

Bulk Oxygen and Nitrous Oxide Delivery Systems: Design and Dangers

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A survey of hospitals with anesthesia residency training programs was undertaken to determine the frequency and types of complications encountered with the use of bulk supplies of oxygen and nitrous oxide. Of the responding hospitals, 98 per cent dispense oxygen from a central source and 80 per cent dispense nitrous oxide from a central source. Nearly a third of the hospitals responding reported the occurrence of serious or potentially serious accidents related to their bulk gas delivery systems. In three instances accidents resulted in patient deaths. More than half of the reported incidents were decreases in oxygen pipeline pressure, often resulting in insufficient delivery of oxygen for clinical use. Most complications related to pipeline accidents could have been prevented by observance of National Fire Protection Association regulations. Anesthesiologists should be familiar with these regulations and should understand the designs of gas delivery systems in their institutions. (Key words: Oxygen, supply lines; Anesthetics, gases, nitrous oxide; Equipment, medical gas systems; Operating rooms, medical gas systems.)

DELIVERY of oxygen and nitrous oxide via pipelines from a central source to operating rooms and other areas throughout the hospital is a convenient, economical method of supplying medical gases. Such systems are being used in increasing numbers in hospitals throughout the world. Many physicians have little awareness of the designs of these systems, as well as the complications that can occur with their use. Current design of medical gas systems in the United States is founded

chiefly upon the principles set forth in the standards of the National Fire Protection Association (NFPA) and the Compressed Gas Association (CGA).¹⁻⁵ Both these organizations publish pamphlets that suggest safe standards for installation and use of central gas supply systems. These standards are incorporated into law in only a few states, although they must be observed to obtain hospital accreditation by the Joint Commission on Accreditation of Hospitals.^{6,7} Additionally, most insurance companies require compliance with these regulations.⁸ Unfortunately, there is no regulatory agency to inspect and certify these systems periodically, and in most instances compliance with standards is left to the gas supplier and the individual hospital. As a result, shortcuts may be taken during the installation of the systems to save time or money. The shortcuts can result in fatal complications. Serious complications after installation include crossing of nitrous oxide and oxygen pipelines, loss of pressure in the system, excessive pipeline pressure, switching of Schrader adaptors, filling of the oxygen reservoir with nitrogen, and contamination of the nitrous oxide supply with higher oxides of nitrogen.⁹⁻¹³

No figures on the number of deaths attributable to medical gas pipeline accidents in the United States are available. In the United Kingdom, the Medical Defense Union keeps accurate records of anesthetic complications, which are reported annually to the membership. From 1964 through 1973 there were 29 deaths or permanent complications attributable to problems with the gas supply or anesthetic apparatus in the United Kingdom. Three of those cases resulted from failure or mistakes in the piped oxygen supplies to the operating room.¹⁴ Many of the malfunctions that occur are detected before fatalities occur and are not reported. There is therefore little information regarding the frequency

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TABLE 1. Reported Malfunctions of Gas Delivery Systems

Malfunction	Number of Reports
Insufficient O ₂ pressure	37
Excessive O ₂ and N ₂ O pressure	7
Crossed pipelines	6
Depletion of N ₂ O	5
Failure of low-pressure alarm	4
Leaks in N ₂ O pipeline	3
Leaks in wall connectors	2
Freezing of N ₂ O regulators	2
Low O ₂ flow	2
Supply tanks of O ₂ filled with N ₂	1
N ₂ O stolen	1
Leaks in O ₂ pipeline	1
Water in O ₂ pipeline	1
O ₂ hose exploded due to heat of OR light	1
Malfunction not specified	3
TOTAL	76

and types of malfunctions that occur with these systems.

The present survey was undertaken to ascertain the frequency and types of complications that occur with pipeline medical gas systems in the United States.

Methods

A questionnaire was sent to the directors of all 220 anesthesiology residency training programs listed in the 1974-1975 *Directory of Approved Residencies*. The questionnaire asked whether the hospital had piped oxygen and nitrous oxide. Program directors were also asked whether they were aware of any difficulty with the gas delivery systems. If any difficulty had been experienced, they were asked to describe the malfunction. The returned questionnaires were reviewed by us.

Results and Discussion

Of the 220 questionnaires sent, 193 (88 per cent) were completed and returned. Of those hospitals responding, 190 (98 per cent) use a central supply of oxygen and 152 (80 per cent) also use a central supply of nitrous oxide. Fifty-nine institutions (31%) reported malfunction of their gas delivery systems on one or more occasions during

the tenure of the reporting anesthesia department director. A total of 76 incidents was reported. The types of incidents are summarized in table 1. There were three deaths reported to us. One hospital reported that the tanks used for central oxygen supply were marked to contain oxygen; however, they contained nitrogen. Use of these tanks to supply the hospital was felt to have contributed to the deaths of two infants. Another patient died while being anesthetized in a new operating room where the oxygen and nitrous oxide pipelines were crossed.

LOW-PRESSURE PIPELINE DYSFUNCTIONS

The most frequently occurring malfunction (51 per cent) was partial or complete loss of pressure in the system. Loss of pressure resulted from several factors, summarized in table 2. Damage to the pipeline during hospital construction projects was the most frequent cause of low or absent oxygen pressure. These instances occurred during projects such as the resurfacing of a parking lot and the remodeling of a recovery room, when the oxygen pipeline was cut or crushed by construction equipment. NFPA regulations require that buried pipelines be protected from physical damage. They also require that pipelines within the hospital be protected.² When construction is being done, those responsible for the construction must be made aware of pipeline locations.

Another frequently encountered reason for insufficient oxygen pressure was debris and other material left in the line following installation. Following pipeline installation the line must be completely free of debris. NFPA regulations require that all pipelines be checked to assure that they are gas tight after installation.^{1,2} They also require that each segment of pipeline be checked for pressure differentials, which might indicate the presence of debris.

The delivery capability of the oxygen delivery system was often insufficient for the needs of the hospital. Low pressure occurred on numerous occasions in six institutions because the capacity of the reservoir was too small. We also received two reports of systems that were designed in such a

way that flow rates were insufficient to run ventilators in the operating room. Prior to installation of a medical gas delivery system, hospital engineering and anesthesiology departments must carefully review the hospital's utilization of medical gases and anticipate future needs.

Despite adequate planning, the main reservoir of oxygen sometimes becomes depleted in periods of high use. A reserve supply of oxygen must be available as a back-up for every bulk oxygen delivery system. The reserve supply system should automatically supply oxygen when the main supply becomes depleted or malfunctions. Most reserve supplies consist of several large cylinders whose contents are automatically fed into the system when pressure in the main supply fails.²

Alarms are an important part of an oxygen delivery system. These alarms must be able to detect decreases in pressure before they become clinically important. Alarm signals and gauges must be located where they can be reliably observed. We encountered one report of a hospital that lost oxygen pressure at night. The alarm system was located in the hospital telephone operator's office. It sounded, but the operator did not know what it meant and did nothing about it. We locate our alarms in the hospital engineer's office and in the operating room. Alarms should sound when: 1) the main supply is down to less than an average one day's supply; 2) the pipeline pressure is above or below normal pressure by 20 per cent; 3) the reserve system has been put into use; 4) the reserve supply has fallen to one day's supply.²

Alarm systems have been disconnected or failed to sound. Alarms must be checked periodically. Low-pressure alarms are checked by closing the shut-off valve upstream from the alarm and opening an outlet downstream. As line pressure falls, one observes the operation of the alarm. Testing of high-pressure alarms is difficult since it requires the creation of excessive pressure in the pipeline. The high-pressure alarm can be tested when the reserve system enters the main pipeline downstream from the alarm and the main shut-off valve. With a system such

TABLE 2. Causes of Low or Absent Oxygen Pressure Reported

Etiology	Number of Reports
Pipeline damaged during construction	8
Pipeline obstructed	6
Depletion of O ₂ —insufficient capacity	6
Freezing of regulator during O ₂ delivery	4
Unannounced system shutdown	3
Lightning damage to regulators	1
Wrong wall connectors installed	1
Regulator malfunction	1
Cause not specified	7
TOTAL	37

as this, the hospital can receive oxygen from the reserve system at normal pressure while excessive pressure is created in the area of the alarm.¹⁵

We had one report of low pressure that developed because lightning struck near the liquid supply tank, probably damaging the regulators. The supply tank in this instance was located atop a hill and hence was vulnerable to such damage.

In two institutions line pressure failure occurred when the engineering department shut off the oxygen supply in the middle of the operating room schedule. The anesthesia departments had not been notified of these planned shutdowns. A similar incident also occurred in our operating room.

HIGH-PRESSURE PIPELINE DYSFUNCTIONS

Excessive pipeline pressures have occurred in our hospital and in six others. Such surges of pressure can result in damage to equipment and harm to patients. High pipeline pressures should not occur. NFPA regulations require that all bulk gas delivery systems be equipped with a pressure-relief valve that releases excess pressure when the pipeline pressure rises to 50 per cent above normal. The gas is vented outside the hospital. The valve must shut off when the pressure is released. The safety regulations in the United Kingdom do not require such a valve on liquid oxygen systems.¹⁶ The Department of Health and Social Security of the United Kingdom has not received any report of high pipe-

line pressure in the past 5 years, and hence seems to feel it is unnecessary to have high-pressure alarms.¹⁷ The NFPA, however, recommends that a high-pressure relief valve, properly set, and a high-pressure alarm are components of a medical gas delivery system. Additionally, anesthesia machines should be equipped with pressure gauges and pop-off valves to vent excess pressure. Such an increase in pressure can occur by combustion of foreign material in the pipeline downstream from the main pressure-relief valve. Presently, few commercially available anesthesia machines in the United States provide pipeline pressure gauges and pop-off valves. We feel that these safeguards should be available on all anesthesia machines.

COMPLICATIONS OF NITROUS OXIDE PIPELINES

Crossing nitrous oxide and oxygen pipelines during construction continues to occur and to cause death. We received five reports of crossed nitrous oxide and oxygen pipelines and one report of crossed oxygen and nitrogen pipelines. One death resulted from this error. NFPA regulations require that after installation of any pipeline system the system be checked to be sure that the intended gas is the only gas being supplied.² When hoses in the operating room are sent out for repair, one must also be certain that when they are returned they are fitted with the proper connectors. We had one report of the nitrous oxide hose connector fitting into the oxygen outlet after being sent out for shortening.

We have not surveyed pipeline accidents reported outside the United States. However, crossed oxygen and nitrous oxide pipelines in a leading London hospital recently resulted in irreversible brain damage in a 26-year-old woman.¹⁸ In a 5-month period 23 deaths occurred in a newly constructed wing of a general hospital in Sudbury, Ontario. Four emergency rooms in that hospital supplied with piped-in nitrous oxide and oxygen had their pipelines crossed because of an error in the design plans. Patients receiving oxygen in these emergency rooms received nitrous oxide instead of oxygen. An official inquest found that nine of the 23 deaths were clearly caused by the crossed pipelines. The

causes of death in the remaining 14 cases could not be firmly established. The jury made 66 recommendations, among which were the recommendations that testing procedures for piped medical gases should be legislated and that any new hospital should be inspected and a certificate of worthiness be obtained before use of the medical gas delivery system. The jury also suggested that color coding of each segment of pipe should be utilized during pipeline installation.¹⁹

There were several reports in our survey of depletion of nitrous oxide systems because they were too small to meet demand. Two other hospitals' regulators froze during high use of nitrous oxide. There were three reports of leaks in nitrous oxide pipelines. All regulations regarding pipeline construction, testing and alarms apply equally to nitrous oxide and to oxygen, and must be strictly followed.²

One hospital reported low supplies of nitrous oxide because tanks of nitrous oxide were being stolen. The abuse of nitrous oxide by both medical and non-medical individuals is increasing, especially among young people. Nitrous oxide is usually used without oxygen, and hence the risk of hypoxia and death is great. There should be frequent security checks of nitrous oxide supply systems.

Discussion

The high incidence of serious hazards related to medical gas supply systems is alarming. Although we surveyed only those hospitals with anesthesiology residency programs, our results are in all probability indicative of problems that occur in other hospitals throughout the United States. Lack of compliance with existing NFPA regulations is common. The major reason is that no formal system of inspection exists to assure that hospitals and gas suppliers comply with NFPA regulations. Although compliance with NFPA regulations is required for hospital accreditation, it is unlikely that the Joint Commission on Accreditation of Hospitals makes a detailed inspection of gas supply systems in hospitals at the time of inspection.

We suggest that all physicians be aware of the designs and hazards of medical gas delivery systems. We also recommend that the

systems in all hospitals be reviewed carefully by the hospital engineers, by the suppliers of medical gases, and by the anesthesia department chiefs to insure full compliance with NFPA regulations.

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References

1. NFPA 50, Bulk Oxygen Systems 1974. National Fire Protection Association, 470 Atlantic Avenue, Boston, Massachusetts
2. NFPA 56F, Nonflammable Medical Gas Systems 1974. National Fire Protection Association, 470 Atlantic Avenue, Boston, Massachusetts
3. Oxygen, CGA G-4, Compressed Gas Association, 500 Fifth Avenue, New York, N.Y., 1969
4. Standard for Bulk Oxygen Systems at Consumer Sites, CGA G-4.2, Compressed Gas Association, 500 Fifth Avenue, New York, N.Y., 1964
5. Standard for the Installation of Nitrous Oxide Systems at Consumer Sites, CGA G-8.1, Compressed Gas Association, 500 Fifth Avenue, New York, N.Y., 1964
6. Dormette WHL: Anesthesiologists, hospitals and the National Fire Protection Association. *Anesth Analg (Cleve)* 51:271-276, 1972
7. McCormick JM: National fire protection codes—1968. *Anesth Analg (Cleve)* 47:538-545, 1968
8. Dorsch JA, Dorsch SE: *Understanding Anesthesia Equipment: Construction, Care and Complications*. Baltimore, Williams and Wilkins, 1975, pp 15-25
9. Feeley TW, McClelland KJ, Malhotra IV: The hazards of bulk oxygen delivery systems. *Lancet* 1:1416-1418, 1975
10. Sprague DH, Archer GW: Intraoperative hypoxia from an erroneously filled liquid oxygen reservoir. *ANESTHESIOLOGY* 42:360-362, 1975
11. Mazze RI: Therapeutic misadventures with oxygen delivery systems: The need for continuous in-line oxygen monitors. *Anesth Analg (Cleve)* 51:787-792, 1972
12. Epstein RM, Rackow H, Lee ASJ, et al: Prevention of accidental breathing of anoxic gas mixtures during anesthesia. *ANESTHESIOLOGY* 23:1-4, 1962
13. Clutton-Brock J: Two cases of poisoning by contamination of nitrous oxide with higher oxides of nitrogen during anesthesia. *Br J Anaesth* 39:388-392, 1967
14. Wylie WD: "There, but for the grace of God . . ." *Ann Coll Surg Engl* 56:171-180, 1975
15. Carson W, Gibson E: Piped medical gas systems. *Lancet* 2:84, 1975
16. Hospital Technical Memorandum Number 22, Piped Medical Gases, Medical Compressed Air and Medical Vacuum Installation, Department of Health and Social Security, H. M. Stationery Office, London, 1972
17. Bolton J: Piped medical-gas systems. *Lancet* 2:231-232, 1975
18. The Times, London, No. 59, 486, August 28, 1975, p 2
19. The Toronto Star, April 10, 1974