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Implications of a Work-Site Smoking Cessation Program

Workplace Violence: Preventive and Interventive Strategies

Overtime Work and Blood Pressure

Hydrogen Sulfide Inhalation and Pulmonary Function

# Measurement and Reduction of Nitrous Oxide in Operating Rooms

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*In a program designed to lower exposure to anesthetic gases, nitrous oxide in the breathing zone of anesthesiologists was continuously monitored by means of a direct reading apparatus and a specially designed collar. Initially, the average concentration during anesthesia in intubated patients, determined in 30 operating rooms of seven hospitals, was 68 ppm. During mask anesthesia in children, it was 407 ppm (nine operating rooms, nine hospitals). The main hygienic measures were: a check of the anesthesia apparatus, improvement of the general ventilation in the operating room, and the application of a "double mask." With a combination of measures, the concentration during anesthesia in intubated patients was reduced from 61–90 ppm to 2–15 ppm. During mask anesthesia in children, the concentration decreased from 134–764 ppm to 9–42 ppm. The monitoring system used reveals important differences in the exposure during the separate phases of the anesthesia (induction, maintenance, and extubation). It also indicates which factors determine the exposure of the anesthetist and allows accurate determination of the personal exposure.*

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In several studies in anesthetists, an increased incidence of spontaneous abortions and congenital malformations in their offspring were reported.[1–4] In a department in *The Journal of Occupational and Environmental Medicine*, Perry[5] suggested that bias might have played a role in the questionnaire studies that showed an adverse effect on health. However, even if these studies are considered as only an indication that anesthetics produce adverse effects, it is prudent to apply available methods to diminish the exposure to these substances.

Many investigators have measured the nitrous oxide concentration present in operating rooms under different conditions. "Averaging" systems using absorbent materials fixed on the person have been used, as well as "direct reading" gas analyzers that sample from a fixed location more or less close to the person. Of the more recent studies investigating the effects of hygienic measures in balanced anesthesia in adults, two- to fivefold reductions of $N_2O$ concentration were reported.[6–12] Reiz et al[13] were the first to report the use of a double mask and measured 15 ppm in front of the anesthetist's face during inhalation anesthesia, compared with 145 ppm in similar situations in which the conventional mask was used. A problem with the interpretation of these studies is that the extent of the reported or estimated reductions depends on many other parameters in each situation, so there is little indication of the minimum exposure that can be reached during an anesthesia by a combination of measures.

The value of $N_2O$ recommended by the National Institute for Occupational Safety and Health[14] is 25 ppm, primarily to prevent "decrements in performance, cognition, audiovisual ability and dexterity."

In our opinion, the most informative method to measure $N_2O$ exposure should use a sampling probe fixed to the worker at mouth level (for accurate determination of the exposure) combined with a direct reading instrument to supply clues for causes of high exposure and for appropriate measures. Such a technique was used by Pothmann et al,[15] but they reported only an "exposure index" based on all anesthetics.

The study described here was done at the request of the management of nine hospitals to determine the exposure of anesthetists to nitrous oxide and to check the efficiency of hygienic measures that were recommended after the initial investigations.

## Methods

Measurements of $N_2O$ concentrations were performed during 174 anesthesias in which $N_2O$ was used, in 39 operating rooms in nine hospitals. During the first part of the study, 90 measurements were carried out in the original situation. Based on these findings, measures were recommended to lower the $N_2O$ concentrations. To evaluate the efficiency, 72 follow-up measurements were performed in 26 operating rooms in six hospitals involving 26 anesthetists. To be able to make valid comparisons, only two types of anesthetic procedures were studied. The first was "balanced anesthesia" in adults, which consists of three phases. The first phase is an induction with a short-acting intravenous anesthetic agent, followed by administration of a $N_2O/O_2$ mixture (80/20% by volume) by means of a face mask, and insertion of an endotracheal tube in the trachea of the patient. During the second, "peroperative" (during the operation) phase, the lungs of the patient are ventilated with a $N_2O/O_2$ mixture (66/33% by volume) together with a volatile anesthetic. At the end of the surgical procedure, the anesthetic gases are turned off and, when the patient is awake and breathing spontaneously, the endotracheal tube is removed (extubation phase). The operation chosen for this study was that which was most frequently carried out in each hospital and which usually took approximately 1 hour.

The second type of anesthetic procedure was mask anesthesia in children undergoing tonsillectomy according to Sluder's technique, adenoidectomy, drainage of the middle ear, or a combination of these. During the induction and peroperative phase, $N_2O$ (66 to 80%), oxygen, and halothane were administered by means of a face mask. The anesthesia is concluded by administration of 100% oxygen ("prerecovery phase").

Athough all anesthetic apparatus had an evacuation system, no special scavenging device was available. Most of the apparatus had a high-flow, half-open system. In each hospital, the measures were done in two to five identical operating rooms.

### Measurements

Air was continuously sampled in the breathing zone of the anesthetist by means of a "collar" made of a silicone tube (inner diameter, 12.5 mm) connected via a Y-shaped piece and a 4-m-long tube of the same diameter as the silicone tube to an infrared gas analyzer (Miran 1B; Foxboro, East Bridgewater, MA) fitted with a particulate filter. The flow was 18 L/min. The front of the collar was perforated by 35 holes with a total surface of 110 mm.$^2$ The collar was fixed behind the subject in such a way that the air sampling took place at chin level. Silicon rubber was used because its flexibility allows the anesthetist to perform his activities in the usual way. Absorbance of $N_2O$ by the silicon tube appeared to be small and did not affect the results.

The stated detection limit of the Miran analyzer for $N_2O$ was 0.3 ppm; above 1.5 ppm, the accuracy of the analyzer was better than 15% and the reproducibility (coefficient of variation: SD/mean) was <3%. Calibration was done yearly; no adjustments were required. Every 3 seconds, the concentration was plotted on a x-y recorder. The time-weighted average (TWA) concentration was computed for the three phases of anesthesia separately and for the total procedure.

### Hygienic Measures

Based on the preintervention measurements and inspection of the apparatus and facilities, all measures that could contribute to a reduction of the exposure were recommended; only one of these recommendations required a financial investment, namely, the purchase of a double mask.

The recommendations fell into four classes.

1. General measures. These consisted of repair of defects. The following measures were taken in half or more of the operating rooms ($n$ = 39): *anesthesia apparatus*—elimination of leakage at the $N_2O$ connector, adjustment of underpressure of the evacuation system, elimination of leakage at the point of connection of the endotracheal tube with the rebreathing tube and from the trachea by adjustment of the cuff-pressure of the endotracheal tube, and cleaning and applying petroleum jelly on the conical connections of canisters; *capnograph*—connection of the outlet for gas sampling to the evacuation system; *ventilation*—increase of the ventilation rate of the operating room up to 22 changes/hour.
2. Use of the double mask. The double mask (MEDICVENT AB, Umea, Sweden) can be consid-

**TABLE 1**
Balanced Anesthesia: Personal Monitoring of Concentrations (ppm) During the Three Phases of Anesthesia*

| Hospital | Duration of Each Phase (min) | Condition | n | Phase: Induction | Phase: Peroperative | Phase: Extubation | Total Anesthesia |
|---|---|---|---|---|---|---|---|
| 4 | 3-60-7 | O | 6 | 200 ± 43 | 66 ± 3 | 240 ± 42 | 90 ± 5 |
| | | DM | 6 | 0 ± 0 | 5 ± 1 | 100 ± 21 | 15 ± 2 |
| 1 | 3-62-5 | O | 7 | 366 ± 157 | 34 ± 5 | 210 ± 18 | 61 ± 9 |
| | | GM,DM | 4 | 15 ± 1 | 10 ± 2 | 90 ± 6 | 16 ± 1 |
| | | GM, WN | 3 | 0 ± 0 | 10 ± 1 | 210 ± 13 | 21 ± 1 |
| | | GM,DM,WN | 3 | 0 ± 0 | 10 ± 2 | 90 ± 4 | 15 ± 2 |
| 2 | 3-52-5 | O | 3 | 290 ± 48 | 45 ± 3 | 177 ± 15 | 68 ± 3 |
| | | GM,DM | 4 | 20 ± 1 | 7 ± 1 | 30 ± 11 | 10 ± 1 |
| | | GM, WN | 2 | 0 ± 0 | 7 ± 1 | 180 ± 1 | 21 ± 0 |
| | | GM,DM,WN | 3 | 0 ± 0 | 7 ± 2 | 29 ± 3 | 9 ± 2 |
| | | GM,DM,WN,AI | 4 | 0 ± 0 | 2 ± 1 | 10 ± 2 | 2 ± 1 |
| 3 | 5-175-9 | O, No measures | 7 | 278 ± 120 | 54 ± 7 | 239 ± 56 | 69 ± 7 |
| 7 | 4-58-6 | O, No measures | 4 | 0 ± 0 | 36 ± 3 | 457 ± 95 | 71 ± 11 |
| 8 | 4-76-6 | O, No measures | 6 | 450 ± 63 | 475 ± 45 | 358 ± 21 | 465 ± 39 |
| 9 | 3-50-7 | O, No measures | 7 | 166 ± 26 | 6 ± 1 | 124 ± 10 | 27 ± 2 |

* Mean scores ± SD. O, original situation; GM, general measures; DM, double mask; WN, induction without nitrous oxide; AI, additional instruction; *n*, number of operations.

ered a local scavenging system. It consists of a flexible inner mask, through which the anesthetic gas-mixture is administered, within a rigid outer mask. A suction unit connected to the space between the masks removes the anesthetic gases that escape between the face and the mask. In the *induction phase,* the mask must be used conventionally. During intubation, it must be kept close to the patient's mouth and nose: the suction removes the escaping gas flow (which preferably should be interrupted) as well as the nitrous oxide exhaled by the patient. In this way, the anesthestist is protected from both sources. In the *peroperative phase*, the double-mask must be disconnected from the combined administration/scavenging system after intubation. The administration tube, which is situated centrally in the suction tube, must then be connected to the conical connector of the endotracheal tube. The suction removes possible leakage from the connector and from the patient's airways (leakage along the cuff or by diffusion through the cuff); it also protects the surgeon when operating on the head. In the *extubation phase*, immediately after disconnecting the patient from the anesthetic apparatus, the double mask must be reinstalled and kept close to the patient's mouth and nose to remove the exhaled gases. One hospital (number 3) didn't apply the double mask for balanced anesthesia because of financial reasons.

3. Training. All anesthetists were briefly instructed in the use of the double mask. In three hospitals, the anesthetists were eager to further improve their techniques with the help of additional instruction.
4. Induction without $N_2O$. This recommendation was followed in three hospitals.

Several combinations of measures were utilized, eg, general measures and the double mask.

## Results

The concentrations of nitrous oxide before and after hygienic measures had been taken are shown in Tables 1 and 2. In six hospitals, for balanced anesthesia, the durations of the induction, peroperative, and extubation phases were on average 3 ± 0.5 min, 60 ± 9 min, and 6 ± 1 min (mean ± SD). For mask anesthesia in children, the duration of the corresponding phases was 2.5 ± 0.5 min, 5.5 ± 1 min, and 1 ± 0 min. One hospital (number 3) had outlying durations. The durations of the phases in the original situation and after following the various suggested measures were essentially the same. The prevailing situation in the operating rooms was studied two to seven times.

For the "balanced anesthesia," the $N_2O$ in a specific situation varied little between operations (Table 1). At concentrations of less than 20 ppm, the standard deviation was usually only a few parts per million. Above 20 ppm, the coefficient of variation was about 30% for the induction phase, 10% for the peroperative phase, and 20% for the extubation phase. For mask anesthesia in children, the coefficient of variation was, with a few exceptions, below 15%, irrespective of the phase of the anesthesia (Table 2).

**TABLE 2**
Mask Anesthesia in Children: Personal Monitoring of Concentrations (ppm) During the Three Phases of Anesthesia*

| Hospital | Duration of Each Phase (min) | Condition | n | Phase: Induction | Phase: Peroperative | Phase: Prerecovery | Total Anesthesia |
|---|---|---|---|---|---|---|---|
| 6 | 2-6-1 | O | 5 | 1547 ± 189 | 600 ± 53 | 180 ± 11 | 764 ± 60 |
| | | GM,DM | 5 | 50 ± 3 | 21 ± 4 | 10 ± 2 | 26 ± 2 |
| 9 | 2-3-1 | O | 5 | 410 ± 38 | 303 ± 19 | 103 ± 6 | 306 ± 12 |
| | | GM,DM | 6 | 13 ± 4 | 23 ± 5 | 20 ± 4 | 20 ± 3 |
| 1 | 3-6-1 | O | 5 | 1306 ± 108 | 180 ± 16 | 80 ± 9 | 506 ± 31 |
| | | GM,DM | 4 | 90 ± 6 | 22 ± 2 | 8 ± 5 | 42 ± 6 |
| 2 | 2-7-1 | O | 5 | 290 ± 78 | 100 ± 25 | 60 ± 8 | 134 ± 11 |
| | | GM,DM | 4 | 90 ± 3 | 25 ± 3 | 10 ± 2 | 37 ± 3 |
| | | GM,DM,AI | 4 | 9 ± 3 | 11 ± 2 | 5 ± 1 | 10 ± 1 |
| 3 | 10-4-2 | O | 6 | 402 ± 14 | 228 ± 20 | 210 ± 11 | 335 ± 7 |
| | | GM,DM | 5 | 80 ± 7 | 25 ± 3 | 12 ± 4 | 58 ± 4 |
| | | GM,DM,AI | 5 | 7 ± 2 | 15 ± 3 | 7 ± 1 | 9 ± 1 |
| 4 | 2-6-1 | O | 5 | 1025 ± 50 | 240 ± 31 | 160 ± 14 | 407 ± 25 |
| | | GM,DM | 5 | 90 ± 7 | 30 ± 3 | 15 ± 4 | 42 ± 3 |
| | | GM,DM,AI | 5 | 8 ± 1 | 10 ± 3 | 5 ± 1 | 9 ± 2 |
| 5 | 3-6-1 | O, No measures | 6 | 498 ± 172 | 70 ± 4 | 20 ± 2 | 193 ± 52 |
| 7 | 3-5-1 | O, No measures | 6 | 280 ± 19 | 50 ± 7 | 28 ± 5 | 212 ± 15 |
| 8 | 3-6-1 | O, No measures | 7 | 533 ± 145 | 366 ± 70 | 220 ± 43 | 401 ± 89 |

* Mean scores ± SD. Abbreviations are defined in the footnote to Table 1.

## Balanced Anesthesia

In the original situation, one hospital (number 8) had exceptionally high concentrations of nitrous oxide, resulting in a TWA concentration for the complete anesthesia of 465 ± 39 ppm. In the other six hospitals, the TWA concentration was, on average, 64 ppm. In no hospital was the concentration below the 25-ppm value recommended by the National Institute for Occupational Safety and Health (Table 1).

In comparing the three phases of anesthesia, hospital 8 was excluded because of its abnormal pattern; the induction phase of hospital 7 was excluded because no $N_2O$ was used. The induction and extubation phases were associated with much higher concentrations (260 ± 79 ppm and 241 ± 114 ppm, respectively) compared with the peroperative phase (40 ± 21 ppm).

## Effect of Hygienic Measures

Because this study was performed primarily to determine the lowest concentrations that could reasonably be achieved by a combination of measures, the data do not always permit the evaluation of the effect of a single measure.

*General Measures.* General measures were effective for the peroperative phase and caused a reduction from 34 to 10 ppm (hospital 1) and from 45 to 7 ppm (hospital 2). An effect on the induction cannot be judged because the general measures were combined with induction without $N_2O$ or with the double mask.

*Double Mask.* The effect of the double mask as the only measure during balanced anesthesia was clearly seen in hospital 4: a reduction to zero, 5, and 100 ppm for the three phases of anesthesia, and from 90 to 15 ppm for the TWA concentration. During the intubation phases in hospitals 1 and 2, the double mask in combination with general measures reduced the concentrations to 15 and 20 ppm, respectively. We are convinced that these values could have been lower if the double mask had been used according to the instructions that we had provided. Furthermore, its effect appears during the extubation phase (a phase when general measures alone had no effect): a decrease from 210 to 90 ppm (hospital 1) and from 177 to 30 ppm (hospital 2). Additional instruction added to the effectiveness of the double mask, resulting in a further lowering of the concentrations to 10 ppm during the extubation phase and from 7 to 2 ppm during the peroperative phase (hospital 2).

*Combinations of Measures.* The minimum TWA concentrations reached with general measures and use of the double mask were 10, 16, and 15 ppm (originally 68, 61, and 90 ppm for hospital 2, 1, and 4, respectively). After these measures, omitting $N_2O$ from the induction phase had no effect on the TWA concentration. Maximal effective application of the double mask resulted in a TWA concentration as low as 2 ppm (hospital 2).

## Mask Anesthesia in Children

In the original situation, during the induction, peroperative, and prerecovery phases, the average concentrations were 699 ± 471 ppm, 237 ± 172 ppm, and 118 ± 79 ppm, resulting in TWA concentrations for the total anesthesia of 134 to 764 ppm (average, 362 ± 191 ppm) (Table 2).

During the induction phase, the concentrations were lowered initially to an average of approximately 69 ppm (all hospitals); after additional instruction and improved procedures, the concentrations were lowered to approximately 8 ppm (three hospitals). During the peroperative phase, the value initially reached was 24 ppm on average; after instruction, the value was 12 ppm. For the complete anesthesia, this finally resulted in 9 to 10 ppm (all hospitals).

## Discussion

Studies with an intervention design, in which a single measure was introduced, found reductions to only 71 ppm,[7] 20 ppm,[8] or 45 ppm;[9] application of the double mask resulted in a value of 15 ppm.[12] By using a combination of measures, we reached values of 2 to 15 ppm (three hospitals) for balanced anesthesia.

Studies in which a cross-sectional design was used and in which the effect of single measures was estimated[10,12] do not allow a prediction of the concentration after the introduction of combinations of measures. To our knowledge, no other investigators evaluated the combined effect of several measures in a intervention-type study.

Our study shows that the concentrations of $N_2O$ to which anesthetists are exposed can be considerably reduced. Thanks to this strong effect and the relatively small variations in the concentrations in a specific situation, the decreases achieved are statistically significant despite the small number of observations. In one hospital, a TWA concentration as low as 2 ppm was reached. The anesthetists in this hospital made considerable efforts to refine their anesthesia techniques to reduce the exposure.

As far as mask anesthesia in children is concerned, no other studies are available. By using a combination of general measures, double masks, and additional instruction, we succeeded in lowering the TWA concentrations from 134, 335, and 407 ppm to 10, 9, and 9 ppm, respectively.

In our opinion, a reasonable evaluation of the variable exposure to anesthetic gases during anesthesia and the effect of a program of preventive measures can only be based on measurements that are both continuous and that reflect personnel exposure. This study shows that careful application of a combination of hygienic measures can considerably reduce the concentrations of $N_2O$ in operating rooms.

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