ORIGINAL ARTICLE

Nitrous oxide pollution in operating theatres in relation to the type of leakage and the number of efficacious air exchanges per hour

M. SARTINI, G. OTTRIA, M. DALLERA, A.M. SPAGNOLO, M.L. CRISTINA
Department of Health Sciences, University of Genoa, Italy

Key words

Nitrous oxide • Operating theatre • Efficacious air exchanges per hour

Summary

Introduction. *As occupational exposure to anaesthetic gases is one of the main risks for operating theatre staff, an environmental monitoring campaign was conducted in order to evaluate the degree of pollution by nitrous oxide (N_2O) in the operating theatres of some hospital facilities in Liguria.*
Methods. *Any leaks (systemic and/or managerial) of anaesthetic gas and the number of efficacious air exchanges per hour supplied by air-conditioning systems were evaluated by means of an IR spectrometer, which was wired to a computer for data collection and analysis. The concentration of nitrous oxide in the centre of each operating theatre was measured by means of chemo-adsorbent cartridges analysed by gas chromatography.*
Results. *In 76.0% of the operating theatres examined a mean environmental concentration of N_2O below the legal limits was recorded. The highest mean concentrations were generally associated with the presence of systemic leaks. Supplying an adequate number of efficacious air exchanges per hour enabled environmental concentrations of anaesthetic gas to be kept within acceptable levels.*
Discussion and conclusions. *Training personnel in the correct management of the operating theatre and of anaesthesia equipment, and ensuring the availability of an adequate air-conditioning system enable the risk of exposure to nitrous oxide to be minimised. This can be achieved through a concerted effort on the part of all involved, in accordance with the concept of ongoing improvement in healthcare services.*

Introduction

The prevention of occupational diseases and accidents is a fundamental element of social safety, a concept that is manifest in the rules laid down by EU directives [1] to safeguard health and safety in the workplace.
Like any other workplace, the hospital environment is obliged to conform to these rules, which regulate its activities with regard to protecting the health of both staff and patients. This means that sources of possible risk (chemical, physical, biological) must be constantly and thoroughly monitored [2]. In surgical departments, where safety conditions and the quality of the micro-environment must be guaranteed even more than elsewhere, the critical zone is the operating theatre. A safe and salubrious operating theatre is an environment in which all sources of pollution and any micro-environmental alterations are kept strictly under control. This can be achieved only through careful planning, maintenance and periodic checks, as well as proper ongoing training for staff.
Among the main direct sources of contamination, anaesthetic gases are particularly important. This problem has been the focus of numerous investigations, which have suggested that prolonged exposure to high levels of anaesthetic gases are probably linked to the onset of certain pathologies [3, 4]. In this regard, Circular N° 5 issued on 14/03/1989 [5] by the Ministry of Health indicates exposure limits (for nitrous oxide: 100 ppm in operating theatres built before 1989 and 50 ppm in others), analytical methods of control and guidelines to reduce environmental pollution.
To prevent pollution by anaesthetic gases in the operating theatre, it is clearly important to be aware of its possible sources. These can be summarised essentially as the distribution system of the gases, anaesthesia equipment and administration techniques of the gases themselves [6, 7]. Therefore, in response to the legal obligations concerning the safeguard of workers exposed to the inhalation of anaesthetic gases [1], and with reference to the procedures laid down in the Manual for the Accreditation of Health Facilities in the Liguria Region – which prescribes at least 15 efficacious air exchanges per hour in operating theatres [8] – a programme has been undertaken to monitor the levels of pollution by nitrous oxide in the operating theatres of various hospital facilities in Liguria. The results reported in the present paper.

Methods

A monitoring campaign lasting approximately two years was carried out. Thirty-three operating theatres were examined: 11 in general surgery departments and 22 in specialist surgery departments. The facilities exa-

Tab. I. Mean, standard deviation (S.D.), range and percentiles (50th-75th) of the values of environmental N_2O (ppm) recorded in the various facilities examined.

	N° Obs.	$[N_2O]$ Mean ± S.D.	$[N_2O]$ Range (min-max)	$[N_2O]$ Percentiles (50th-75th)	
Facility A	40	53.7 ± 70.8	0.5-276.3	16.4	96.0
Facility B	54	88.0 ± 107.8	1.7-515	42.1	113.6
Facility C	15	107.8 ± 95.1	0.5-257.7	88.0	200.3
Facility D	8	66.1 ± 77.0	0.5-176.0	26.5	145.8
Facility E	6	36.3 ± 27.9	4.3-75.8	32.4	59.4
Facility F	8	35.4 ± 71.5	3.8-212.0	11.3	17.0
Facility G	6	4.6 ± 4.5	0.5-12.6	4.0	6.0
Facility H	13	12.5 ± 11.0	0.5-37.4	11.4	18.0
Total	150	64.9 ± 87.9	0.5-515.1	22.0	88.0

mined had all been built before 1989, had not been subsequently restructured and were equipped with a turbulent-flow air-conditioning system.

Sampling was carried out weekly in each operating theatre by means of both active and passive sampling techniques. Active sampling was performed by means of a portable infra-red spectrometer (Miran 1B2 Foxboro Company) able to detect, in conditions of simulated surgical activity, any leaks of anaesthetic gas from the main supply system or from anaesthesia equipment. Leaks were them classified as "systemic" if they were due to faults in the central supply system, and as "managerial" if they were due to insufficient control and inadequate preparation of anaesthesia equipment on the part of the operating theatre staff. Examinations were carried out on both high- and low-pressure circuits, with particular attention being paid to potentially critical points, such as connections between joints, valves, vaporisers, flow-meters, etc. The spectrometer was wired to a portable computer, which enabled the data to be gathered for subsequent statistical analysis.

Passive sampling was carried out during surgical activities in the operating theatres by means of chemo-adsorbent cartridges (Radiello®) containing a molecular sieve and active carbon, specific for anaesthetic gases and vapours. The analytes captured were then extracted by means of an H_2O/methanol mixture (60/40%, v/v) and analysed [9] by means of the head space technique using GC CROMPACK CP 9002 (Split-Splitless injector; ECD detector; Gas carrier: N_2 and $Ar\text{-}CH_4$ (10% v/v of CH_4); Split ratio 10/1. Analytic sensitivity limit of the instrument: 0.5 ppm for N_2O. PORAPLOT Q CP7550 capillary column of 12.5 metres, diameter 0.32 mm). The gas chromatograph was set to the following temperature programme: 40 °C for 2 min, 10 °C/min up to 150 °C, 6 °C/min up to 200 °C, isotherm for 5 min. Injector: 150 °C. ECD detector: 300 °C.

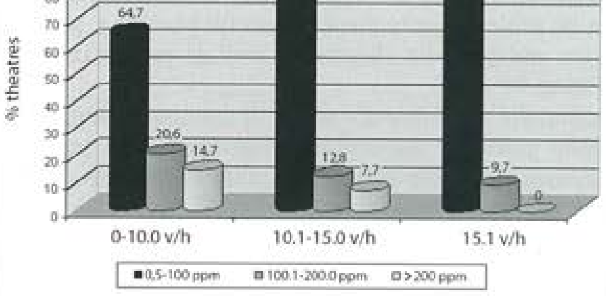
During environmental monitoring, the actual number of efficacious air exchanges per hour was also measured in each of the operating theatres examined, in accordance with the tracer-gas dilution method described in regulation EN ISO 12569 [10]. Measurements were taken with the portable infra-red spectrometer (Miran 1B2).

In the descriptive analysis, the following parameters were evaluated: mean, standard deviation (S.D.), percentiles (50th and 75th) and frequency distribution. Statistical analysis of the data gathered was carried out by means of the STATA programme, and the following tests were applied: Bravais-Pearson linear correlation coefficient "r" and Wilcoxon's test.

Results

The mean concentration of environmental nitrous oxide in the totality of the operating theatres examined was 64.9 ± 87.9 ppm, with a range between 0.5 and 515 ppm. The 50th percentile was 22.0 ppm and the 75th percentile was 88.0 ppm (Tab. I). In the individual facilities, the highest mean value of N_2O (107.8 ± 95.1 ppm) was recorded in facility C, while the lowest (4.6 ± 4.5 ppm) was recorded in facility G. In 76.0% of the operating theatres examined, a mean environmental concentration of nitrous oxide between 0.5 and 100 ppm was recorded; in 14.7%, the value was between 100.1 and 200.0 ppm, while 9.3% of the theatres registered a mean concentration above 200 ppm.

Fig. 1. Percentage of operating theatres showing given concentrations of N_2O as a function of the number of efficacious air exchanges/h.



Tab. II. Frequency distribution of the mean environmental concentration of N_2O measured in the operating theatres examined, as a function of the number of efficacious air exchanges per hour.

$[N_2O]$ (ppm)		N° efficacious air exchanges per hour (v/h)							
	N° Obs.	0-10 N°	0-10 %	10.1-15 N°	10.1-15 %	> 15 N°	> 15 %	Not measurable N°	Not measurable %
0.5-100	114	44	64.7	31	79.5	28	90.3	11	91.7
100.1-200	22	14	20.6	5	12.8	3	9.7	0	0
> 200	14	10	14.7	3	7.7	0	0	1	8.3
Total	150	68	100	39	100	31	100	12	100

Next, the mean concentration of N_2O in the centre of each operating theatre was measured as a function of the number of air exchanges per hour: 64.7% of operating theatres with a number of air exchanges between 0 and 10 v/h showed a mean concentration below 100.0 ppm; among the operating theatres with a number of exchanges between 10.1 and 15.0 v/h, the percentage rose to 79.5%, and reached 90.3% among those with a number of exchanges greater than 15 v/h. (Fig. 1, Tab. II). Analysis of the values recorded revealed a statistically significant correlation between the mean environmental concentrations of nitrous oxide and the number of efficacious air exchanges per hour in the operating theatres examined ($r = -0.3471$; $p < 0.01$).

The data gathered were analysed in relation to the presence or absence of leaks (managerial and/or systemic) and to the number of efficacious air exchanges per hour. The mean concentration of nitrous oxide proved to be 56.6 ppm in those operating theatres in which only leaks of a managerial nature were detected; 84.9 ppm in those in which systemic leaks were found; 81.4 ppm in those where both types of leak were present, and 24.1 ppm in the absence of leaks. Mean environmental nitrous oxide concentrations greater than 100 ppm were registered in operating theatres with a number of efficacious air exchanges per hour below 10 v/h in the presence of systemic leaks (Tab. III).

Tables IV-a, IV-b and IV-c report the mean values, percentiles (50th, 75th) and maximum and minimum values of the leaks detected in relation to the type of leak and the number of efficacious air exchanges per hour. Statistical analysis showed significant differences between the environmental concentrations of anaesthetic gas in the presence or absence of leaks, whether systemic or managerial (Wilcoxon test: systemic leaks $z = -3.47$, $p < 0.001$; managerial leaks $z = -4.068$, $p < 0.001$).

Discussion and conclusions

Evaluation of the mean environmental concentrations of nitrous oxide in the 33 operating theatres of the hospital facilities examined revealed in general a substantially satisfactory situation. Indeed, only in hospital facility C was a mean level of N_2O pollution above the legal indications recorded, while the 50th percentile shows values below one quarter of the legal limit (100 ppm) (Tab. I).

Nevertheless, deeper analysis of the data gathered reveals a fairly heterogeneous overall picture. This is demonstrated by the very broad range of mean concentrations of nitrous oxide recorded (0.5-515 ppm) (Tab. I). This finding underscores the importance of constant environmental monitoring for chemical pollution in operating theatres. If, however, such action is to go beyond the simple registration of data, it must necessarily be associated to an ongoing process of evaluation of the results achieved, in order to enable timely preventive and remedial intervention to be undertaken. In conformity with the concept of continuous improvement that underlies

Tab. III. Mean concentrations of environmental N_2O in the presence/absence of leaks and as a function of the number of efficacious air exchanges per hour.

Type of leak	$[N_2O]$ mean (ppm)	N° air exchanges: 0-10 v/h			N° air exchanges: 10.1-15 v/h			N° air exchanges: >15 v/h		
		$[N_2O]$ mean (ppm)	$[N_2O]$ 50thP (ppm)	$[N_2O]$ 75thP (ppm)	$[N_2O]$ mean (ppm)	$[N_2O]$ 50thP (ppm)	$[N_2O]$ 75thP (ppm)	$[N_2O]$ mean (ppm)	$[N_2O]$ 50thP (ppm)	$[N_2O]$ 75thP (ppm)
M˚	56.6	39.3	21.8	40.0	89.2	80.2	150.5	15.1	15.1	22.7
S^	84.9	142.2	84.0	246.3	39.3	11.9	16.0	48.3	26.0	61.3
M˚ + S^	81.4	108.6	99.7	175.0	58.4	24.9	54.1	52.6	25.6	80.4
No leaks	24.1	38.1	18.9	66.1	15.5	3.2	4.1	10.3	8.7	13

M˚ = managerial leaks; S^ = systemic leaks; 50thP = 50th percentile; 75thP = 75th percentile

Tab. IV-a. Mean, standard deviation (S.D.), percentiles (50th, 75th), minimum and maximum leakage values (ppm) in operating theatres with a number of efficacious air exchanges per hour from 0 to 10 v/h.

		Air exchanges 0-10 v/h			
		$[N_2O]$ Mean ± S.D.	$[N_2O]$ 50th p	$[N_2O]$ 75th p	$[N_2O]$ Range (Min-Max)
M˙		350.3 ± 134.6	363.5	391.0	144.0-597.0
S^		440.1 ± 132.1	445.0	532.0	167.0-630.0
M˙ + S^	M˙	380.2 ± 137.6	394.7	481.5	150.0-688.0
	S^	350.5 ± 127.8	357.6	482.0	136.0-595.3

M˙ = managerial leaks; S^ = systemic leaks; M˙ + S^ = managerial plus systemic; 50thP = 50th percentile; 75thP = 75th percentile

Tab. IV-b. Mean, standard deviation (S.D.), percentiles (50th, 75th), minimum and maximum leakage values (ppm) in operating theatres with a number of efficacious air exchanges per hour from 10.1-15 v/h.

		Air exchanges 10.1-15 v/h			
		$[N_2O]$ Mean ± S.D.	$[N_2O]$ 50th p	$[N_2O]$ 75th p	$[N_2O]$ Range (Min-Max)
M˙		423.0 ± 77.3	406.2	487.9	330.0-541.0
S^		399.4 ± 154.4	400.5	494.0	173.0-754.0
M˙ + S^	M˙	408.5 ± 167.5	341.0	515.0	137.0-723.0
	S^	404.7 ± 145.3	363.2	538.0	201.5-659.0

M˙ = managerial leaks; S^ = systemic leaks; M˙ + S^ = managerial plus systemic; 50thP = 50th percentile; 75thP = 75th percentile

Tab. IV-c. Mean, standard deviation (S.D.), percentiles (50th, 75th), minimum and maximum leakage values (ppm) in operating theatres with a number of efficacious air exchanges per hour above 15 v/h.

		Air exchanges > 15 v/h			
		$[N_2O]$ Mean ± S.D.	$[N_2O]$ 50th p	$[N_2O]$ 75th p	$[N_2O]$ Range (Min-Max)
M˙		317.7 ± 14.5	317.7	328.0	307.5-328.0
S^		472.9 ± 135.6	452.0	585.5	232.0-648.5
M˙ + S˙	M˙	400.5 ± 142.6	391.2	519.7	203.0-622.0
	S^	377.5 ± 122.9	352.0	444.0	210.0-592.0

M˙ = managerial leaks; S˙ = systemic leaks; M˙ + S˙ = managerial plus systemic; 50thP = 50th percentile; 75thP = 75th percentile

the Liguria Region's Manual for the Institutional Accreditation of Healthcare Activities [8], such intervention should be developed through the involvement of various professional figures, from hospital management to technical departments and operating theatre staff.

The present paper reports a statistically significant relationship between the number of efficacious air exchanges per hour and the levels of nitrous oxide pollution detected in the operating theatres examined. In the presence of leaks, whether they be of a systemic nature, a managerial nature, or both, an air-conditioning system that provides a sufficient number of efficacious air exchanges per hour (≥ 15 v/h) is able to keep down the environmental concentrations of anaesthetic gas. Moreover, in the absence of leaks, such a system is able to reduce gas pollution to minimum values, which, in such a situation, are determined almost exclusively by the normal anaesthesia procedures (sedation, intubation and extubation manoeuvres).

The highest mean concentrations of nitrous oxide (Tab. III) were associated with leaks of a systemic type, that is to say, leaks caused by defective functioning of the central system of distribution of medical gases. Moreover, in some cases, the leaks detected were due to inadequate control of the anaesthesia equipment at the beginning of the operating session on the part of the theatre staff responsible. As a result, some components of the equipment (balloons, reservoirs, joints, etc.) failed to be replaced even though they were clearly worn.

In conclusion, it is evident that intervention should be undertaken, on the one hand, to train staff in the proper management of the operating theatre and anaesthesia equipment, and on the other hand, to ensure the availability of an air-conditioning system able to supply an adequate number of efficacious air exchanges per hour. This dual approach can significantly reduce environmental pollution by nitrous oxide and, consequently, minimise the risk of occupational exposure for operating theatre staff.

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■ Correspondence: Prof.ssa Maria Luisa Cristina, Department of Health Sciences, University of Genoa, via Pastore 1, 16132 Genoa, Italy - Tel. +39 010 3538883 - Fax +39 010 3538216 - E-mail: cristinaml@unige.it