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Occupational Disease among Operating Room Personnel:

A National Study

Report of an Ad Hoc Committee on the Effect of Trace Anesthetics on the Health of Operating Room Personnel, American Society of Anesthesiologists*

A national study of occupational disease among operating room personnel was conducted by mailing questionnaires to 49,585 exposed operating room personnel in four professional societies and to 23,911 unexposed individuals in two professional societies serving as a comparison group. The results indicate that female members in the operating room-exposed group were subject to increased risks of spontaneous abortion, congenital abnormalities in their children, cancer, and hepatic and renal disease. This increased risk of congenital abnormalities was also present among the unexposed wives of male operating room personnel. No increase in cancer was found among the exposed males, but an increased incidence of hepatic disease similar to that in the female was found. Although the present study does not establish a cause–effect relationship between the increases in these diseases and exposure to the waste anesthetic gases in the operating room, considerable evidence in the experimental animal suggests such a relationship. It is therefore reasonable to assume that this relationship may also apply to the clinical situation. In consideration of the potential health hazards involved, a strong recommendation is made for the venting of waste anesthetic gases in all anesthetizing locations. (Key words: Toxicity: trace concentrations; Equipment: exhaust systems; Operating rooms: exhaust systems; Anesthetics, volatile: trace concentrations; Anesthetics, gases: trace concentrations.)

* *Chairman*, Ellis N. Cohen, M.D., Professor of Anesthesia, Stanford University; Byron W. Brown, Ph.D., Professor of Biostatistics, Community and Preventive Medicine, Stanford University; David L. Bruce, M.D., Associate Professor of Anesthesia, Northwestern University; Helmut F. Cascorbi, M.D., Ph.D., Professor of Anesthesiology, Case Western Reserve University; Thomas H. Corbett, M.D., Assistant Professor of Anesthesia, University of Michigan; Thomas W. Jones, D.D.S., Professor of Clinical Dentistry, University of Alabama; Charles E. Whitcher, M.D., Associate Professor of Clinical Anesthesia, Stanford University.

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Send reprint requests to: Department of Anesthesia, Stanford University, 300 Pasteur Drive, Stanford, California 94305.

THE PRESENT REPORT, prepared by the American Society of Anesthesiologists Ad Hoc Committee on Effects of Trace Anesthetic Agents on Health of Operating Room Personnel, summarizes a two-year effort to investigate the health experience of anesthesia and operating room personnel in the United States. Preliminary studies in Russia, Denmark, the United Kingdom, and the United States had suggested that an increased rate of spontaneous abortion was to be found among women working in operating rooms and presumably exposed to waste anesthetic gases. A number of animal studies have supported this suspicion and further suggest that if abortions are caused by anesthetics, they should be considered in the larger context of mutagenesis, teratogenesis, and carcinogenesis.

Interest in this question has been considerable, and the problem has received careful review by the National Research Council Ad Hoc Committee on Adverse Reactions to Anesthetic Agents, and the Scientific Advisory Council for the Association of University Anesthetists. Strong interest has also been shown by governmental agencies, principally by the National Institute for Occupational Safety and Health (NIOSH). In June 1972, a workshop was convened in Salt Lake City under the auspices of NIOSH to discuss the problem. At this meeting, attended by representatives of government, members of professional anesthesia societies, health and hospital associations, and involved scientists,

a unanimous recommendation was made for initiation of a national study to define the problem as precisely as possible. Following completion of the study, a criteria document would be issued establishing standards and recommendations for control. An Ad Hoc Committee was appointed by the American Society of Anesthesiologists (ASA) and charged with preparation of a study protocol to be submitted to NIOSH for approval and funding. Preparation of the protocol was quickly accomplished, and on October 16, 1972, a contract for a two-phase study to investigate the health of operating room personnel was signed by the ASA and by NIOSH.

A questionnaire was designed and mailed to 73,496 individuals,† including the entire memberships of the American Society of Anesthesiologists, the American Association of Nurse Anesthetists, the Association of Operating Room Nurses, and the Association of Operating Room Technicians. These individuals represent essentially all personnel in the United States who are continuously exposed to trace anesthetics in the operating room environment. Questionnaires were also mailed to the membership of the American Academy of Pediatrics and to a segment of the membership of the American Nurses Association, which served as comparison groups. These mailings took approximately six weeks. Three months later, a second mailing was sent to those individuals failing to respond to the original questionnaire.

During the next six months statistical analyses of the preliminary data were reviewed on several occasions at executive sessions of the Ad Hoc Committee attended by a number of invited consultants. A complete tabulation of the then-available data was made during the summer of 1973. It seemed apparent, even at that stage of analysis, that a number of important positive findings were present. These were considered serious enough to warrant a preliminary release of the committee findings, coupled with a strong recommendation to initiate operating room anesthetic scavenging procedures as rapidly as possible.

Despite the strength of these positive findings, several deficiencies were uncovered in this early analysis. Concern was expressed regarding the large percentage of non-respondents (45 per cent), and it was considered essential to define the characteristics of this non-responding group. Accordingly, personal letters were addressed and telephone calls attempted to each non-responding woman member of the pediatric society. This group was selected for representative analysis because of its geographic stability, and because additional data were needed in this relatively small but important control group.

Final questionnaires were accepted by February 15, 1974, and a detailed analysis of the data carried out in the succeeding weeks. Although the information presented in the current report does not provide unequivocal evidence concerning the several occupational diseases studied, it seems likely that a number of serious environmental problems do exist in the operating room. Corrective measures are indicated, and appropriate steps have been carefully considered. These are described below.

Finally, although specific health hazards are designated, no data which allow us to prove a direct cause–effect relationship between them and trace concentrations of anesthetic gases are presently available. Considerable supportive evidence is to be found in experimental animal data, but human studies do not exist. This emphasizes the importance of the second phase of the study, which is planned for 1978. By that time it is assumed that the proportion of personnel working in ventilated and anesthetic-scavenged operating rooms will have increased from the present 21 per cent to almost 100 per cent. At that time, if the results of the second survey indicate reduction in the incidences of the reported problems to control levels, we can more safely assume that the anesthetic gases are indeed the causative agents. However, even before such evidence becomes available, the Ad

† Later mailings were also made to the American Society of Oral Surgeons and to a segment of the American Dental Association, which add 7,791 more individuals to the study. These data are being analyzed separately and will be the subject of a second report.

Hoc Committee strongly urges that all operating rooms be cleaned of trace concentrations of anesthetic gases.

Background

The discovery of an occupational disease frequently results from the identification of clusters of specific disease entities among individuals engaged in similar occupations or environments, followed by isolation of the offending agent in the laboratory.

In 1967, Vaisman[1] surveyed 303 Russian anesthesiologists and reported an unusually high incidence of headache, fatigue, irritability, nausea, and pruritus. He also noted that 18 of 31 pregnancies among the female anesthesiologists ended in spontaneous abortion. In addition, two of the pregnancies ended in premature delivery and one in congenital malformation.

In 1968, Bruce *et al.*[2] published a study of the causes of death among anesthesiologists over a 20-year period. This survey revealed a trend toward higher than normal incidences of death from reticuloendothelial and lymphoid malignancies. It was based on 441 deaths among members of the American Society of Anesthesiologists from 1947 to 1966. In 1969, Li *et al.*[3] similarly studied the causes of death among chemists, and found a higher proportion of deaths from cancer than among other professional men. Nearly half the excess cancer deaths were attributable to malignant lymphomas and cancer of the pancreas. This excess mortality may relate to the exposure to noxious chemicals in a fashion comparable to that for the anesthetist.

In 1970, Askrog and Harvald[4] reported a high rate of spontaneous abortion among anesthetists in Denmark. Their study revealed that approximately 20% of all pregnancies ended in spontaneous abortion, compared with a rate of approximately 10 per cent among the same group prior to operating room employment. In 1971, Cohen *et al.*[5] reported a 38 per cent abortion rate among physician anesthetists and a 30 per cent abortion rate among operating room nurses, with a 10 per cent abortion rate for control groups of other female physicians or general duty nurses. Miscarriages occurred earlier in gestation in both operating room nurses and anesthetists, compared with their control groups. These results suggested a fetal lethality, possibly due to anesthetic gases, although the studies did not incriminate any specific anesthetic agents, nor was a cause–effect relationship established.

In 1972, Knill-Jones *et al.*[6] studied 563 married women anesthetists and 828 nonanesthetist married women doctors, and found the frequency of spontaneous abortion to be higher (18.2 per cent) when the anesthetists were working, than when they did not work (13.7 per cent). The miscarriage rate in the control group was 14.7 per cent. The incidence of congenital anomalies was also higher when the mother worked, and 12 per cent of anesthetists and 6 per cent of the controls suffered involuntary infertility.

In 1973, Corbett *et al.*[7,8] surveyed 621 female nurse-anesthetists in Michigan. The incidence of malignancy among the group was three times the expected rate. This survey also revealed a high incidence of birth defects among children of the nurse-anesthetists. The overall incidence of congenital anomalies was significantly higher when the mother practiced during pregnancy than when the mother did not practice (16 vs. 6 per cent).

Industrial toxicologists have been concerned for many years with the chronic exposure of workers to low concentrations of industrial chemicals and gases, and Threshold Limit Values (TLV)‡ have been established for a number of agents. The first documentation of occupational exposure of operating room personnel to anesthetic gases was reported in 1969, when Linde and Bruce[9] described peak levels of 27 ppm halothane and 428 ppm N_2O in the operating room. In 1970, Askrog and Petersen[10] reported average concentrations of 85 ppm halothane and 7,000 ppm N_2O in the inhalation zone of the anesthesiologist when a nonrebreathing system was used. In 1971,

‡ These concentrations were established by the American Conference of Government Industrial Hygienists (A.C.G.I.H.) and subsequently through the Occupational Safety and Health Act (O.S.H.A.), and represent time-weighted averages reflecting conditions under which it is believed that workers may be repeatedly exposed without adverse effect.

Corbett *et al.*[11] found levels of methoxyflurane in the operating room ranging from 2–10 ppm in the area of the anesthetist, and from 1–2 ppm around the surgeons. The latter authors demonstrated that methoxyflurane concentrations could be reduced significantly by the use of a gas trap placed over the pop-off valve which vented waste anesthetic gases to the wall suction. Later that year, Whitcher *et al.*[12] documented concentrations of halothane in the operating room environment and demonstrated a tenfold reduction in atmospheric contamination of the operating room through use of appropriate scavenging equipment, which shunted the waste gases into the operating room ventilation system outlet. Additional studies of atmospheric concentrations of N_2O[13] and of trichloroethylene[14] in the operating room followed.

Certain chemicals and environmental pollutants are known to be carcinogenic, teratogenic, mutagenic, and/or embryolethal. A systematic study of the carcinogenicity of anesthetic agents has not been done. The embryotoxic and teratogenic effects of anesthetic concentrations of inhalation agents have been well demonstrated in animal studies by Fink *et al.*,[15] Basford and Fink,[16] Smith *et al.*,[17] and others. This toxicity is manifested by increased fetal death rates and increased rates of congenital anomaly in the offspring of both mammalian and avian species.[18,19] The immunosuppressive effects of anesthetics have also been documented.[20] Bone marrow depression in humans from chronic exposure to N_2O has been demonstrated in leukemia patients by Eastwood *et al.*,[21] and in normal subjects by Parbrook.[22] Green[23] reported differences in toxicity from N_2O for various strains of rats by measuring leukocyte counts and DNA–RNA ratios of thymus tissue. The Long-Evans rat proved to be the most sensitive. Corbett *et al.*[24] demonstrated fetal lethality in Long-Evans rats exposed to low concentrations of N_2O during early pregnancy. Concentrations of the anesthetic in these studies ranged from 1,000 to 10,000 ppm. Bruce *et al.*[25] were unable to demonstrate toxic effects on pregnancy using low concentrations of halothane in mice, and Corbett *et al.*[26] were unable to demonstrate a toxic effect on pregnancy using low concentrations of methoxyflurane in Sprague-Dawley rats.

Evidence for the metabolism of a number of anesthetics was reviewed by Van Dyke and Chenoweth[27] in 1965. Since that time, the metabolic pathways of several anesthetic agents have been determined. Toxicity related to these anesthetics frequently appears to be associated with their metabolic degradation rather than the parent agent itself.

Studies by Stier *et al.*[28] and by Rehder *et al.*[29] demonstrated that metabolites of halothane could be recovered from the urine of patients as long as 20 days following anesthesia. In 1970, Holaday et al.[30] found long-term storage of methoxyflurane in patients, with excretion of metabolites for as long as 10 days following surgical anesthesia. Subsequent clinical studies by Corbett and Ball revealed the exhalation of N_2O as long as 56 hours after anesthesia.[13] Studies of the retention of anesthetic agents in anesthesiologists following routine occupational exposure have demonstrated traces of halothane in expired air for as long as 64 hours, methoxyflurane for 29 hours, and N_2O for 7 hours following the administration of clinical anesthesia. Increased fluoride ion concentration has been found in an anesthesiologist following 6½ hours of occupational exposure to methoxyflurane.[11]

It is not known whether long retention of low concentrations of these anesthetic agents is harmful. Cascorbi *et al.*[31] investigated the possibility of enzyme induction due to chronic exposure to low concentrations of anesthetic gases. There is a wide variation in the rates of metabolism of anesthetic agents from person to person,[32] and nonspecific stimulation of drug-metabolizing enzymes in laboratory animals by inhalation of anesthetic agents has also been demonstrated.[33,34] Chenoweth *et al.*[35] were able to demonstrate hepatomegaly and histologic changes in the livers of rats following chronic exposure of these animals to low concentrations of halothane or methoxyflurane. Bruce *et al.*[36] found focal lesions in livers of rats exposed daily to halothane and N_2O simultaneously for periods of six weeks.

Methods

The present study consisted of a survey of 49,585 operating room personnel whose names were supplied by their individual professional societies. The exposed personnel included members of the American Society of Anesthesiologists (ASA), the American Association of Nurse Anesthetists (AANA), and the Associations of Operating Room Nurses and of Operating Room Technicians (AORN/T). These individuals represent essentially all exposed operating room personnel in the United States. Their levels of anesthetic exposure, however, range from relatively high exposure among the physician anesthetists and nurse-anesthetists to substantially lower exposure among operating room nurses and technicians. Mail surveys of the four societies were carried out simultaneously with the permission and support of each society. Results from the operating room nurses and operating room technicians have been combined for all analyses. Two professional societies, the American Academy of Pediatrics (AAP) and the American Nursing Association (ANA), provided 23,911 individuals who served as an unexposed comparison group. Personnel within the study societies who reported that they were not working in the operating room (see below for details) provided further control groups.

A questionnaire was mailed to every member of each society, with the exception of the American Nursing Association, where a 10 per cent nationwide sample was used. The questionnaire consisted of a legal-size form printed on both sides (Fig. 1*A* and *B*). The forms were individually numbered, and as the responses were received, they were checked off address lists prepared by the societies. The data were edited for inadmissible replies, ambiguities, obvious errors, and missing data. Acceptable forms were keypunched into standard punch cards and entered into a 360/67 IBM computer. Xerox copies of unacceptable forms were returned to the respondents, with indications of deficiencies and a request for correction and return.

After the data were stored in the computer in a temporary file, they were again checked by computer for inconsistencies, missing data, inadmissible entries, and unusual responses. When possible, these deficiencies were corrected.

A second mailing was sent to those who did not respond to the first mailing. Responses to the second mailing were handled in the same manner, but first- and second-responder data were stored separately in the computer bank for comparison. A special study was carried out among the female members of the American Academy of Pediatrics, to determine whether the non-responders after two mailings in this group were different from those members who had responded to the first or second mailing. This study involved a third mailing, with follow-up telephone calls to those who did not respond to the mailing.

After the data from the several mailings had been edited, corrected, and stored in the computer in permanent files, the exposed and unexposed groups of respondents were compared to determine whether there were important differences in occurrence rates of five major characteristics: spontaneous abortion rate,§ congenital abnormality rate, cancer rate, hepatic disease rate, and renal disease rate. The rates for spontaneous abortion were based on the number of spontaneous abortions per 100 pregnancies reported over the last ten years (ignoring therapeutic abortions in both the numerator and denominator). Congenital abnormality rates were based on the number of liveborn babies with one or more reported abnormalities per 100 liveborn babies born over the last ten years. For male respondents, all rates refer to the pregnancies and liveborn babies of their spouses. With regard to disease, the rates were based on the number of cases diagnosed within the last ten years per 100 respondents.

Rates were standardized by the direct method[37] adjusted for both age and smoking in the case of spontaneous abortion and congenital abnormality rates, and age alone

§ Spontaneous abortion defined as the loss of the product of conception prior to the twentieth week of gestation.

EFFECTS OF WASTE ANESTHETICS ON HEALTH

File Number [0] (1 7)

Form Approved
OMB No 68 R1331

INSTRUCTIONS: This form should take only 5 to 10 minutes to fill out. Print numbers clearly in the appropriate boxes. Most answers require only a check. Please fill out both sides of the page.

Soc. Sec. No. [ ] (8 16) Birthdate: Mo [ ] Year 19[ ] (17 20) Sex: M [ ] F [ ] (21)

WORKING ENVIRONMENT: Check area of your primary assignment (only one check for each year)

Year	OR	ICU	OB	Dental	Other hospital duties	Not working in hospital	
1963							(22)
1964							(23)
1965							(24)
1966							(25)
1967							(26)
1968							(27)
1969							(28)
1970							(29)
1971							(30)
1972							(31)

If you have not worked in the OR during the past 5 years, disregard the next four questions:

Are your operating rooms air conditioned? ..... Yes [ ] No [ ] Don't Know [ ] (32)

Is this a recirculating ventilating system? ..... Yes [ ] No [ ] Don't Know [ ] (33)

Are overflow anesthetic gases currently exhausted from the OR? ..... Yes [ ] No [ ] Don't Know [ ] (34)

If yes, when was this system completed? ..... Month [ ] Year 19[ ] (35 38) Don't Know [ ] (39)

QUESTIONS CONCERNING YOUR OWN HEALTH:

Have you ever had cancer or leukemia? ..... Yes [ ] No [ ] (40)

If yes, year of onset ..... 19[ ] (41 42)

Diagnosis: site _____ type _____

Have you had other health problems during the past 10 years?

Liver? ..... Yes [ ] No [ ] (43) Diagnosis _____

Kidney? ..... Yes [ ] No [ ] (44) Diagnosis _____

Other? ..... Yes [ ] No [ ] (45) Diagnosis _____

QUESTIONS CONCERNING YOUR PREGNANCY HISTORY:

(For males, this section applies to your wife)

Have you been studied for infertility? ..... Yes [ ] No [ ] (46)

If yes, what was the diagnosis? _____

Was an abnormality found? ..... Yes [ ] No [ ] (47)

Total number of pregnancies ..... [ ] (48 49)

Total number of pregnancies and miscarriages in the past ten years ..... [ ] (50 51)

Additional comments after completing questionnaire: _____

NIOSH – 18 (CHe)
1/73

(Please turn page over)

FIG. 1A. Questionnaire form.

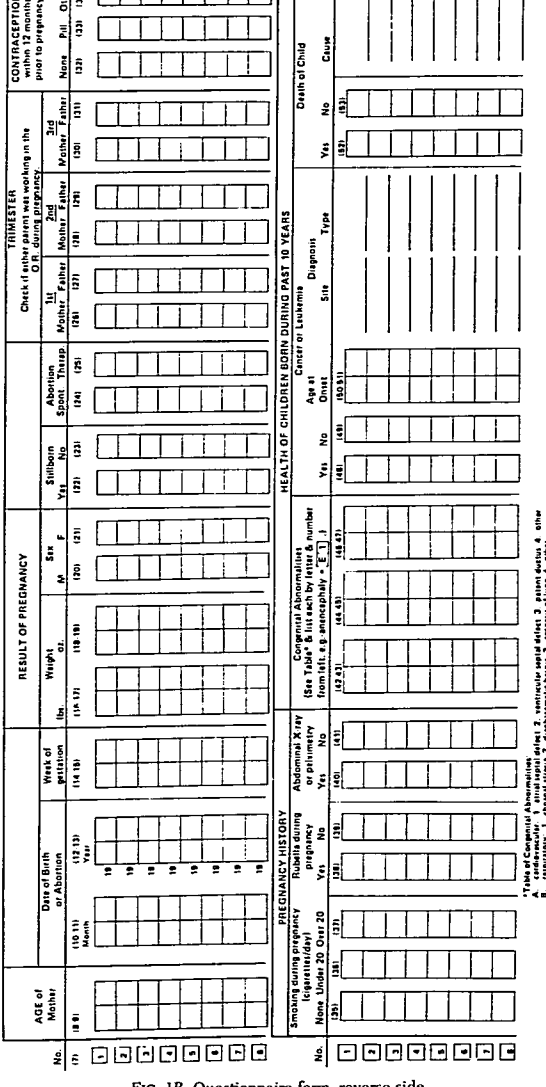

FIG. 1B. Questionnaire form, reverse side.

in the case of disease rates. ¶For the former, age and smoking habit of the mother at the time of pregnancy were used in the adjustment calculations; for the latter, age of the respondent at the time of the survey was used. In calculating spontaneous abortion and congenital abnormality rates, the standard population utilized consisted of one third smokers and two thirds non-smokers, with age distributions ascribing 30 per cent to less than 30 years of age, 40 per cent in the age range of 31–37 years, and 10 per cent more than 37 years of age. For the adjustment of disease rates, the standard population used for all groups had age distributions: 40 per cent less than 40 years of age; 40 per cent in the age range of 40–54 years; 20 per cent more than 54 years of age. Standard errors for the adjusted rates were computed by the usual method, assuming that cell rates were binomially distributed proportions, and pooling the exposed and unexposed cell data to estimate standard errors of differences to test the null hypothesis that rates do not differ with exposure. To determine significance, "*P* values" were computed, using one-sided tests against the alternative that exposed groups have higher risks. Comparisons of spontaneous abortion rates and congenital abnormality rates for exposed and unexposed groups were made separately for female respondents and for wives of male respondents. Disease rates were also analyzed separately by sex.

Results were individually analyzed for each of the several societies working in the operating room. Those respondents who reported that they were working in the operating room at the time of their pregnancy were separated from those who reported no exposure. For pregnant women working in the operating room, exposure was defined as exposure during the first trimester of pregnancy *and* work in the operating room during the calendar year previous to the event. In the case of the male respondents, exposure was defined as work in the operating room during the calendar year prior to the pregnancy. Spontaneous abortion rates and congenital abnormality rates were compared for the exposed and the unexposed groups within each of the exposed societies, *i.e.*, the ASA, the AANA, and the AORN/T. In addition, the rate for the exposed group in each society was compared with the rates determined for the parallel control society, *i.e.*, the American Academy of Pediatrics for the physician anesthetists, and the American Nursing Association for the nurse-anesthetists, operating room nurses, and technicians. Respondents in the control societies who reported operating room exposure (*e.g.*, pediatric anesthesiologists) were separated out and not used in the calculation of rates for the control groups. Duplication of memberships in the study and control societies was checked by social security number. Negligible overlap was found, but detected duplications were assigned to the exposed groups.

In analyzing disease rates, only the comparisons between societies were utilized. No efforts were made to compare exposed with unexposed members within a society, since effects here might be expected to be due to chronic exposure, and exposure information for respondents was available for the last ten years only. Data from respondents in the exposed study societies were deleted from the comparisons when they reported no exposure to the operating room within the last ten years. Similarly, respondents in the control societies were deleted from the analysis of disease rates when they reported any operating room exposure during the last ten years.

In defining the types of congenital abnormalities, the form (Fig. 1*B*) shows the categorization of questions asked of the respondent. After these data had been assembled, it was felt that further details as to the types of abnormality were needed. Therefore, all respondents reporting a liveborn baby with an unspecified type of congenital abnormality ("other" on the form) were sent a letter requesting a specific diagnosis of the abnormality. This information was edited by a physician, coded, and then added to the data in the computer. Data on types of abnormality were used to determine the distribution of congenital abnormalities between the exposed and unexposed groups.

¶ Smoking data available only during period of gestation.

The abnormalities were then further categorized and analyzed according to whether they were thought to be multifactorial in inheritance.[38] The first question was investigated by chi-squared comparison of the distribution of types of defects among babies with congenital abnormalities. The second question was studied by applying the same analysis described earlier, using standardized rates, but restricting the count of defects to multifactorial abnormalities.

Since definitions of rates for cancer, hepatic disease, and renal disease were diffuse and each involved many forms of disease, several sub-analyses were carried out. Rates were compared for specific diagnoses, or eliminating certain other specific diagnoses. For cancer, the rates for lymphoma and leukemia were computed separately and compared sex-specific for the exposed and unexposed groups. Subjects more than 65 years of age were excluded from this analysis. For hepatic disease, rates were computed excluding reported cases of serum hepatitis, since it was anticipated that serum hepatitis rates might be higher for operating room personnel frequently exposed to blood. For renal disease, the rates were computed excluding pyelonephritis and cystitis, since the risks of these infections were thought to be unrelated to the anesthetic exposure.

In addition to the calculation of disease rates for cancer, hepatic disease, and renal disease, modified as described in the preceding paragraph, the distributions of the several diagnoses within each category were compared for exposed and unexposed groups, using the chi-squared test for common distribution.

Several further analyses which are not reported in the Results section were carried out. The rates for spontaneous abortion presented in the Results section were computed on a per-100-pregnancy basis, and the congenital abnormalities on a per-100-liveborn baby basis. The statistical analyses (standard errors and tests of significance) took the events to be independent even though certain women contributed reports on several pregnancies. Thus, the statistical tests do not discount for correlations in the clusters of data per respondent and may claim a higher degree of statistical significance than a closer analysis would indicate. To investigate the effect of this simplifying approach, two types of additional analysis were done. The first consisted of looking only at the last pregnancy reported by each respondent. Of course, this analysis disregards a substantial portion of the data, and the results show attenuation of the significance levels obtained with the complete sets of data. However, the results confirmed statistical significance in most of the critical comparisons and provided an additional justification for the results that are presented below.

In another analytical approach, the multiple logistic model was used to describe the binary spontaneous abortion data. This multiple logistic analysis** was carried out to adjust for the individual characteristics of each individual mother, including her previous pregnancies within the study period, and to see whether multiple adjustment for all interfering variables for which information was available would minimize or magnify the results obtained by simple direct adjustment for age and smoking. The multiple logistic results are not reported in the present paper, but they confirm and strengthen the results reported below in terms of simple age- and smoking-standardized rates, and serve to add detail in terms of the relative risks of exposure for women with various characteristics. The multiple logistic approach was also applied to the congenital abnormality data, and again the results confirmed the results of the simpler adjusted-rate approach reported in this paper.

The multiple logistic analyses showed that second responders were different from first responders and that this factor interacted with the exposure factor. Nevertheless, higher risks for exposed personnel confirmed the simpler adjusted-rate analyses. Further

** This approach provided an estimate of the probability of spontaneous abortion as a function of all of the following simultaneous variables: exposure during the first trimester, first or second responder, history of previous spontaneous abortion, age of the mother at the time of pregnancy, smoking habit of the mother at the time of the pregnancy, and the first-order interactions among the first three listed variables (previous exposure, first or second responder, and abortion history).

TABLE 1. Total Mailing and Numbers of Responses to the First and Second Mailings by Society and by Sex

Society	Membership Surveyed	Responses					
		First Mailing		Second Mailing		Total Responses	
		Number	Per Cent	Number	Per Cent	Number	Per Cent
ASA							
Men	9,793	5,579	57.0	979	10.0	6,558	67.0
Women	1,399	892	63.8	167	11.9	1,059	75.7
AAP							
Men	7,024	2,452	34.9	441	6.3	2,893	41.2†
Women*	886	384	43.3	69	7.8	639	72.1†
AANA							
Men	2,627	1,666	55.0	228	10.4	1,894	65.4
Women*	11,967	6,064	50.7	1,072	8.6	7,136	59.3
AORN/T							
Men	1,666	646	38.8	245	14.7	891	53.5
Women*	22,133	9,946	44.9	2,326	10.5	12,272	55.4
ANA							
Men	320	112	35.0	30	9.3	142	44.3
Women*	15,681	5,111	32.6	1,449	9.2	6,560	41.8
	73,496	32,852		7,006		40,044	

* These are estimates based on samples of several hundred names on the address lists, classified by sex on the basis of name only.

† The results from first and second mailings to female AAP members were supplemented by 186 further responses obtained in a third mailing to the non-respondents. Recent mailings to male AAP members have now increased the number of responses to 3,998 (56.9 per cent), although these data are not included in the analysis.

light on non-responder bias was cast by the special study of "non-responders" among the female pediatricians. It was found that the rates obtained from the 186 "non-responders" were very nearly equal to the rates calculated from the 639 first and second responders. This provided further indication that non-responder bias is not an interfering influence in the study results presented below.

Results

Table 1 shows the numbers of persons surveyed in the several society memberships, and the numbers of responses, by mailing and by sex. In addition to the responses from the first and second mailings, additional responses from the special study of the non-respondents among female members of the American Academy of Pediatrics brought their response rate up to 72.1 per cent of all female members of the association, comparable to the 75.7 per cent rate for female members of the American Society of Anesthesiologists.

Table 2 indicates the numbers of pregnancies reported by the male and female respondents in the survey. Table 3 presents spontaneous abortion rates for female members of the several societies, excluding data from the unexposed members of the study groups and data from exposed members of the control societies who reported that they had worked in the operating room. The rates are standardized for both age and smoking habit at time of pregnancy. Rates for the

TABLE 2. Numbers of Pregnancies (Excluding Therapeutic Abortions) Reported by Respondents in the Several Socieities

	Wives of Male Respondents	Female Respondents	Total
ASA	5,790	848	6,638
AAP	2,534	381	2,915
AANA	2,107	3,491	5,598
AORN/T	436	5,896	6,332
ANA	79	2,626	2,705
	10,946	13,242	24,188

study groups are higher than those for the control societies and attain statistical significance ($P < .01$) for the physicians and for the operating room nurses and technicians.

Table 4 presents standardized spontaneous abortion rates for exposed and unexposed groups within the several societies. The figures for the exposed groups are, of course, the same as reported in table 3. The rates for the unexposed nurse-anesthetists and operating room nurses and technicians are very close to the rate for unexposed members of the American Nursing Association. However, members of the American Society of Anesthesiologists who report exposure neither during the first trimester nor during the calendar year previous to the event have a rate of spontaneous abortion of 15.7, markedly higher than the rate for female pediatricians (8.9) and almost as high as the rate for exposed female anesthesiologists (17.1). The rate for female pediatricians seems remarkably low, but it is closely comparable to the rates reported by unexposed members of the American Dental Association and unexposed members of the American Society of Oral Surgeons, in a concomitant survey still in progress.

Tables 3 and 4 show statistically significant evidence that spontaneous abortion rates are higher among women working in the operating room than in comparable groups of women working outside the operating room. If this increased risk of abortion is caused by insult to the fetus from some environmental hazard, such as ambient anesthetic gases, it might be anticipated that the effect might also be evidenced by earlier abortions among operating room women, and a decrease in the sex ratio (male/female) of liveborn babies. Indeed, earlier reports had suggested both possibilities.[4,5] These questions were pursued in the present analysis. No statistically significant differences were found in the average number of weeks' gestation at the time of abortion, when exposed and unexposed groups of women were compared, nor was there any evidence that the sex ratio was decreased in the exposed groups.

Table 5 presents the spontaneous abortion rates reported by male respondents and standardized for the ages and smoking habits of the spouse at the time of her pregnancy.

TABLE 3. Spontaneous Abortion Rates for Female Respondents*

Organization	Rate	Organization	Rate	P
ASA	17.1 ± 2.0 (468)	AAP	8.9 ± 1.8 (308)	<0.01
AANA	17.0 ± 0.9 (1,826)	ANA	15.1 ± 0.9 (1,948)	0.07
AORN/T	19.5 ± 0.9 (2,781)	ANA	15.1 ± 0.9 (1,948)	<0.01

* Rates calculated per hundred pregnancies (excluding therapeutic abortions) and standardized for age and smoking habit at pregnancy (see Methods). The standard error accompanies the rate. The standard error and the one-sided significance test "P value" are based on standard binomial theory applied to standard rates. The total number of pregnancies contributing to the rate is given below each rate. Unexposed persons have been deleted from the groups on the left-hand side and exposed persons from societies on the right-hand side. (See Methods for definitions of "exposed" and "unexposed").

TABLE 4. Spontaneous Abortion Rates for Exposed and Unexposed Members of the Several Study Socieities*

	ASA	AANA	AORN/T
Unexposed mother	15.7 ± 3.3 (138)	14.4 ± 1.4 (676)	15.1 ± 1.2 (1,533)
Exposed mother	17.1 ± 2.0 (468)	17.0 ± 0.9 (1,826)	19.5 ± 0.9 (2,781)
Significance	$P = 0.35$	$P = 0.06$	$P < 0.01$

* Age and smoking standardized rate per 100 pregnancies, with standard error and total number of pregnancies. See Methods for description of statistical calculations and definitions of exposure.

TABLE 5. Spontaneous Abortion Rates for Wives of Male Respondents*

Organization	Rate	Organization	Rate	P
ASA	11.6 ± 0.6 (3,416)	AAP	12.6 ± 0.8 (1,982)	0.84
AANA	11.7 ± 1.0 (1,350)	ANA	10.0 ± 3.3 (54)	0.36
AORN/T	18.4 ± 4.1 (237)	ANA	10.0 ± 3.3 (54)	0.04

* Rates per hundred pregnancies, with standard error and total number of pregnancies reported by each group. See explanatory footnote in table 3.

Along with rates for the other societies, data are also reported for male members of the ANA and the AORN/T, although there are very few male members of these organizations. There is little evidence that male exposure results in abortion in the spouse.

Table 6 compares congenital abnormality rates for the exposed female members of the study societies with the unexposed members of the control societies. The rate for the

TABLE 6. Congenital Abnormality Rates for Children of Female Respondents*

Organization	Rate	Organization	Rate	*P*
ASA	5.9 ± 1.4 (384)	AAP	3.0 ± 1.1 (276)	0.07
AANA	9.6 ± 0.8 (1,480)	ANA	7.6 ± 0.7 (1,629)	0.03
AORN/T	7.7 ± 0.6 (2,210)	ANA	7.6 ± 0.7 (1,629)	0.47

* Standardized rates are calculated on the number of liveborn babies with one or more congenital abnormalities (skin excluded) per 100 liveborn infants. Standard errors and numbers of liveborn babies are given with the rates. See the footnote in table 3 concerning standardization of these rates and other details of calculation.

TABLE 7. Congenital Abnormality Rates for Children of Exposed and Unexposed Women within the Several Study Societies*

	ASA	AANA	AORN/T
Unexposed mother	3.4 ± 1.2 (116)	5.9 ± 1.0 (566)	7.0 ± 0.9 (1,275)
Exposed mother	5.9 ± 1.4 (384)	9.6 ± 0.8 (1,480)	7.7 ± 0.6 (2,210)
Significance	$P = 0.13$	$P < 0.01$	$P = 0.23$

* Standardized congenital abnormality rates, per 100 liveborn babies, with standard errors and number of liveborn babies per group. Skin abnormalities were excluded from the enumeration. See footnotes for tables three and six for more detail concerning calculations and definitions of exposure.

TABLE 8. Congenital Abnormality Rates for Children of Wives of Male Respondents*

Organization	Rate	Organization	Rate	*P*
ASA	5.4 ± 0.4 (2,988)	AAP	4.2 ± 0.5 (1,714)	0.04
AANA	8.2 ± 0.9 (1,168)	ANA	3.7 ± 2.5 (49)	0.13
AORN/T	6.4 ± 2.5 (203)	ANA	3.7 ± 2.5 (49)	0.22

* Standardized congenital abnormality rate, per 100 liveborn babies, skin abnormalities excluded, with standard errors and total liveborn babies per group. See footnote to table 3 for further details concerning calculations and definition of groups.

female ASA members was double that for the members of the AAP, and the rate for the AANA was more than 25 per cent higher than the rate for the ANA, both differences attaining at least borderline significance ($P = 0.07$ and 0.03, respectively). All skin abnormalities are excluded in computing these rates.

Table 7 presents the congenital abnormality rates for unexposed and exposed groups within each of the three study societies. The rates for the unexposed personnel in the societies are very close to the rates reported in table 6 for the parallel control societies. The rate for the exposed nurse-anesthetists (9.6) is more than 50 per cent higher than the rate for members reporting that they were not exposed during and just before pregnancy (5.9), and this difference is highly significant ($P < 0.01$).

Congenital abnormality rates among the liveborn infants of the wives of male respondents are reported in table 8. The rates for wives of males exposed to the operating room are uniformly higher than the rates for wives of unexposed males in the control societies.

TABLE 9. Distributions of Congenital Abnormalities (Skin Excluded) by Organ System, for Babies Born of Female Members of the Physician Societies*

	ASA		AAP	
Organ System	Per Cent	Number	Per Cent	Number
Cardiovascular	37	10	0	
Respiratory	7	2	0	
Musculoskeletal	26	7	29	2
Gastrointestinal	0		0	
Central nervous system	19	5	14	1
Urogenital	11	3	77	4
Total congenital abnormalities	100	27	100	7

* Only data from exposed respondents are included in the study group, and only data from unexposed respondents are included in the control group.

TABLE 10. Congenital Abnormality Rates Age- and Smoking-standardized per 100 Live Births for Female Respondents and Wives of Male Respondents, Using Selected Multifactorial Categories*

	ASA	AAP	*P*
Female respondents	1.24 ± 0.47 (384)	0.21 ± 0.21 (276)	0.06
Wives of male respondents	1.56 ± 0.21 (2,988)	0.90 ± 0.24 (1,714)	0.03

* Atrial septal defect, patent ductus, congenital hip, clubfoot, cleft palate or lip, pyloric stenosis, anencephaly, spina bifida, and hydrocephalus.

The difference for male physicians is statistically significant ($P = 0.04$). The differences for the nurses and technicians, though larger than for physicians, are not statistically significant. The numbers of male respondents in these groups, however, are limited.

Tables 6, 7, and 8 show statistically significant or borderline significant differences in the congenital abnormality rates for babies born of women and also the spouses of men who work in the operating room, compared with babies born of control women and the spouses of men who work outside the operating room. However, even if this difference is valid, the limited numbers of abnormalities reported make it difficult to determine whether any specific type of abnormality is occurring with unusually high frequency. Table 9 presents the breakdown of abnormalities according to organ system for the physician groups, but the numbers do not afford clear conclusions.

In reviewing the congenital abnormalities, a category of multifactorial inheritance that included atrial septal defect, patent ductus, congenital hip, cleft palate or lip, clubfoot, pyloric stenosis, anencephaly, spina bifida, and hydrocephalus was defined. When the abnormality rates for these multifactorial abnormalities were compared between the babies of the exposed and the unexposed physician groups, it was found that the rates were distinctly different, as shown in table 10. These differences support the suggestion that the increased risk of congenital abnormality among operating room personnel may be due to environmental hazard as well as to genetic differences.[38]

TABLE 11. Cancer Rates for Female Respondents, Skin Excluded*

Organization	Rate	Organization	Rate	P
ASA	3.0 ± 0.6 (1,008)	AAP	1.6 ± 0.5 (566)	0.05
AANA	2.6 ± 0.2 (6,107)	ANA	1.8 ± 0.2 (5,400)	<0.01
AORN/T	2.3 ± 0.2 (11,843)	ANA	1.8 ± 0.2 (5,400)	0.07

* Rates are age-standardized and are calculated on the basis of the number of respondents reporting a cancer diagnosis within the last ten years per 100 respondents. Standard error and total number of respondents are given for each rate. Respondents for the societies on the left were included only if they reported working in the O.R. one or more of the last ten years. Respondents for societies on the right were included only if they reported no O.R. exposure in the last ten years.

TABLE 12. Cancer Rates for Male Respondents, Skin Excluded*

Organization	Rate	Organization	Rate	P
ASA	0.7 ± 0.1 (6,233)	AAP	0.7 ± 0.2 (2,495)	0.49
AANA	1.5 ± 0.5 (1,858)	ANA	0.0 (109)	0.13
AORN/T	0.3 ± 0.2 (851)	ANA	0.0 (109)	0.27

* Age-standardized rate, per 100 respondents, with standard error and total number of respondents. See footnote to table 11 for further details.

Table 11 presents the age-standardized cancer rates for the several study and control societies for female respondents. Table 12 presents analogous rates for the male respondents. There is strong evidence for a higher risk for exposed females than for unexposed females. Table 13 shows the breakdown of cancer diagnoses by type for females. The incidence of lymphoma and leukemia is in-

TABLE 13. Comparison of the Distribution of Cancer Cases by Type for Female Respondents in the Several Societies

	ASA		AAP		AANA		AORN-T		ANA	
Cancer	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number
Cervix	7	2	0		22	34	35	71	13	12
Breast	50	14	80	8	40	61	29	59	51	48
Uterus	18	5	10	1	14	21	10	21	16	15
Thyroid	11	3	0		1	2	6	12	2	2
Leukemia and lymphoma	4	1	0		3	5	3	5	1	1
Melanoma	4	1	0		3	5	2	4	2	2
Miscellaneous	6	2	10	1	17	25	15	31	15	20
Total cases	100	28	100	10	100	153	100	203	100	94

TABLE 14. Hepatic Disease Rates for Female Respondents, Serum Hepatitis Excluded*

Organization	Rate	Organization	Rate	*P*
ASA	4.9 ± 0.7 (921)	AAP	2.9 ± 0.8 (512)	0.04
AANA	3.8 ± 0.3 (5,178)	ANA	1.7 ± 0.2 (4,512)	<0.01
AORN-T	2.1 ± 0.2 (9,741)	ANA	1.7 ± 0.2 (4,512)	0.08

* Rates are calculated per 100 respondents, with standard error and total number of respondents per group. See footnote to table 11 for further details.

TABLE 15. Hepatic Disease Rates for Male Respondents, Serum Hepatitis Excluded*

Organization	Rate	Organization	Rate	*P*
ASA	4.1 ± 0.3 (5,828)	AAP	2.6 ± 0.4 (2,337)	<0.01
AANA	4.7 ± 0.6 (1,614)	ANA	5.1 ± 2.2 (86)	0.58
AORN/T	4.2 ± 1.2 (763)	ANA	5.1 ± 2.2 (86)	0.65

* Rates are calculated per 100 respondents, with standard error and total number of respondents per group. See footnote to table 11 for further details.

creased approximately threefold in exposed females ($P = 0.05$ for exposed groups *vs.* unexposed groups using age-standardized rates). No statistically significant differences in other types of female cancer were found, within the limited numbers of cases reported, and there were no differences found between exposed and unexposed males (data not shown).

There were markedly higher rates of hepatitis for the study societies compared with the control societies, and these elevated rates were statistically significant. Since operating room personnel administer blood and therefore run a high risk of infection, a diagnosis of serum hepatitis was disregarded in a recalculation of hepatic disease rates. Table 14 shows the hepatic disease rates for females, and table 15 the rates for males, with serum hepatitis excluded. Even excluding serum hepatitis, the evidence for increased risk of hepatic disease for both sexes when exposed to the operating room environment seems strong. However, an analysis of the types of hepatic disease according to the diagnosis reported by the respondent does not shed further light on the nature of the risk. Table 16 presents the tabulations of types of diagnoses of hepatic disease reported by the female respondents in the several societies. The results for males are similar (not shown).

In calculating the rates for renal disease, diagnoses of infectious origin such as pyelonephritis and cystitis were excluded. Tables 17 and 18 present the renal disease rates for females and for males for the several study and control societies, excluding unexposed respondents from the study society data and exposed respondents from the control society data. All rates are standardized for the age of the respondent. There is some evidence in these results to indicate that nurse anesthetists and operating room nurses and technicians have a higher risk of kidney disease than do nurses outside the operating room. The differences for the females are statistically significant ($P = 0.01$ for the AANA *vs.* ANA; $P = 0.04$ for the AORN/T *vs.* the ANA). No particular type of renal disease stood out as more frequent in occurrence. These differences were not present in the physician groups, and the reason remains obscure.

Conclusions

The results of the survey strongly suggest that working in the operating room (and

TABLE 16. Comparison of the Distributions of Hepatic Disease Diagnosis for Female Respondents in the Several Societies

	ASA		AAP		AANA		AORN/T		ANA	
	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number
Hepatitis	38	17	50	4	39	76	43	81	32	26
Infectious hepatitis	31	14	25	2	18	34	23	43	28	23
Infectious mononucleosis	11	5	0		9	17	11	21	15	12
Cholecystitis	4	2	12	2	10	19	7	13	5	4
Miscellaneous	14	7	13	2	24	48	16	32	20	16
Total cases	100	45	100	10	100	194	100	190	100	81

TABLE 17. Renal Disease Rates for Female Respondents, Pyelonephritis and Cystitis Excluded*

Organization	Rate	Organization	Rate	P
ASA	2.4 ± 0.5 (908)	AAP	1.9 ± 0.7 (506)	0.28
AANA	3.1 ± 0.2 (5,216)	ANA	2.3 ± 0.2 (4,550)	0.01
AORN/T	2.9 ± 0.2 (9,960)	ANA	2.3 ± 0.2 (4,550)	0.05

* Rates are calculated per 100 respondents, with standard error and total number of respondents per group. See footnote to table 11 for further details.

TABLE 18. Renal Disease Rates for Male Respondents, Pyelonephritis and Cystitis Excluded*

Organization	Rate	Organization	Rate	P
ASA	4.2 ± 0.3 (5,743)	AAP	4.6 ± 0.5 (2,334)	0.76
AANA	4.3 ± 0.6 (1,604)	ANA	1.1 ± 1.1 (86)	0.07
AORN/T	2.6 ± 0.7 (761)	ANA	1.1 ± 1.1 (86)	0.19

* Rates are calculated per 100 respondents, with standard error and total number of respondents per group. See footnote to table 11 for further details.

presumably exposure to trace concentrations of anesthetic agents) entails a variety of health hazards for operating room personnel and their offspring.

SPONTANEOUS ABORTION

Survey data provide statistically significant evidence that the risk of spontaneous abortion is increased for women exposed to the operating room environment during the first trimester of pregnancy and the preceding year. The increased risk was observed in female physician anesthetists, nurse-anesthetists, and operating room nurses and technicians. The risk is estimated to be 1.3 to two times that of unexposed personnel.

There appears to be no increased risk of spontaneous abortion for the wives of exposed male respondents, compared with the wives of unexposed male respondents.

CONGENITAL ABNORMALITIES

There is evidence for an increased risk of congenital abnormalities among the liveborn babies of exposed female respondents. An intra-group analysis of the exposed nurse-anesthetists compared with the unexposed members of this group indicated an increase of more than 60 per cent ($P < 0.01$). The exposed female physician anesthetists showed a twofold increase compared with the unexposed female physician anesthetists and female pediatricians ($P = 0.13$ and 0.07, respectively). There was also an increase of 25 per cent in the incidence of congenital abnormalities for the wives of exposed male physician anesthetists ($P = 0.04$). This unexpected finding represents a matter for serious concern and deserves further investigation.

A separate analysis of the multifactorial abnormalities in the children of both female respondents and the wives of male respondents strengthens the above conclusions and provides evidence for an environmental effect.

CANCER

The data suggest an increased occurrence of cancer in the exposed female respondents compared with those in unexposed control groups. The increases ranged from approximately 1.3 to somewhat less than twofold, with $P = 0.05$, <0.01, and 0.07 for the physician anesthetists, the nurse-anesthetists, and the operating room nurses and technicians, respectively. Separate analyses by type and location of tumor indicate that, with the exception of leukemia and lymphoma, there is no effect at a particular location or for a specific type of cancer. The increased occurrence of cancer was not verifiable in exposed male respondents.

HEPATIC DISEASE

Hepatic disease was reported more frequently in the exposed female respondent groups compared with unexposed controls (even after excluding serum hepatitis). The range of increase was approximately 1.3- to 2.2-fold, with P values of 0.04, <0.01, and 0.08 for the three comparisons. A similar statistically significant increase in hepatic disease was reported by the exposed male physician anesthetists compared with the male pediatricians ($P < 0.01$).

RENAL DISEASE

The exposed female groups reported higher rates of renal disease (pyelonephritis

and cystitis excluded) ranging from 1.2- to 1.4-fold in magnitude ($P = 0.28$ for female physicians, 0.01 and 0.05 for the two nurse comparisons). No increased risk of renal disease for male physician anesthetists was observed.

Although differences in disease rates described for each of the above conditions are consistently present between the exposed and unexposed individuals on both intra- and inter-group analysis, there are a number of difficulties in interpretation. For example, while the AAP provides an appropriate comparison group for the ASA, and the ANA balances the AORN/T, no proper comparison group is available for the AANA, whose members in many respects are between physicians and nurses in their training and exposure. Since reporting rates are critical to the analysis, differences in medical background may result in either over- or under-reporting of certain diseases by members of the AORN/T when compared with members of the AANA or the ASA. Caution must therefore be applied in choosing the appropriate control for inter-group analysis, and an additional hazard is present in making inter-group comparisons between the exposed societies.

The conclusion that operating room personnel are subject to a health hazard, and that such a hazard is the result of anesthetic gases in the ambient air of the operating room, must be advanced with caution. The findings presented here are survey data, retrospective in nature, obtained by mail, and involve data that are subject to misinterpretation, misrecollection, and variation due to the experience and education of the responder. Thus, despite the strong support from animal studies, the consistency of our clinical data with results reported in other studies, the internal consistencies in comparisons of exposed groups in this study with control groups, and the generally high statistical reliability of the results, there remains the possibility that the increased rates for the exposed groups may be due to some undetected biases. There may be an unknown hazard in these locations which is unrelated to anesthetics. However, based on all the information gathered, the committee concludes that an increase in disease rates in operating room personnel is present, and that exposure to waste anesthetic gases in the operating room provides the most reasonable explanation.

Current Status of Waste-gas Scavenging

Waste anesthetic gases are widely distributed throughout the operating room.[9,12] The major sources of pollution are the pop-off valve and the ventilator. Other sources of leaks include poorly fitted components of the breathing system, spilled liquid anesthetics, and worn-out seals in high-pressure hose connectors. All operating room personnel are exposed.

Early reports of special apparatus for scavenging appeared in 1969,[39,40] and more elaborate equipment was subsequently shown to reduce waste gas concentrations by approximately 90 per cent.[12] A detailed preliminary report on current scavenging technology is scheduled for publication this year,[41] and additional studies of anesthetic gas scavenging are currently in progress under NIOSH Contract #HSM 99-73-73. Technology presently available for anesthetic gas scavenging requires the trapping of waste gases at the site of overflow on the breathing circuit followed by disposal to the outside atmosphere. In addition, the room air-conditioning system helps eliminate residual waste gases resulting from leaks in the anesthetic apparatus. Apparatus for trapping the waste gases at the site of overflow is currently available for most anesthetic breathing systems. Unfortunately, no scavenging is yet available for open systems, largely employed by dentists, who administer an estimated 4.5 million inhalation anesthetics per year.†† The development of open-system scavenging is presently under investigation.

The waste-gas disposal system includes two major components. The first component is an interface system which joins the scavenging trap at the breathing system with the disposal tube or duct in the operating room. This interface serves to balance positive pressure present at the site of overflow

†† Projected from data obtained from the Northern California Society of Oral Surgeons and Southern California Society of Oral Surgeons.

with negative pressure existing at the disposal tube or duct, thus avoiding interference with the anesthetic breathing system. The second component of the disposal system carries the waste gases from the operating room to the outside atmosphere.

Several alternative disposal routes may be used. Assuming a non-recirculating air-conditioning system, disposal of the waste gases into the air-conditioning exhaust grill remains an efficient and inexpensive method. The disposal of halogenated compounds into activated charcoal is efficient,[12] but unfortunately not applicable to nitrous oxide. The recirculating air-conditioning system may also be used, provided that the waste gases are introduced into the exhaust duct downstream from the point of recirculation. Use of a separate specialized scavenging duct with blower is feasible, and wall suction offers yet another possible alternative, provided flammable anesthetics are not used.

All scavenging systems add complexity, if not hazards, to the administration of anesthesia. For example, the exhaust grill method presents the hazard of occlusion when operating room personnel accidentally step on the exhaust tubing. Moreover, if the waste gas line enters the air-conditioning exhaust duct downstream from the grill, negative pressure is apt to be excessive and the breathing bag rapidly empties. This phenomenon is prevented by means of a pressure-balancing interface system when wall sunction is used for scavenging. A further concern is the need for compliance with NFPA Code No. 56-A, which specifies that flammable vapors shall not be emptied into a central suction system.[13] Finally, the use of wall suction requires that the compressor be vented to the outside, away from personnel or air intakes.

Not all recommended scavenging methods are equally effective. One example of an ineffective method is venting to the OR floor on the assumption that the heavier anesthetic gases will remain near the floor away from the inspired air of personnel. Although anesthetics are heavier than air, turbulence induced by the air-conditioning system effectively stirs up even the heaviest agents. The result is an almost equal distribution throughout the operating room except in the immediate region of the "pop-off" valve.[12] One frequently-used anesthetic ventilator disposes of approximately 10 liters per minute of high-pressure driving gas into the disposal system. If the wall suction is used for disposal, the scavenging flow rate must meet the requirement for 1–2 times the anesthetic gas flow rate, plus 10 liters of driving gas per minute, in order to achieve efficiency. Thus the mere availability of a scavenging device in no way guarantees its efficacy.

No scavenging system is 100 per cent effective, and waste gases are invariably present in the atmosphere. These may be partially removed by the air-conditioning system, and their rate of removal depends on the rate at which fresh air enters the operating room and the patterns taken by air currents through the room. In the past, most air-conditioning systems for operating rooms were non-recirculating, with the air exhausted to the outside. Such a system is efficient in removing waste anesthetic gases, but the operating cost is high. Recirculating systems, which are more economical, are permissible, because high-efficiency particulate air filters (HEPA) efficiently remove bacteria. Unfortunately, these filters do not remove the waste gases, and the reduced intake of outside air (typically only five exchanges per hour compared with 15 for non-recirculating systems) results in an increased residual waste gas level.

Laminar-flow air-conditioning systems move large volumes of air over wide areas. Such systems may work in combination with standard non-recirculating systems and provide 15 exchanges per hour of fresh air. These create no special problem for the accumulation of waste gases. However, laminar-flow systems which take in a lower exchange rate of pure air are certain to increase the exposure of personnel.

The necessity for an atmospheric monitoring program seems inescapable, and such a program has previously been recommended by this committee in a report to the ASA House of Delegates, October 1973. The appearance of anesthetic gas leaks is unpredictable, and detection may be difficult. Pollution may thus persist despite the conscientious use of scavenging. An effective clean-air

program for the operating room should promptly identify and eliminate all major sources of contamination. In addition, it may prove desirable to monitor personnel exposed to unsuspected anesthetic gas leaks.

What are the minimum levels of waste gases achievable and what are the costs? As an example, the unscavenged operating room typically contains halothane in the range of 10 ppm and nitrous oxide in the range of 600 ppm. After scavenging, these values are reduced to the range of 1 ppm for halothane and 60 ppm for nitrous oxide. Further reduction to less than 0.05 ppm for halothane and 1 ppm for nitrous oxide is achievable by additional effort to eliminate all leaks from the anesthesia apparatus, by using low-flow techniques, and by maintaining a high flow rate of fresh air into the air-conditioning system.

The cost of scavenging a "pop-off" valve is approximately $65, and most anesthetic ventilators can be equipped for scavenging for less than $100. In addition to the cost of the scavenging equipment, the cost of maintaining a monitoring program must be included to insure continuing purity of the environmental air.

Specific data on safe levels of exposure to waste inhalation anesthetics are not available. The present survey indicates disease rates which are dose-related. Thus, the more heavily exposed groups, such as the anesthetists, generally show a higher incidence of disease in comparison with less-exposed personnel, such as the operating room nurses and technicians. Unfortunately, there are no data which permit quantitative comparison of the anesthetic exposure levels for these groups. At present, the best recommendation is to reduce the exposure of all personnel to the lowest possible level consistent with reasonable cost. Preliminary experiments indicate the possibility of maintaining the N_2O pollution level below 1 ppm and halothane levels below 0.05 ppm, but further work is needed to confirm the practicality of maintaining such levels.‡‡

‡‡ Although our data refer to concentrations of N_2O and halothane, this does not imply that these are the only trace anesthetics present in the operating room, nor is concern restricted to these agents alone.

Implications and Future Studies

Many of the positive findings in the present survey had been suggested by a number of earlier studies published in several countries. Questions of occupational morbidity are even now being widely discussed throughout the United States. It is therefore important that these risk data be made generally available to the medical community, and that there be no delay in initiating a national effort to formulate policies and institutional plans for appropriate precautionary measures. All personnel working in operating rooms, particularly women of childbearing age, should be informed of these findings and allowed to determine individually whether they will continue to work in operating rooms not provided with scavenging equipment.

The question frequently arises as to whether a pregnant anesthetist or nurse should remove herself entirely from this environment. Unfortunately, the answer is not clear, and as with most medical decisions, a value judgment must be made, taking into consideration physiologic, psychological, and economic factors. It would appear that the increased rates of spontaneous abortion and congenital abnormalities of children of operating room personnel makes it reasonable to advise such individuals to avoid unscavenged operating rooms at least during the first trimester of pregnancy. Additional factors, including a history of habitual abortion and/or malformations in previous children, may make this advice more urgent. On the other hand, the hazard of spontaneous abortion and malformation in well-vented operating rooms (halothane concentrations in the order of magnitude of 1 ppm and nitrous oxide 60 ppm or less) may be no greater than that for unexposed health care personnel. There is at present no information with which to define safe concentrations for the volatile anesthetics.

Despite the possibility of pollution control through alternative measures such as use of regional anesthesia or closed anesthetic systems, it is recommended that scavenging facilities be provided in all anesthetizing locations. No doubt the use of a low-flow closed system will reduce pollution. However, the high-flow techniques, now in widespread use, were introduced because of pre-

sumed patient safety. Any widespread change to closed systems might well increase anesthetic mortality and morbidity. Moreover, use of regional anesthetics does not totally eliminate the need for scavenging facilities. An anesthetic procedure planned as a regional block may require inhalation anesthetics, when surgery outlasts the regional anesthesia, or if failure of the regional block occurs. In addition to these considerations, yet other reasons exist for the institution of anesthetic gas scavenging. Recent studies by Bruce *et al.*[14] indicate that four-hour exposures to trace concentrations of anesthetics result in measurable decrements of perceptive, cognitive, and motor skills.

Scientific studies designed to elicit information defining the exact nature of anesthetic effect on health must largely be limited to laboratory animal experimentation. One area in which human information might have been obtained was the careful study of abortuses from operating room personnel. Recent federal legislation has made such studies difficult to conduct. Thus, the only studies possible are in animals deliberately exposed to anesthetics of various durations and dosages. It is hoped that qualified reproductive physiologists will find this topic of sufficient interest and importance to devote their attention to deriving data defining the effects anesthetics have on pregnancy and gestation. Despite the limitations imposed by species differences, useful information might very well accrue from such animal studies.

The most important future study will be the second national survey. This will be done in 1978 after passage of sufficient time to allow the majority of operating rooms in the United States to be equipped with scavenging devices. It also provides time for individuals working in these newly protected environments to accumulate significant amounts of health experience. If the only variable that changes in the intervening years is the institution of venting devices, and the data no longer show the differences and trends found in the present study, a strong case will have made for the correctness of the decision to move ahead with such scavenging practices.

Successful completion of this study required the cooperation of numerous individuals. Ms. Ann Varady, Dr. Laurie Smith, and Mr. David Himmelberger provided statistical and programming skills. Rosalie de la Torre served as Stanford study coordinator, and Mr. Glenn Johnson served as ASA coordinator. Drs. M.R. Bernfield and H.M. Cann offered consultation in the areas of pediatric teratology and geneties, and Drs. R. Miller and C. Stark in areas in epidemiology and biostatistics. The manuscript was reviewed by Professors R. Miller, L. Moses, and P. Basch. Finally, the study would never have become a reality without the dedicated support and scientific advice of Dr. Joseph K. Wagoner, Director of Field Studies and Clinical Investigation, and Dr. William M. Johnson, former Deputy Director, NIOSH, to whom much credit is due.

The Ad Hoc Committee was appointed during the presidential tenure of Dr. M. T. Jenkins and continued through the tenures of Drs. E. S. Siker and D. W. Little. Cooperating representatives from the various societies included Mr. John French, AANA; Dr. I. M. Jacobi, ANA; Dr. R. G. Frazier, AAP; and Ms. Jerry Peers, AORN.

ADDENDUM

Tapes of the study data are on file at the National Institute for Occupational Safety and Health, Cincinnati. Interested parties should inquire directly.

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