Anesthesiology
78:875–879, 1993

J. B. Lippincott Company, Philadelphia

Laparoscopy Explosion Hazards with Nitrous Oxide

George G. Neuman, M.D., George Sidebotham, Ph.D.,† Eduard Negoianu, M.D.,* Jeffrey Bernstein, M.D.,‡ Aaron F. Kopman, M.D.,§ Robert G. Hicks, M.D.,¶ Stanley T. West, M.D.,** Laurence Haring, M.D.††*

Background: During laparoscopic surgery utilizing carbon dioxide as the insufflating agent, nitrous oxide will diffuse into the peritoneal cavity if it is used as part of the anesthetic. Bowel perforation and the subsequent release of volatile bowel gas could create a explosion hazard.

Methods: Two related studies were undertaken. The first quantified the transfer of nitrous oxide, over time, in 19 female patients undergoing laparoscopy. The second established the lower limits of flammability of a range of concentrations of methane and hydrogen diluted with nitrogen (simulated bowel gas) in a range of concentrations of nitrous oxide diluted with carbon dioxide (simulated peritoneal gas).

Results: The mean concentrations of N_2O at 10, 20, and 30 min from the time of insufflation were 19.9 ± 4.8%, 30.3 ± 6.8%, and 36.1 ± 6.9%, respectively. The maximum reported concentrations of methane and hydrogen in bowel gas are 56% and 69%, respectively. The concentration of nitrous oxide necessary to support combustion of 56% methane is approximately 47%. By contrast, the concentration of nitrous oxide needed to support combustion of 69% hydrogen is approximately 29%.

Conclusions: The authors have shown that it is possible for nitrous oxide to reach concentrations in the peritoneal cavity that can support combustion of bowel gas. **(Key words: Anesthetics, gases: nitrous oxide. Explosion hazard. Surgery: laparoscopy.)**

THE use of laparoscopic surgical techniques for various gynecologic procedures has increased over the last 20 yr, and as well as in general surgery over the last 2 yr, following the initial report of laparoscopic cholecystectomy.[1] An ever-increasing array of procedures, including bowel resections, herniorraphies, and loop colostomies, as well as the increased use of laser and electrocautery techniques in both gynecological and general surgical laparoscopies, has created a greater potential for both intentional and unintentional bowel perforation and the release of flammable bowel gas into the gas-filled peritoneal cavity. Carbon dioxide, which is used for insufflation, does not support combustion. However, nitrous oxide will diffuse into any closed gas space and will support combustion if present in a high enough concentration. The transfer rate of nitrous oxide into the peritoneal cavity after the creation of a pneumoperitoneum with air has been reported to be very rapid.[2]

During laparoscopic surgery, if the nitrous oxide concentration in the peritoneal cavity reached levels that could support combustion of highly volatile bowel gas (methane and hydrogen), an explosion hazard could exist.

To further evaluate this potential hazard, we undertook two related studies. The first quantified the transfer of nitrous oxide into the peritoneal cavity in a series of patients undergoing laparoscopy. The second was designed to establish the lower limits of flammability of a range of clinically observed concentrations of methane and hydrogen (maximum concentration 56% and 69%, respectively)[3,4] diluted with nitrogen (simulated bowel gas) in a range of concentrations of nitrous oxide diluted with carbon dioxide (simulated peritoneal gas).

---

* Attending Anesthesiologist, Department of Anesthesiology, St. Vincent's Hospital and Medical Center of New York.

† Assistant Professor, Department of Chemical Engineering, The Cooper Union for the Advancement of Science and Art.

‡ Attending Anesthesiologist, Department of Anesthesiology, South Nassau Communities Hospital, Oceanside, New York.

§ Associate Professor of Anesthesiology, Cornell University Medical College, New York, New York.

¶ Chairman Emeritus, Department of Anesthesiology, St. Vincent's Hospital and Medical Center of New York.

** Attending Gynecologist, Department of Obstetrics and Gynecology, St. Vincent's Hospital and Medical Center of New York.

†† Resident, Department of Anesthesiology, St. Vincent's Hospital and Medical Center of New York.

Received from St. Vincent's Hospital and Medical Center of New York, New York, New York; and at The Cooper Union for the Advancement of Science and Art, New York, New York. Accepted for publication January 26, 1993.

Address reprint requests to Dr. Neuman: Department of Anesthesiology, St. Vincent's Hospital and Medical Center of New York, 153 West 11th Street, New York, New York 10011.

Materials and Methods

Nitrous Oxide Transfer to the Peritoneal Cavity

After institutional approval was obtained, 19 ASA physical status 1 or 2, female patients undergoing laparoscopic surgery were studied. Anesthesia was induced intravenously with 2 μg/kg fentanyl and 3–5 mg/kg thiopental. To facilitate tracheal intubation, 0.4 mg/kg of atracurium was administered. Ventilation was controlled and an end-tidal carbon dioxide tension was maintained between 35 and 38 mmHg. The concentration of the end-tidal gases was determined by mass spectrometry using the SARA (System for Anesthetic and Respiratory Analysis, Allegheny International Medical Technology, St. Louis, MO). Anesthesia was maintained with oxygen in an end-tidal concentration of 33%, nitrous oxide 66%, and either isoflurane (end-tidal concentration 1.2%) or enflurane (end-tidal concentration 1.7%). Additional fentanyl was administered as needed. After an adequate level of anesthesia was achieved, the surgeon insufflated the peritoneal cavity with carbon dioxide to a pressure of 17 mmHg (3–4 liters of CO_2) and a Wolf operating laparoscope was inserted into the peritoneal cavity through a single 10-mm sheath. A sterile gas sampling tube was connected to the lumen of the laparoscope *via* a three-way stopcock to analyze the composition of the gases in the peritoneal cavity. Before the samples were obtained, the stopcock was open to air for 3 s, allowing gases from the peritoneal cavity to fill the lumen of the laparoscope. Next, the stopcock was turned, connecting the lumen of the laparoscope to SARA. Three reproducible (within 2% of each other) samples were obtained at each time interval and averaged. During the sampling period (usually less than 3 min), the flow of CO_2 was turned off. Peritoneal gas samples were taken at 10-, 20-, and 30-min intervals after the start of insufflation.

Flammability Study of Simulated Bowel Gas in Nitrous Oxide/Carbon Dioxide

A diffusion flame burner was used to simulate the potential condition that could exist in the peritoneal cavity following a bowel perforation. Bowel gas (fuel) would flow into a nitrous oxide/carbon dioxide atmosphere (oxidizer) in the peritoneal cavity as a fuel jet and could be ignited by a cautery device or laser beam. The experimental apparatus (fig. 1) consisted of a central tube through which a fuel gas flows and an outer concentric tube through which the oxidizer flows through the annular space. On ignition, a diffusion flame is established at the junction separating the fuel and oxidizer. The rate of combustion is controlled by the rate at which fuel and oxidizer diffuse to the flame.

Two concentric quartz tubes were used. The simulated bowel gas flowed through the inner tube (8 mm internal diameter, 2 mm wall thickness) and the oxidizer through the outer tube (24 mm internal diameter, 2 mm wall thickness). Diffusion flames were established and anchored at the exit of the inner tube. The exit of the outer tube was 10 cm above the burner rim, sufficiently far to prevent entry of ambient air. Glass beads were placed in the annulus to distribute the oxidizer uniformly. All gases were obtained from cylinders with at least 99% purity. The gaseous flow rates were regulated by mass flow controllers that were calibrated with a soap bubble meter.

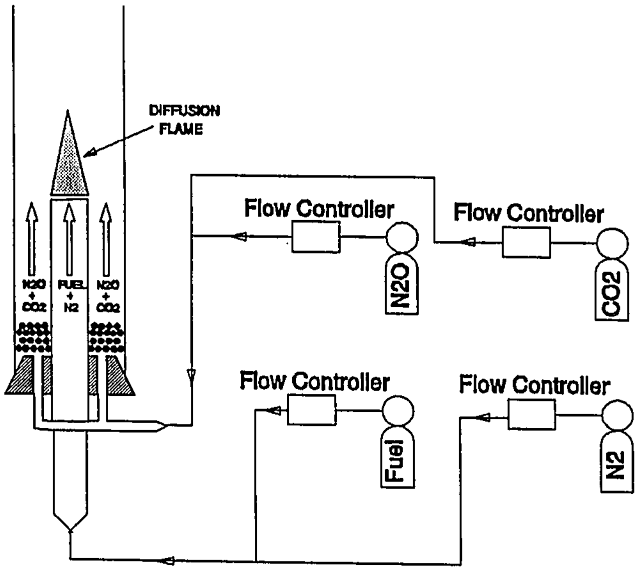

Fig. 1. A diffusion flame burner was used to simulate the potential condition that could exist in the peritoneal cavity following a bowel perforation. Two concentric quartz tubes were used. The simulated bowel gas was flowed through the inner tube (8 mm internal diameter, 2 mm wall thickness) and the oxidizer through the outer tube (24 mm internal diameter, 2 mm wall thickness). Diffusion flames were established and anchored at the exit of the inner tube. The exit of the outer tube was 10 cm above the burner rim, sufficiently far to prevent entry of ambient air. Glass beads were placed in the annulus to distribute the oxidizer uniformly. All gases were obtained from cylinders with at least 99% purity. The gaseous flow rates were regulated by mass flow controllers that were calibrated with a soap bubble meter.

Hydrogen and methane are the two primary flammable gases found in the bowel, and nitrogen is the primary inert gas.[3,4] Bowel gas (fuel) was simulated as hydrogen/nitrogen or methane/nitrogen mixtures. The gas in the peritoneal cavity (oxidizer) was simulated by mixtures of nitrous oxide and carbon dioxide. A flow of flammable fuel (either hydrogen or methane) in the inner tube and of nitrous oxide in the outer tube were established and held constant throughout the experiment. The fuel flow rates were 89.5 standard cubic centimeters per minute for methane and 153 standard cubic centimeters per minute for hydrogen. The nitrous oxide flow rate was 1.15 standard liters per minute. These flow rates were chosen to achieve laminar flow and to establish an adequate flame height. A flame was ignited above the exit of the inner tube. To dilute the fuel, a fixed flow of nitrogen was added to the methane or hydrogen fuel in the inner tube and the flow rates were recorded. Once the flows were stabilized, carbon dioxide was slowly added to the nitrous oxide stream in the outer tube. Eventually, the flame would lift from the burner rim and, ultimately, extinguish. The limiting condition for which a flame existed was recorded. The flame for the limiting case was observed for at least 5 min to ensure the existence of a stable flame. The procedure was repeated at incrementally higher nitrogen flow rates.

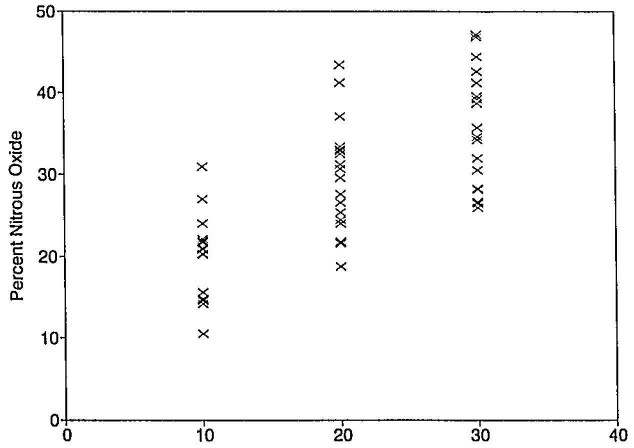

Fig. 2. The distribution of the nitrous oxide samples obtained from the peritoneal cavities of 19 female patients undergoing laparoscopic surgery. The mean concentrations at 10, 20, and 30 min from the time of insufflation were 19.9 ± 4.8%, 30.3 ± 6.8%, and 36.1 ± 6.9%, respectively. The maximum nitrous oxide concentrations measured at each time interval were 36%, 43%, and 47% after 10, 20, and 30 min, respectively.

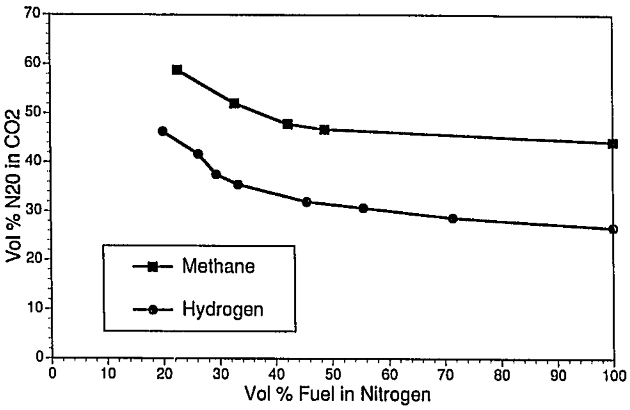

Fig. 3. Flammability curve: the percentage of nitrous oxide in carbon dioxide is plotted against the percentage of fuel (methane, solid squares or hydrogen, solid circles) in nitrogen that supported combustion. Therefore, for a given fuel, the combinations of fuel and oxidizer that lie above and to the right of the curve are capable of supporting combustion.

Results

Nitrous Oxide Transfer to the Peritoneal Cavity

Nineteen female patients were studied. The mean age was 30 ± 5 yr. The mean weight was 58 ± 12 kg. Ten patients received nitrous oxide and isoflurane and nine patients received nitrous oxide and enflurane. The distribution of the nitrous oxide samples obtained from the peritoneal cavities is presented in figure 2. The mean concentrations at 10, 20, and 30 min from the time of insufflation were 19.9 ± 4.8%, 30.3 ± 6.8%, and 36.1 ± 6.9%, respectively. The maximum nitrous oxide concentrations measured at each time interval were 36%, 43%, and 47% after 10, 20, and 30 min, respectively.

Flammability Study of Simulated Bowel Gas in Nitrous Oxide/Carbon Dioxide

In figure 3, the percentage of nitrous oxide in carbon dioxide is plotted against the percentage of fuel (methane or hydrogen) in nitrogen that supports combustion (flammability curve). Therefore, for a given fuel, the combinations of fuel and oxidizer that lie above and to the right of the curve are capable of supporting combustion. The maximum observed level of methane in bowel gas is 56%. The concentration of nitrous oxide necessary to support combustion of 56% methane is approximately 47%, the maximum level measured in this study. By contrast, the concentration of nitrous oxide needed to support combustion of 69%

hydrogen is approximately 29%, which is well within the range we measured. Figure 4 illustrates the flammability curve for hydrogen superimposed over the boundaries of that fuel and oxidizer (nitrous oxide). The shaded region in figure 4 represents possible flammable gas combinations achievable during laparoscopic surgery.

Discussion

The use of nitrous oxide as an insufflating agent during laparoscopic surgery has declined in the last 15 yr. Reports on its use appeared in the literature at least until 1984.[5] A theoretical concern by Robinson *et al.* in 1975[6] drew attention to the possibility of an explosion hazard if nitrous oxide were used as the insufflating gas. He theorized that hydrogen and methane could diffuse from the bowel into the peritoneal cavity and ignition spark from the electrocautery could cause an explosion. In a subsequent study,[7] small amounts of hydrogen were measured in the peritoneal cavity. However, it was felt that, unless a bowel perforation occurred, causing a large volume of bowel gas to escape in the peritoneal cavity, the risk of explosion did not outweigh the benefits of nitrous oxide over carbon dioxide, which was known to cause hypercarbia and cardiac arrhythmias during anesthetics in spontaneously breathing patients. The report[8] of an intraabdominal explosion causing the death of a patient undergoing laparoscopic surgery in which nitrous oxide was used as the insufflating gas, as well as other reports of less severe episodes of intraperitoneal combustion,[9] led to the gradual abandonment of nitrous as an insufflation agent in favor of carbon dioxide.

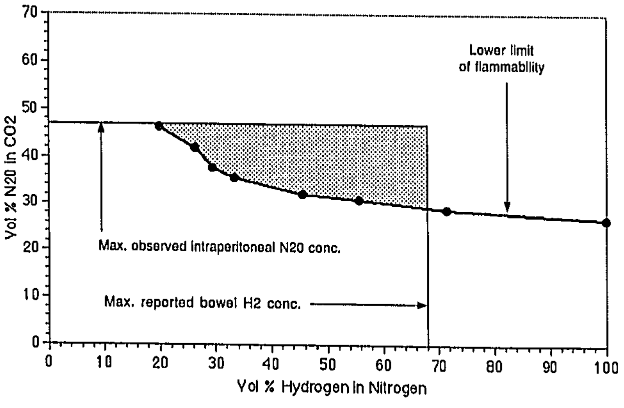

Fig. 4. The flammability curve for hydrogen superimposed over the upper boundaries of hydrogen observed in bowel gas and nitrous oxide recorded in this study. The shaded region represents possible flammable gas combinations achievable during laparoscopic surgery. If the maximum concentration of hydrogen is achieved (69%), an intraperitoneal concentration of 29% nitrous oxide would be necessary to support combustion.

The composition of intestinal gas has been elucidated.[3,4] Five gases—nitrogen, oxygen, carbon dioxide, hydrogen, and methane—comprise greater than 99% of intestinal gas. The composition is highly variable. The maximum measured concentrations of hydrogen and methane in bowel gas reported in the literature are 69% and 56%, respectively. The results of a previous study[10] measuring the concentration of nitrous oxide remaining in the abdomen at the conclusion of a brief laparoscopic examination (mean duration 9.5 min) showed a significant increase in concentration with time (maximum nitrous oxide concentration was 12.8%). In our study, we sampled at defined intervals over a longer period of time. We confirmed the results of the previous study for nitrous oxide concentrations and demonstrated that nitrous oxide concentrations can increase rapidly in the peritoneal cavity. The maximum nitrous oxide concentration measured in our study was 47%, 30 min after beginning insufflation. The theoretical limit of nitrous oxide concentration in a closed internal gas space approaches the alveolar concentration over time.[11]

If the concentration of nitrous oxide is great enough to support combustion of clinically observed concentrations of either methane or hydrogen, a hazard could exist. For methane, the risk is minimal, because, at the maximum concentration (56%), a minimum of 47% nitrous oxide is required to support combustion. This is the observed ceiling for nitrous oxide in our study. However, for hydrogen, as presented in figure 4, there is a large region of potential flammability that is clinically achievable during laparoscopic surgery.

The dynamics of gas exchange in the peritoneal cavity during laparoscopy are complex. Carbon dioxide is continuously insufflated into the abdomen to maintain a previously determined intraabdominal pressure. Carbon dioxide is escaping from the peritoneal by two mechanisms. First, the highly diffusible carbon dioxide (diffusing capacity relative to oxygen of 20.5[12]) is moving out of the peritoneal cavity faster than the less diffusible nitrous oxide (diffusing capacity of 14.0[12]) can move in. Therefore, there is a net loss of peritoneal gas through absorption, which is replaced by the carbon dioxide infusion. Second, there is gas leakage through the puncture site and through the laparoscope during probe insertion and movement. Obviously, the fewer the number of puncture sites, the less the gas leakage, and the less gas turnover. Only one puncture site was used during the laparoscopic procedures in this study.

The composition of the intraluminal bowel gas will change, as well, during the administration of nitrous oxide, and, over time, a combustible mixture may be present within the bowel itself.[11]

We have shown that it is possible for nitrous oxide to reach concentrations in the peritoneal cavity that can support combustion of clinically observed concentrations of methane and, especially, hydrogen. We have not proven that an explosion hazard exists, but our data indicate that an intraabdominal deflagration is possible. There is sufficient oxidizer (nitrous oxide) available; however, the fuel source (methane and hydrogen) is quite variable, both in quantity and in method of entrance into the peritoneal cavity. The extreme case would be an unrecognized bowel perforation in a patient with a large intraluminal gas volume comprised mainly of hydrogen. If this leak went unrecognized for a number of minutes and the gas was subsequently ignited, it might be possible to have an explosion such as the one described above. However, the incidence of bowel perforation and, especially, unrecognized perforation is extremely low and, to our knowledge, there have been no reports of interperitoneal deflagrations during laparoscopies utilizing carbon dioxide insufflation.

As laparoscopic surgical techniques become more complex, the chance of intentional or unintentional bowel perforation becomes more likely. If a bowel perforation is recognized, the peritoneal cavity should be vented and purged with carbon dioxide, and the nitrous oxide removed from the anesthetic mixture. By eliminating or reducing the concentration of nitrous oxide during laparoscopic surgery, this hazard can be minimized or eliminated.

References

1. Dubois F, Icard P, Berthelot GH: Coelioscopic cholecystectomy. Preliminary report of 36 cases. Ann Surg 211:60–62, 1990
2. Johnson WC: Pneumoperitoneum for ventral hernia repair: Anesthesia complications. JAMA 271:968, 1971
3. Levitt MD, Bond JH: Volume, composition and source of intestinal gas. Gastroenterology 59:921, 1970
4. Calloway DH: Gas in the alimentary canal, Handbook of Physiology, vol. V. Edited by Code CF. Washington DC, American Physiologic Society, 1967, pp 2839–2859
5. Chamberlain G: The recovery of gases insufflated at laparoscopy. Br J Obstet Gynaecol 91:367–370, 1984
6. Robinson JS, Thompson JM, Wood AW: Laparoscopy explosion hazards nitrous oxide. Br Med J 3:764, 1975
7. Drummond GB, Scott DB: Laparoscopy explosion hazards with nitrous oxide. Br Med J 1:586, 1976
8. El-Kady AA, Abd-El-Razek M: Intraperitoneal explosion during female sterilization by laparoscopic electrocoagulation. Int J Gynaecol Obstet 14:487–488, 1976
9. Edgerton WD: Laparoscopy in the community hospital: Setup, performance, control, Gynecological Laparoscopy: Principles and Techniques. Edited by Phillips JM, Keith L. New York, Stratton Intercontinental, 1974, pp 79–90
10. Cameron AE, Dear GL, Pocock TJ, Tennant RW: Gas exchange in the abdominal cavity during laparoscopy. J R Soc Med 76:1015–1018, 1983
11. Eger EI II, Saidman LJ: Hazards of nitrous oxide anesthesia in bowel obstruction and pneumothorax. ANESTHESIOLOGY 26:61–66, 1965
12. Nunn JF: Applied Respiratory Physiology. London, Butterworths, 1977, pp 328–329