gauge stainless steel cannula and approximately 250 ml of air transferred from the larger to the smaller bags by lightly squeezing the larger bag. This procedure was a direct gas transfer between the bulk sample and sample collection bag. It was carried out with the sample collection bags removed from the Perspex water chamber. The bulk sample bags were then disconnected and the concentrations of nitrous oxide in air in the eight collection bags were determined by means of gas chromatography immediately after gas transfer and at intervals of 24, 48 and 72 h thereafter. The retention of nitrous oxide recorded at each time interval was expressed as the percentage of the initial concentration of nitrous oxide in the sample bag immediately after it had been partially filled.

RESULTS

The concentrations of nitrous oxide in the samples of air collected by means of the water displacement–sample aspiration method immediately after sample collection and 24 h later at the three concentrations selected for this study are detailed in Table I.

At the three concentrations of nitrous oxide in air tested (1000, 100 and 30 p.p.m.) the slow transfer of the air sample resulted in losses of less than 1.5% at the two higher concentrations and less than 4% at the lowest concentration, 30 p.p.m. The latter value was equivalent to nitrous oxide 1.2 p.p.m. in air. Twenty-four hours later further significant losses of nitrous oxide were recorded in the two groups of sample bags at the 1000- and 100-p.p.m. concentrations of nitrous oxide (P < 0.01). These losses were, however, very small, being a mean 1.7% and 0.6% respectively. At the lowest concentrations of 30 p.p.m. a slight mean increase of nitrous oxide of 1.7% was recorded.

<table>
<thead>
<tr>
<th>Group</th>
<th>Initial concn N₂O in bulk sample bags (p.p.m. v/v ± SD = 100%)</th>
<th>N₂O immediately after sample collection (% ± SD)</th>
<th>N₂O 24 h after sample collection (% ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 p.p.m.</td>
<td>1045 ± 59 (880–1103)*</td>
<td>98.6 ± 1.7</td>
<td>96.9 ± 2.6</td>
</tr>
<tr>
<td>100 p.p.m.</td>
<td>104 ± 10 (92–118)</td>
<td>98.5 ± 2.2</td>
<td>97.9 ± 1.6</td>
</tr>
<tr>
<td>30 p.p.m.</td>
<td>32.3 ± 3 (25–36)</td>
<td>96.1 ± 7.0</td>
<td>97.8 ± 3.9</td>
</tr>
</tbody>
</table>

TABLE I. Mean concentration of nitrous oxide in air expressed as a percentage of the concentration of nitrous oxide in the air samples from which it was collected. *(Range in parentheses)
The differences between the mean concentrations of nitrous oxide in air in the bulk sample bags and their corresponding sample collection bags immediately after collection and 24 h later are detailed in table II.

**TABLE II. Analyses of the differences between the mean concentrations of nitrous oxide in air in the initial bulk samples and the aspirated samples immediately after collection and 24 h later. BS = bulk sample; AS = aspirated sample; n.s. = not significant.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Differences in N₂O concentration</th>
<th>t value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 p.p.m.</td>
<td>BS v. AS 0 h</td>
<td>0.64</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>AS 0 h v. AS 24 h</td>
<td>1.75</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>BS v. AS 24 h</td>
<td>3.61</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>100 p.p.m.</td>
<td>BS v. AS 0 h</td>
<td>2.06</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>AS 0 h v. AS 24 h</td>
<td>0.7</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>BS v. AS 24 h</td>
<td>3.6</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>30 p.p.m.</td>
<td>BS v. AS 0 h</td>
<td>1.58</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>AS 0 h v. AS 24 h</td>
<td>0.03</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>BS v. AS 24 h</td>
<td>1.68</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

The mean percentage of nitrous oxide retained by the eight loose sample bags at 24, 48 and 72 h after filling with air containing approximately 25 p.p.m. v/v of nitrous oxide in air by the manual inflation transfer technique are detailed in table III.

**TABLE III. Mean concentration of nitrous oxide in air expressed as a percentage of the concentration of nitrous oxide in the sample bags at various intervals after filling.**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Concentration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial concentration N₂O</td>
<td>25.3 ± 2.9</td>
</tr>
<tr>
<td>in sample bags</td>
<td>(range = 23-30)</td>
</tr>
<tr>
<td>p.p.m. v/v ± SD = 100%</td>
<td>(n = 8)</td>
</tr>
<tr>
<td>24 h</td>
<td>95.0 ± 6.0</td>
</tr>
<tr>
<td>48 h</td>
<td>92.0 ± 5.5</td>
</tr>
<tr>
<td>72 h</td>
<td>94.0 ± 7.4</td>
</tr>
</tbody>
</table>

Twenty-four hours after transfer of the eight air samples containing ±25 p.p.m. of nitrous oxide in air, there was a mean loss of 5% of nitrous oxide in the sample. A further mean 3% of the nitrous oxide was lost in the next 24 h and at 72 h the mean concentration of nitrous oxide in the air in the sample bags was 94% of the original concentration. This result reflected a 2% increase over the mean 48 h concentration. At the mean concentration of 25 p.p.m. v/v of nitrous oxide in air, this was equivalent to a 2 p.p.m. increase. This slight discrepancy can be attributed to the accuracy limitations of nitrous oxide detection of the gas chromatograph at the low concentration selected to determine the loss of nitrous oxide from the sample bags.

**DISCUSSION**

The simple continuous sampling method which has been devised will provide a convenient and low-cost method for routinely monitoring nitrous oxide pollution in operating theatres and dental surgeries. The method meets all the requirements for an air sampling system laid down by the American Dental Association's Council on Dental Materials and Devices (1977). The mean losses of nitrous oxide which occurred with the collection of the air sample and its storage for 24 and 72 h at the lowest concentration tested (30 and 25 p.p.m. v/v) were less than 6% of the mean concentration of nitrous oxide present in the prepared bulk samples. At these concentrations the loss represented 1.8 p.p.m. v/v of nitrous oxide in air which is considered to be a negligible loss in an air pollution monitoring procedure. This method of sampling has been used routinely in our laboratory for more than 18 months since it was devised. It has been found to be reliable in the hands of both our staff and those of lay personnel who have operated the equipment on our behalf in a survey of nitrous oxide pollution which is being conducted in operating theatres in hospitals in Johannesburg.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


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**METHODE SIMPLE D’ÉCHANTILLONNAGE DE L’AIR POUR SURVEILLER LA POLLUTION PAR LE PROTOXYDE D’AZOTE**

**RESUME**

Il vient d’être mis au point un dispositif simple et peu onéreux permettant l’échantillonnage en continu et à faible débit de l’air, afin de surveiller la pollution par les gaz anesthésiants. L’appareil se compose d’un cylindre en Perspex rempli d’eau dans lequel est suspendu un sac à double paroi et en pellicule flexible servant à la collecte des échantillons de gaz. Les échantillons d’air peuvent être aspirés dans le sac de collecte à des débits aussi faibles que 1 ml min⁻¹, en laissant s’écouler l’eau du cylindre à un débit contrôlé. Le maintien de l’intégrité de l’échantillon, l’aspiration et l’entreposage des échantillons de protoxyde d’azote dans l’air à des concentrations de 1000, 100 et 30 p.p.m. v/V ont été surveillés par chromatographie en phase gazeuse. Les sacs d’échantillons ont retenu en moyenne 94% du protoxyde d’azote des échantillons d’air contenant 25 p.p.m. de protoxyde d’azote, pendant une durée d’entreposage de 72 h.

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**TECNICA SENCILLA PARA EL MUESTREO DE AIRE DESTINADA A LA VIGILANCIA DE LA POLUCION MOTIVADA POR OXIDO NITROSO**

**SUMARIO**

Se construyó un dispositivo sencillo y barato para llevar a cabo el muestreo de aire, mediante circulación lenta y continua, para que fuera posible la vigilancia de la polución ocasionada por los elementos anestésicos gaseosos. El dispositivo consistía de un cilindro de Perspex lleno de agua en el que se suspendió una bolsa de doble pared de película flexible destinada a la recogida de muestras gaseosas. Las muestras de aire pudieron aspirarse hasta la bolsa de recogida con regímenes de flujo tan bajos como de 1 ml min⁻¹, al permitir que el agua purgara desde el cilindro a un ritmo controlado. Se examinó mantenimiento de la integridad de las muestras, con aspiración y almacenamiento de muestras de óxido nitroso en el aire, a concentraciones de 1,000, 100 y 30 p.p.m. v/V, haciendo uso de cromatografía de gases. Las bolsas de muestreo retuvieron una media de 94% de óxido nitroso en las muestras de aire que presentaban 25 p.p.m. de óxido nitroso, por espacio de 72 horas de almacenamiento.