catheter and meticulous postoperative follow up and care of such patients.

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Minimal-flow Nitrous Oxide Anesthesia

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The common practice of using high flows of nitrous oxide and oxygen for anesthesia is wasteful[1–3] and is responsible for pollution of the atmosphere of operating rooms which may have harmful effects on health of personnel.[4–7] Availability of an oxygen electrode[8] has made it practical to measure within seconds the concentration of oxygen in an anesthetic system, thereby permitting the use of nitrous oxide in a closed system. The following report presents data accumulated using an oxygen electrode to minimize the waste of nitrous oxide and other agents during clinical anesthesia.

Methods

Three groups of adult patients were studied. Current anesthetic methods were employed, namely, induction with thiopental, relaxation where necessary with gallamine, succinylcholine, and *d*-tubocurarine, and flows of 3½ l of nitrous oxide and 1½ l of oxygen for 15 to 20 minutes to eliminate nitrogen from the system and provide for absorption of generous amounts of nitrous oxide. At 15 minutes or shortly after, the flows of both N_2O and O_2 were decreased for the first group of 118 patients to quantities which would maintain the inflow concentration of O_2 at 35 per cent (arbitrarily chosen) and would keep the reservoir bag at a constant volume. This necessitated minute-to-minute adjustments of gas flows. Oxygen concentrations were monitored throughout the procedures using Hudson, Harlake, and Foregger oxygen meters, which were calibrated daily with pure oxygen and room air. Minute flows of gas necessary to achieve these conditions were recorded each 5 minutes. Ventilation of the patients was measured by means of either a graduated bellows or a Wright ventilation meter. Respiration was manually controlled at 1.5 times that predicted from the Radford nomogram.[9]

Group II consisted of 108 patients who were anesthetized as were those of Group I, but were mechanically ventilated at 1½ times the level predicted from the Radford nomogram 15 to 25 minutes after induction. Gas flows were decreased to 300 ml O_2 and 200 ml N_2O using either halothane or methoxyflurane as needed. The oxygen concentration of the inhaled gas was monitored and data were recorded each 5 minutes.

A third group of 117 patients was anesthetized and mechanically ventilated as in Group II, with the exception that gas inflows at 20 minutes were decreased to 500 ml each of N_2O and O_2. Data were recorded at one, two and three hours.

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Results

The scatter of values for uptake of nitrous oxide for Group I patients was great at the 15-minute period, but data became more consistent as time progressed. The average nitrous oxide uptake was less than 100 ml/min at 35 minutes, then slowly decreased further as saturation with nitrous oxide was approached. The average uptake at 60 minutes was 73 ml/min (table 1).

The concentration of inhaled oxygen gradually decreased as Group II patients absorbed less nitrous oxide with approaching saturation. The oxygen concentration did not drop below 30 per cent in any patient weighing less than 80 kg within the first 60 minutes. It was not allowed to drop below 20 per cent in any patient, but a few patients weighing more than 80 kg needed increased flows of oxygen when the concentration approached 20 per cent. Average oxygen concentrations at two and three hours were 33 and 29 per cent (table 2).

Average values of inhaled oxygen concentrations at one, two and three hours in Group III patients were 37, 34, and 30 per cent (table 3). The numbers of patients involved diminished with time because relatively few operations lasted three hours.

Discussion

Some years ago, it was found that patients were adequately oxygenated when gas flows of 500 ml each of N_2O and O_2 were used.[2] Because of lack of easy determination of oxygen concentrations, no attempt was made at the time to use nitrous oxide in a closed system.

In 1966, Smith[10] reported that patients breathing spontaneously absorbed 75 ml/min of N_2O at 60 minutes. Our figure of 73 ml/min of N_2O is close to that found by Smith, and indicates that nitrous oxide can be used in a closed anesthetic circuit when the oxygen concentration is monitored.

The situation with Group II differs. Because of a small gas leak from the ventilator, a completely closed system was not utilized. The results indicated that all patients weighing less than 80 kg were adequately oxygenated using 300–200-ml flows. The lowest

TABLE 1. Nitrous Oxide Flow into a Closed Circuit to Maintain 35 Per Cent Oxygen

	Minutes after Induction							
	15	20	25	30	35	40	45	60
Number of patients	18	56	94	118	115	112	103	60
Nitrous oxide, ml/min	406	221	163	111	96	86	78	73
Standard deviation	232	122	101	54	37	37	27	24

TABLE 2. Per Cent Oxygen Using 300 ml/Min Oxygen and 200 ml/Min Nitrous Oxide

	Minutes after Induction											
	15	20	25	30	35	40	45	50	55	60	120	180
Number of patients	39	92	97	106	105	108	104	101	96	94	30	7
Average per cent oxygen	42	42	41	41	40	40	39	38	38	37	33	29
Standard deviation	4	4	4	4	4	4	5	5	5	5	4	4
Oxygen, per cent, lowest individual value, patients weighing less than 80 kg	34	31	32	32	31	30	30	30	30	30	24	22

TABLE 3. Per Cent Oxygen Using 500 ml/Min Each of Nitrous Oxide and Oxygen

	Minutes after Induction		
	60	120	180
Number of patients	117	25	10
Per cent oxygen	37.5	34.0	30.4
Standard deviation	4	3	4
Oxygen, per cent, lowest individual value, patients weighing less than 80 kg	30	27	21

individual values encountered were 30 per cent at 60 minutes, 24 per cent at 120 minutes and 22 per cent at 180 minutes. Confidence in using this flow rate to ventilate average-sized patients safely is suggested; those who weigh more than 80 kg should either be monitored when this flow is used or be given higher flows of oxygen.

Lin[3] stated that 300 ml/min each of nitrous oxide and oxygen gave prolonged satisfactory oxygenation of patients. Even though Lin's patients were somewhat smaller than North Americans, our results lead us to refrain from giving a 300–300-ml mixture of nitrous oxide and oxygen for any length of time. Most of the oxygen will be used for metabolic requirements, leaving a rather large amount of nitrous oxide that is not absorbed when uptake of nitrous oxide becomes less than 100 ml/min.

The data for Group III in which patients received 500 ml each of N_2O and O_2, were remarkably in agreement with those for Group II, in which patients received only half as much total gas flow. Average oxygenation values were within 1 per cent of each other at corresponding times in the two groups.

Cullen[11] has suggested that flows of 200 ml/min of oxygen and 200–400 ml/min of nitrous oxide might be used. Our data indicate that somewhat less nitrous oxide is necessary. Advantages cited by Cullen include better observation of changes in ventilation, decreased cost of agents, high humidification, and elimination of possible pathologic entities due to pollution.

In conclusion, it appears that adequate oxygenation can be maintained for as long as three hours in patients during controlled ventilation at inflow rates of 300 ml O_2 and 200 ml N_2O/min. During spontaneous ventilation, N_2O uptake averaged 73 ml/min at one hour.

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