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Exposure to anesthetic gases and ethanol during work in operating rooms

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GÖTHE, C.-J., ÖVRUM, P. and HALLEN, B. Exposure to anesthetic gases and ethanol during work in operating rooms. *Scand. j. work environ. & health* 2 (1976) 96—106. The concentration of halothane and ethanol in operating rooms was measured during 37 routine operations performed in nine different departments of surgery at six different hospitals. The time-weighted halothane concentrations in the respiratory zones of anesthetic and surgical nurses were 0.3—34.0 ppm (time-weighted average 7.2 ppm) and 0.1—9.2 ppm (time-weighted average 2.5 ppm), respectively, in the different operating departments. The corresponding ethanol concentrations were 0.3—36.5 ppm (time-weighted average 12.5 ppm) for anesthetic nurses and 1.5—46.6 ppm (time-weighted average 15.3 ppm) for surgical nurses. The anesthetic technique influences the exposure of the operating staff to anesthetic gases, but it does not affect exposure to ethanol. In controlled experiments volunteers were exposed to low concentrations of halothane or ethanol. About 60 % of both substances was retained. The content of ethanol in the end-expired air approached zero within a few minutes after the end of exposure, while low residual concentrations of halothane were demonstrable for more than 1 h. Although exposure to ethanol is insignificant in relation to the metabolic capacity of the body, ethanol indicates the presence of volatile disinfectant components, and its spread through the room atmosphere should be kept in mind when the ventilation of operating rooms is designed. The effective elimination of airborne pollutants in operating rooms calls for good general ventilation in conjunction with local exhaust close to the sources of anesthetic gas leakage. General ventilation mainly affects the concentration of substances well-mixed with the room atmosphere, such as volatile disinfectant components and anesthetic vapor that has spread beyond the actual work zones of the medical staff. For a significant reduction in the concentration of anesthetic gases in the respiratory zones of the medical staff, the gases must be vented at the source of leakage. Since airborne anesthetics occur not only in operating rooms, general ventilation has to meet certain minimum requirements also in anesthetic induction rooms and recovery rooms. Operating rooms and anesthetic induction rooms must also be supplied with local exhaust systems.

Key words: halothane, ethanol, occupational exposure, ventilation, operating room, decay curve.

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The object of the present investigation was to study the manner in which the exposure of medical staffs to anesthetic gases varies with the anesthetic technique employed and the ventilation standard of the operating room. For practical reasons the study was limited to operations performed with halothane as the main anesthetic. As ethanol was consistently encountered in the air samples collected

from operating rooms, the exposure to this substance was also studied.

The investigation is part of a larger project including studies of the ventilation in operating rooms (47), studies of the effect of anesthetic gases on the psychomotor functions of anesthetic nurses (28, 29), and an epidemiologic study of medical staffs exposed to anesthetic gases with special emphasis on detection of fertility and gravidity derangement (to be published).

MATERIAL AND METHODS

Air samples were collected in the work areas of anesthetic and surgical nurses during halothane anesthesia. "Mobile" samplers worn by the staff collected ambient air continuously from each bearer's respiratory zone, and "stationary" samplers collected air from sampling points near the work zones, but outside the actual respiratory zones, of the operating room personnel.

The sampling equipment consisted of a 30-ml glass syringe whose piston was withdrawn at a constant rate by a battery-powered electric motor. The open end of a copper capillary tube attached to the syringe was placed in the measurement zone. The mobile equipment was carried by the staff, i.e., anesthetic and surgical nurses, during their work. The mouth of the capillary tube was placed 5–10 cm from the bearer's nostrils.

Whenever possible, the exposure conditions of the staff were monitored throughout entire work shifts. In order to study the course of exposure during the actual periods of anesthesia, we changed the glass syringes in both the mobile and stationary equipment as close to the initiation and conclusion of anesthesia as the surgical and anesthesiological conditions permitted. This report describes the course of exposure during ongoing anesthesia.

Using the method described, we studied exposure conditions during the administration of halothane in 37 separate routine operations performed in nine operating departments at six major hospitals in the Stockholm and Uppsala areas. A total of 310 air samples from operating rooms and

anesthetic induction rooms were collected during the administration of the anesthetic. One hundred and sixty-two of these samples were taken with mobile samplers in the respiratory zones of anesthetic and surgical nurses, and 148 samples were taken with stationary samplers in the vicinity of the work zones. The duration of sampling lasted from 5 to 58 min and varied from 20 to 40 min for 80 % of the samples (246 of 310). All samples were time-weighted according to the formula $(\sum C_1 t_1)/t$ [t_1 =sampling duration (min) for air sample with concentration C_1 (ppm); t =period for time-weighting (min)], and the time-weighted concentrations of halothane and ethanol during the administration of the anesthetic were calculated.

In addition to the samples described, instantaneous samples were taken at various measuring points in conjunction with situations and work phases which could be suspected of giving rise to heavy exposure to anesthetic gases. Samples of end-expired air were taken from the anesthetic and surgical nurses, according to a given schedule, for the analysis of halothane and ethanol concentrations.

The investigation was supplemented with laboratory exposure trials in which a volunteer inhaled air, supplied by a tube and breathing valve, containing a known and constant concentration of halothane (32 ppm) or ethanol (58 ppm). The content of halothane and ethanol, respectively, in the end-expired air was examined every second to third minute during exposure, and frequent controls were made for more than 1 h after the termination of exposure.

Immediately after collection the samples were assayed for halothane ($\text{CF}_3\text{-CHClBr}$) and ethanol ($\text{C}_2\text{H}_5\text{OH}$) with a gas chromatograph (AID, model 511) fitted with a flame ionization detector. The stainless steel column was 2 m long and 2.2 mm in diameter. It was packed with 2 % Fractronil II (Merck) on 80–100 mesh Chromosorb G (Johns-Manville Co.). The oven temperature was 80°C. Nitrogen flowing at 20 ml/min was used as the carrier gas. The sample volume was 1 ml. The gas standards for halothane and ethanol were prepared on the site in a glass flask whose design and operation are shown in fig. 1. With the equipment

Fig. 1. Glass flask for the production of gas standard: The flask, whose volume had been carefully measured, is evacuated at D with the aid of a vacuum pump. The desired amount of standard (halothane or ethanol) is injected into the flask via capillary tube B after cock A is opened and cock E is closed. The gas standard is removed at C after the establishment of equilibrium.

used, the limit of detection is about 0.2 ppm for halothane and about 0.5 ppm for ethanol.

RESULTS

Table 1 shows exposure conditions in the different operating departments studied. Exposure varied widely, but the ethanol level in the operating rooms was usually higher than the halothane level during surgery.

The time-weighted halothane concentration measured with mobile equipment was nearly three times higher in the respiratory zone of the anesthetic nurses than in that of the surgical nurses. In the work zones of the anesthetic nurses — but not in those of the surgical nurses — a far higher level of halothane was detected in the

samples collected with the mobile equipment than in those collected with the stationary equipment. Moreover, there was a greater spread in the halothane concentrations in instantaneous samples taken from the work zones of the anesthetic nurses than in corresponding samples taken from the work zones of the surgical nurses. The highest instantaneous values recorded for halothane (340 ppm and 23.5 ppm in the work zones of the anesthetic and surgical nurses, respectively) were both recorded in a department for pediatric surgery during anesthesia administered via a face mask without rebreathing.

End-expired air samples were taken simultaneously from the anesthetic and surgical nurses on 35 occasions. There was a good rank-order correlation between the halothane levels in both categories of nurses ($r_s = 0.85$; r_s = Spearman's rank-order correlation coefficient), i.e., when the anesthetic nurse had a high halothane content in her end-expired air in relation to other anesthetic nurses, the surgical nurse had a high halothane concentration in her end-expired air in relation to other surgical nurses. In 86 % of the cases (30 out of 35) the halothane concentration was the highest in the end-expired air of the anesthetic nurses. It was highest in the surgical nurses in only 3 % (1 out of 35) and equally high in the remaining 11 % (4 out of 35). The highest halothane level measured in end-expired air was 9.8 ppm for anesthetic nurses and 4.8 ppm for surgical nurses. These peak values were recorded during one and the same operation performed under anesthesia, with intubation and without rebreathing, in a department of pediatric surgery.

The time-weighted exposure to ethanol was similar for anesthetic and surgical nurses. There was consistent agreement between the ethanol levels in the corresponding air samples collected by mobile and stationary samplers. The highest ethanol concentrations recorded in end-expired air amounted to 12.3 and 14 ppm in anesthetic and surgical nurses, respectively. These peak values were both recorded during the same operation in which also the highest instantaneous levels of 256 and 316 ppm were recorded in the work zones of the anesthetic and surgical staff. The similarity of ethanol exposure

Table 1. Time-weighted halothane and ethanol exposure (ppm) for anesthetic and surgical nurses in different operating departments.

Hospital	Operating department	Anesthetic nurses				Surgical nurses			
		Mobile ^a		Stationary ^b		Mobile ^a		Stationary ^b	
		Halothane	Ethanol	Halothane	Ethanol	Halothane	Ethanol	Halothane	Ethanol
Karolinska	General surgery	3.9	36.5	3.8	36.4	3.6	46.6	3.8	51.4
	Pediatric surgery	34.0	17.5	9.1	15.8	9.2	18.2	9.4	17.0
	Orthopedic surgery	9.0	7.2	4.0	10.0	2.1	12.9	2.2	17.1
Serafimer	General surgery	4.2	10.4	0.8	9.8	0.4	11.6	0.8	11.7
Söder	General surgery I	11.1	14.0	3.8	11.8	2.7	17.5	2.8	14.5
Akademiska	Central operating dept.	0.3	1.9	0.5	2.4	0.1	2.0	0.2	1.4
	Surgical outpatient dept.	7.7	0.3	5.8	0.4	2.6	1.5	2.6	0.5
St. Eriks	Central operating dept.	3.2	1.5	0.9	0.8	0.5	3.3	1.3	1.4
Danderyd	Central operating dept.	2.2	4.6	4.3	5.8	1.0	3.9	—	—
All operating departments		7.2	12.5	3.4	12.6	2.5	15.3	3.0	18.4

^a Samples taken in respiratory zones with mobile equipment.

^b Samples taken in work zones, but outside respiratory zones, with stationary equipment.

for both nurse categories was confirmed by the finding that ethanol levels in 35 pairs of end-expired air samples taken from anesthetic and surgical nurses working in parallel were highest in the anesthetic nurses in 37 % (13 out of 35) of the paired comparisons, in the surgical nurses in 43 % (15 out of 35), and equally great in the remaining 20 % (7 out of 35).

In eight cases end-expired air samples were taken in conjunction with the conclusion of anesthesia and 17–78 min thereafter. Following this "airing" time, which averaged about 40 min, the mean value for the halothane content had dropped from 0.8 to 0.4 ppm, whereas the mean value for the ethanol content had risen from 0.4 to 2.3 ppm. Thus ethanol exposure was significant also after the conclusion of anesthesia and was not restricted to the anesthetic and surgical phases.

Tables 2 and 3 show that the method used for administering anesthesia affects the exposure of anesthetic nurses. The administration of volatile anesthetics via a face mask produced heavier exposure than administration via a tracheal tube. Non-rebreathing anesthetic systems resulted in greater exposure of the anesthetic staff than systems with partial rebreathing. Moreover, exposure tended to be greater when the patient breathed spontaneously than when his respiration was controlled. These differences were more striking in the respiratory zone of anesthetic nurses than in the area immediately outside this zone.

Ethanol exposure did not display such a regular pattern. However, the ethanol concentrations in the corresponding samples taken from mobile and stationary samplers were always on about the same level. This finding suggests that ethanol in the work zones of the operating staff was rather well-mixed with the room air.

In tables 4 and 5 exposure to halothane and ethanol is related to the standard of general ventilation in the operating rooms according to a personal communication from L. Olander. The standard of general ventilation had no decisive effect on the concentration of halothane in the respiratory zones of the operating staff when the anesthetic was administered via a face

Table 6: The effect of local exhaust, close to the pop-off valve of the anesthetic machine, on the airborne concentrations (ppm) of halothane and ethanol.

A. Akademiska Hospital, Central Operating Department. (General ventilation system in operation)

Local exhaust	Anesthetic nurses				Surgical nurses			
	Mobile		Stationary		Mobile		Stationary	
	Halo- thane	Ethanol	Halo- thane	Ethanol	Halo- thane	Ethanol	Halo- thane	Ethanol
On	0.1	1.7	0.2	1.8	0.0	2.0	0.0	1.5
Off	0.8	2.2	1.0	3.6	0.5	1.9	0.5	1.4
Total	0.4	1.9	0.5	2.5	0.1	2.0	0.2	1.5

B. Karolinska Hospital, Department of Pediatric Surgery.

Local exhaust	General ventilation	Anesthetic nurses				Surgical nurses			
		Mobile		Stationary		Mobile		Stationary	
		Halo- thane	Ethanol	Halo- thane	Ethanol	Halo- thane	Ethanol	Halo- thane	Ethanol
On	Off	36.5	28.5	15.6	28.4	12.5	24.8	12.7	24.8
Off	On	31.1	4.8	3.2	4.1	5.0	9.7	5.1	7.0
Total		34.0	17.5	9.2	15.8	9.2	18.2	9.4	17.0

Fig. 2. Concentrations of ethanol and halothane in end-expired air during and after exposure to 58 ppm of ethanol or 32 ppm of halothane (exposure between the arrows).

of operating staff to anesthetic gases have been suspected for a long time (21, 36, 48, 67), efforts made to evacuate airborne anesthetics were primarily justified by a need to eliminate the risk of explosion (13, 24) and unpleasant odor (42). In the past

decade the development of more efficient ventilation systems for operating rooms was given great impetus by discoveries of an increased incidence of pregnancy complications (5, 15, 16, 37, 38, 53, 65) and malignant diseases (12, 20) in occupational groups exposed to anesthetic gases.

Operating staffs are exposed not only to anesthetic gases but also to ethanol, a volatile component in the disinfectants used. Ethanol vapor is more evenly distributed in the operating room than anesthetic gases. Therefore, exposure to ethanol is similar for both anesthetic and surgical personnel. This exposure is not merely limited to the anesthetic and surgical phases themselves, but can be considerable even after the conclusion of surgery. This is apparently because disinfectants containing ethanol are employed by both surgical and anesthetic personnel in the subsequent treatment of patients and the cleansing of instruments.

If it is assumed that about 60 % of the ethanol inhaled is resorbed, a continuous 15 ppm concentration of ethanol in alveolar air (an extreme value in the present

study) corresponds to resorption of only about 25 mg of ethanol per hour. Since an average adult can metabolize about 10 ml (i.e., 8,000 mg) of ethanol per hour (52), the exposure to ethanol cannot be regarded as critical for the operating staff. It is obvious that the small amounts of ethanol inhaled are rapidly eliminated due to the metabolic capacity of the body. However, ethanol should be regarded as an indicator of the presence of volatile disinfectant components, and their spread through the room atmosphere should be kept in mind when the ventilation of operating rooms is designed.

The elimination of halothane is considerably slower than that of ethanol. After an initially rapid elimination, low residual concentrations are demonstrable in end-expired air for a long time. This finding is in agreement with the results reported by Whitcher et al. (68), who found low residual concentrations in many individuals 16 h after exposure. This slow decay is not specific for halothane, but has also been demonstrated for, e.g., methoxyflurane (18).

The fact that the exposure of operating staffs to anesthetic gases is influenced by the anesthetic method has been noted earlier (6, 55). The dissemination of anesthetic gases is easier to control when the gases are supplied via a tracheal tube instead of a face mask, when the patient's respiration is controlled rather than spontaneous, and when rebreathing or partial rebreathing anesthetic systems are employed instead of non-rebreathing systems. Thus in the anesthetic routines it is reasonable also to take into consideration occupational hygiene as, e.g., Feychting et al. (26) and Mostert (44) have emphasized.

The effective ventilation of airborne pollutants in an operating room calls for good general ventilation in conjunction with local exhaust close to the sources of anesthetic gas leakage. General ventilation mainly affects the concentration of substances well-mixed with room air. Thus good general ventilation is a requirement for the elimination of, e.g., volatile disinfectant components, such as ethanol, and anesthetic vapor which has spread beyond the actual work zones. On the other hand, general ventilation only

has a limited effect on the concentration of anesthetic gas close to the source of leakage near which the respiratory zone of anesthetic staff is located.

A number of technical systems have been described which facilitate the ventilation of anesthetic gases from sources of leakage (4, 8, 9, 11, 13, 14, 17, 23, 25, 36, 40, 41, 43, 48, 50, 54, 62, 70). Diverting the anesthetic gases via a tube to the floor fails to produce any satisfactory reduction in the exposure of staff (10, 31). Anesthetic gases should be extracted from the operating room so that there is no risk of recirculation or translocation to adjacent rooms (64).

Certain anesthetic gases can be filtered out of recirculated air with an activated charcoal filter (2, 24, 33, 42, 55, 60, 61, 66). However the view that such a filter, "should prove more satisfactory than merely venting anaesthetic vapours to the exterior," (22) is open to doubt. These filters have a limited capacity, and even the most scrupulously maintained filter system is incapable of blocking the passage of nitrous oxide, which is regularly used in high concentrations in conjunction with other anesthetic gases. Therefore, filter systems should be regarded as supplements to direct evacuation systems, but they are no adequate substitute.

Efficient venting of anesthetic gases right at the source of leakage generally results in a very significant reduction in the concentration of airborne anesthetics (6, 11, 18, 49, 68). However, a local exhaust system obviously does not eliminate the need for general ventilation. If local exhaust systems are to achieve the optimum effect, the evacuation nozzles must be correctly designed and located, and they must produce suction appropriate to other ventilation. In addition, the venting system must not change the function of the anesthetic machine. Staff exposure to anesthetic gases could even increase when ventilation is turned on, if the ventilation is not properly designed (63).

In addition to nitrous oxide, halothane has been the most widely used anesthetic for more than a decade. This circumstance, plus the fact that most studies of airborne anesthetics in operating rooms have been performed in conjunction with halothane anesthesia, has led to a tendency to link

the risks presented by chronic exposure to anesthetics to the substance halothane. This tendency could trigger increased interest in replacing halothane with other volatile anesthetics in the belief that occupational risks would thereby be reduced. However, halothane should only be regarded as a substance indicating the manner in which anesthetic gases can spread into the work zones of the operating staff.

All anesthetic gases should be treated with the same respect. There is no evidence that occupational risks are linked, e.g., to the halogen component in modern volatile anesthetics. Animal experiments have shown that it is possible to induce teratogenic effects not only with halogenated substances such as halothane (7, 35, 58, 69) and methoxyflurane (58), but also with nitrous oxide (19, 27, 51, 59), diethyl ether (57) and cyclopropane (1). Vaismann (65) found a very high incidence of pregnancy complications among female Russian anesthesiologists who had mainly been exposed to diethyl ether at the time of his study.

Special safety regulations have recently been introduced in Sweden in order to reduce the exposure of medical staff to anesthetic gases (3). Since measurable levels of anesthetic gases have been found even outside operating rooms (49, 64), the new regulations make it necessary for general ventilation to meet certain minimum requirements not only in operating rooms but also in anesthetic induction rooms and recovery rooms. Operating rooms and anesthetic induction rooms must also be supplied with equipment making possible local exhaust of anesthetic gases. In operating rooms satisfying the ventilation standards set, the time-weighted exposure of the medical staff should be far less than 250 ppm for nitrous oxide and 5 ppm for halothane under normal conditions (47).

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