THE USE OF THE NONREBREATHING METHOD OF ANESTHESIA

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At present there are two methods in common use of administering anesthesia by an apparatus, the closed system technique with complete rebreathing and the semiclosed system technique with partial rebreathing. Both of these methods present certain hazards to the anesthetized patient. These hazards can be avoided by the use of a nonrebreathing method of anesthesia.

In any closed system with a carbon dioxide absorber the following hazards exist: (1) increased respiratory resistance; (2) accumulation of water vapor in the inspired gases; (3) increased temperature of the inspired gases; (4) possible increase of the arterial carbon dioxide content, and (5) dilution of the gases in the reservoir bag by nitrogen, carbon dioxide and water vapor.

All of these hazards exist as well with the semiclosed system and partial rebreathing, although to a lesser degree. In addition, certain anesthetic agents are incompatible with the use of the carbon dioxide absorber technique.

Increased Resistance: In a closed or semiclosed system a negative pressure develops within the mask during inspiration and a positive pressure during expiration. Resistance to the passage of gases raises the pressure values in either negative or positive phases or both. It is from 2.5 to 3 mm. of water in the to-and-fro system and from 5 to 8 mm. in the circle system (1). It is influenced by the size of the apertures between masks, canisters, breathing bags, intratracheal tubes, size and shape of canisters, length and type of connecting tubing, construction and type of valves and size of granules of absorbent. The narrower the diameters and the longer the conduits are, the greater is the resistance; the wider the diameter and the shorter the conduits, the smaller is the resistance. Increased resistance means increased effort on the part of the patient. The patient at the extremes of age with his poorly developed muscles is frequently unable to overcome this resistance. This leads to the same picture as a partial upper respiratory obstruction, namely, increased respiratory effort, ineffective ventilation, intercostal muscle fatigue, hypoxia, accumulation of carbon dioxide and poor intake of anesthetic agents resulting in inadequate

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anesthesia as well as derangement of the normal physiology. Thus, continued increased inspiratory resistance may produce increased negative intrapulmonary pressure which may lead to pulmonary edema (2) and continued increased expiratory resistance, may produce a positive intrapulmonary pressure which may lead to increased peripheral venous pressure and decreased cardiac output (3). Although this factor is of minor importance in the average adult undergoing anesthesia of short duration, it becomes significant in pediatric and geriatric anesthesias as well as in prolonged anesthesia.

Accumulation of Water: In the closed system, water is formed when the carbonic acid unites with the hydroxide to form water and carbonate. Mainly because of this liberated water and partly owing to the water vapor of the exhaled gases, the relative humidity becomes nearly 100 per cent (4). This heavy saturation with water of the atmosphere in the anesthetic apparatus prevents the patient's lungs from vaporizing water and thereby reduces the heat loss; a rise in body temperature takes place which raises the temperature in the atmosphere. This increased temperature increases the amount of water the gases will hold. Thus, a vicious circle takes place (5). Furthermore, the excess of water vapor may dilute the oxygen content of the inspired gas mixture and produce anoxia. It dilutes the anesthetic gas and binds ether and other water miscible agents, thereby interfering with proper anesthetization. It may cause respiratory obstruction and produce pulmonary edema or atelectasis. Cole (5) suggested that edema of the brain with failure to regain consciousness following anesthesia may be the result of poor water loss through the lungs, kidney and skin. He also stated that it may not be unreasonable to suppose that a condition of water intoxication may be present during deep anesthesia accompanied by marked retention of water, particularly when large amounts of nonsaline fluids are administered intravenously, and that unanticipated cases of "extrarenal uremia" or lower nephron nephrosis may possibly be explained on this basis. Furthermore, episodes of excessive diaphoresis during anesthesia may be an attempt at compensatory water loss through the skin when the lungs have been prevented from performing this function.

Increased Temperature of the Inspired Gases: The absorption of carbon dioxide in the closed system technique is a chemical process in which the liberation of heat accompanies the chemical reaction. This is the heat of neutralization and is brought about as the carbonic acid combines with the hydroxide to form water and carbonates. Approximately 14,000 calories are liberated for each 22.2 liters of carbon dioxide absorbed (4). Because of this heat the temperature of the inspired gases is increased. The average temperature at the face piece is 32 to 33 C. in the circle filter and is 39 to 41 C. in the to-and-fro system. Temperatures as high as 42 C. have been reported (6). This increased temperature is objectionable because it interferes with the heat regulating function of the lungs. The lungs help to lower the body heat; normally they accomplish this in two ways. First, they warm the tidal air and thus lose heat directly. Second, they vaporize the water and thus yield the heat of vaporization. In a closed system and, to a lesser degree, in a semiclosed system, the difference between the temperature of the inhaled and of the exhaled gases may be abolished, thereby preventing the heat loss by the first mechanism. Also, because of the heavy saturation of the gases with water, the loss of water through the lungs becomes abolished, thus preventing heat loss by the second mechanism (5).

Increase of the Arterial Carbon Dioxide Content: In a closed system the removal of the carbon dioxide from the gas mixture is effected solely by the carbon dioxide absorber in the canister. In a semiclosed system a portion of the carbon dioxide is also exhaled into the atmosphere. In either case the concentration of carbon dioxide in the gas mixture depends on the state of efficiency of the carbon dioxide absorber. A fresh charge is sufficiently efficient to return a carbon dioxide concentration as low as 0.01 per cent and as the charge is used a progressive rise in carbon dioxide concentration takes place. The exhaustion of the charge manifests itself in the signs of carbon dioxide retention. Mousel *et al.* (7) have stated, however, that "percentages as high as 2 per cent of carbon dioxide are often impossible to detect by clinical observation of the patient's tidal volume, respiratory rate, pulse and blood pressure changes. Influences of ether, light anesthesia and pain stimulus detract from the ability to judge carbon dioxide build up by simple observation when the absorbent is becoming inefficient." It is only recently that high increases in arterial content of carbon dioxide during anesthesia have been recognized as capable of producing anesthetic disasters. Beecher (8), reviewing the literature on current problems of anesthesia in the period between 1936 and 1939, recorded that if anoxia is present it may lead to hyperventilation and consequent low arterial carbon dioxide tension. If the anoxia is then relieved the respiration will fail from the low carbon dioxide. He quoted Lundy, Tuohy and Adams in their report of the use of carbon dioxide as a respiratory stimulant in 84,202 cases, without apparent untoward results and in many instances of advantage to the patient. Waters stressed the danger of carbon dioxide excess in producing hypertension, then later hyperpnea and fall in blood pressure with depression of respiration. Attention was likewise called to the dangers of hyperventilation in causing atelectasis. These and subsequent reports on anesthesia emergencies and fatalities stressed the dangers of anoxia but rarely of carbon dioxide retention (9–13).

With thoracic surgery becoming a more widely used procedure, findings of dangerously high levels of carbon dioxide in the blood were reported by Beecher and confirmed by others (14–16). Young *et al.* (17) produced hypercapnia in dogs by allowing them to breathe 20 per cent carbon dioxide mixtures and demonstrated that the effect on the heart of vagal stimulation was greatly enhanced. But hypoxia even in the presence of carbon dioxide excess diminished vagal stimulation on the heart. Brown and Miller (18) anesthetized 15 dogs with sodium pentothal and allowed them to breathe a mixture of 40 per cent carbon dioxide in oxygen for four hours, which was followed by a rapid reduction of alveolar carbon dioxide tension. Eleven of the 15 dogs promptly went into ventricular fibrillation and death; the surviving dogs showed cardiac arrhythmias. This group (19) then continued this experiment on a second set of dogs by allowing the concentration in the inspired air to increase to a final level of 80 per cent carbon dioxide until cardiac arrest appeared. The heart rate was consistently depressed during these periods of high carbon dioxide concentrations.

Finally, it is well to report the work of Draper and his associates (20) who were able to have their animals survive for prolonged periods of time in an apneic state provided they were denitrogenated and given 100 per cent oxygen. They found, however, that carbon dioxide tension was considerably elevated despite their oxygenation.

Quiet breathing during anesthesia may result in ineffective alveolar ventilation. Thus, an anesthetic mixture containing a high oxygen content may allow oxygenation of the blood to occur by diffusion respiration as shown by Draper even though the respiratory exchange is insufficient for the removal of the carbon dioxide. The anesthesiologist is, therefore, lulled into a sense of safety that the good color of the patient's skin and blood proved that oxygenation was adequate while the blood and tissues continued to show a high level of carbon dioxide retention. Patrick and Faulconer (21) corroborated these findings in clinical anesthesia.

Ineffective alveolar ventilation which leads to an increase in arterial carbon dioxide tension, if it is continuous, will lead to severe derangement of the normal physiology. This may eventuate into cardiac arrhythmias including ventricular fibrillation or asystole during the operation and make the patient more vulnerable to the effects of surgical trauma, shock and hemorrhage. Postoperatively, the sudden loss of high carbon dioxide tension may produce profound vascular collapse such as so-called cyclopropane shock (22).

Dilution of the Gases in the Reservoir Bag: With a closed or semiclosed system, it becomes obvious that the contents of the inhaled gases are composed not only of the gases delivered by the anesthesia apparatus but also of the exhaled nitrogen, carbon dioxide and water vapors unless they are effectively removed. As has been shown by Crowley *et al.* (23), unless vigorous flushing of the bag is performed, the gases in the reservoir bag become diluted to the point where the oxygen tension reaches anoxic levels. The heavy saturation of the gases with water vapor as well as a high carbon dioxide content may also interfere with proper oxygenation.

Incompatibility of the Carbon Dioxide Absorber with Certain Anesthetic Agents: Certain of the inhalation agents cannot be administered by the carbon dioxide absorber method because of their decomposition into injurious products in the presence of heat. These agents are chloroform, trichloroethylene and ethyl chloride.

TECHNIQUE

We have modified the Stephen-Slater valve and have adopted it to our method of nonrebreathing technique. The modification consists of the substitution of the rubber disk expiratory valve by one of the pop-off type. This valve can be regulated to permit more or less of the expired gases to escape or it can be shut off completely if this is found necessary for assisted or controlled respiration. Furthermore, we employ a small hollow metal tube shaped in the form of an "L," one arm of which fits into the opening of the mask and the other arm slips into the Stephen-Slater valve. For small children we use the original Stephen-Slater valve because the rubber disk expiratory valve offers a minimum of resistance. We use a reservoir bag of 2 liter capacity for children and of 5 liter capacity for adults. The patient is given medication preoperatively and prepared for operation in the usual manner. In the adult anesthesia is begun with a 0.4 per cent solution of thiopental given as an intravenous drip. As soon as the lid reflex is abolished the mask is applied to the patient's face and the inhalation agents are permitted to flow into the reservoir bag. We have used nitrous oxide, 6 or 7 liters, and oxygen, 2 or 3 liters, per minute. Ethylene can be given in the same manner. A total volume of 8 to 10 liters per minute must be given in adults, this amount being an adult's average respiratory minute volume. Trichloroethylene may be added to the gas-oxygen mixture. The same procedure can be followed with ether, chloroform or ethyl chloride.

TABLE 1

Anesthetic Agents	No. of Procedures
Thiopental + nitrous oxide	267
Thiopental + nitrous oxide-ether	114
Thiopental + nitrous oxide-trichloroethylene	87
Nitrous oxide + ether	63
Nitrous oxide + trichloroethylene	50
Total	581

RESULTS

The nonrebreathing technique was used in the administration of a total of 581 anesthetics in the various combinations listed in table 1. In none of these were there any complications attributable to the technique of administration. The longest procedure in this group lasted three hours and twenty minutes, the shortest procedure lasted five minutes. It was our impression that less thiopental was used with this method than with the partial rebreathing technique. This might be because of the better utilization of the narcotizing effect of the nitrous oxide in the absence of higher levels of nitrogen and carbon dioxide in the mixtures.

Not only were smaller amounts of intravenous anesthetic agents used, but the postoperative recovery time was definitely shortened (table 2). In many instances even after an hour of anesthesia, the patient awoke before leaving the operating room. Those patients who had received thiopental and nitrous oxide anesthesia and who had awakened early in the postoperative period did not lapse again into a deep sleep, which is often associated with intravenous anesthesia. Consequently, the postoperative period was not fraught with the danger of respiratory obstruction sometimes resulting in sudden death (24).

Although large total volumes of nitrous oxide were used to keep the reservoir bag inflated, the corresponding volume of oxygen used was

TABLE 2

Anesthetic Agents Combinations	Average Amounts Used				Average Duration of Anesthesia, min.	Average Recovery Time, min.
	Thiopental, mg.	Nitrous Oxide, liters	Ether, cc.	Trichloroethylene, cc.		
Thiopental & nitrous oxide	750	525	—	—	75	15
Thiopental & nitrous oxide & ether	400	288	12	—	48	7
Thiopental & nitrous oxide & trichloroethylene	200	228	—	3	38	2
Nitrous oxide, ether	—	350	21	—	50	10
Nitrous oxide, trichloroethylene	—	154	—	1	22	1

never below 20 per cent in order to avoid any danger of hypoxia. The blood pressure and pulse rates did not show marked rises and falls which could be considered attributable to the nonrebreathing technique. The skin of the patient even in the older group undergoing hip-nailings remained warm and dry throughout the procedure. In the group of young children none showed severe bouts of tachypnea, pallor, diaphoresis, hyperpyrexia and exhaustion occasionally seen with the open and semiopen methods of administration of anesthesia. Lightening of anesthesia frequently occurred in this group. In those patients who had received muscle relaxant drugs, such as succinylcholine, it was a simple matter to seal the expiratory valve and install assisted respiration if it became necessary.

DISCUSSION

The use of the nonrebreathing technique of administering anesthesia introduces many advantages over the open drop, semiclosed and closed techniques and their modifications. Those listed by Stephen (25) in pediatric anesthesia are also applicable in anesthesia for adults. The elimination of the necessity for soda lime greatly decreases the resistance, as well as avoids water accumulation, increased temperature of the inspired gases and possible carbon dioxide retention. Gaseous acidosis is prevented since excess carbon dioxide is exhaled.

The Stephen-Slater valve in the system with its rubber flaps decreases the resistance so that fatigue, exhaustion and adverse intrapulmonary pressure changes are practically nil. Denitrogenation need not be a concern. The partial pressures of the inhalation agents in the reservoir bag will more closely approximate the readings of the flowmeters. Thus maximal utilization of the anesthetic agents along with adequate oxygenation can be accomplished. The nonrebreathing technique makes it difficult to attain deep planes of anesthesia with the inhalation agents, thus avoiding physiological derangement of the cardiovascular system, liver and kidneys. Patients are able to withstand prolonged surgical procedures under light planes of anesthesia complemented with muscle relaxant drugs (26).

The relative inability to achieve high concentration of trichloroethylene with the nonrebreathing method prevents the incidence of cardiac arrhythmias and other attendant dangers of a halongenated compound. Trichloroethylene cannot be used with the carbon dioxide absorber technique since contact with the soda lime will produce the toxic products, phosgene, acetylene and hydrochloride acid. The nonrebreathing technique is thus ideal for the use of this noninflammable and nonexplosive anesthetic agent in many procedures which require the presence of hazardous equipment.

The disadvantage of the nonrebreathing method is that it is less economical than the closed system. Since a child requires 5 to 7 liters and an adult 8 to 10 liters per minute of the inspired gases for an effective ventilation volume, a greater total of gases is necessarily used. The advantages, however, are well worth the increased cost in preventing increased vulnerability to the effects of shock, hemorrhage and prolonged surgical procedures.

Another disadvantage may be the inability to use cyclopropane with the nonrebreathing technique, both from the point of view of cost and fire and explosion hazards.

Summary

The method of the nonrebreathing technique has been presented.

Its applicability with the various combinations of anesthetic agents employed has been demonstrated.

The advantages of this technique over the semiclosed and closed techniques have been shown to be prevention of carbon dioxide excess, of heat retention, of excess water and of increased intrapulmonary resistance.

REFERENCES

1. Adriani, John: The Chemistry of Anesthesia, Springfield, Illinois, Charles C Thomas, 1947, pp. 96–100.
2. MacIntosh, R. R., and Mushin, William W.: Physics for the Anaesthetist, Springfield, Illinois, Charles C Thomas, 1947, pp. 203–207.
3. Best, C. H., and Taylor, N. B.: The Physiological Basis of Medical Practice, Baltimore, The Williams and Wilkins Co., 1945, p. 138.
4. Adriani, John, The Chemistry of Anesthesia, Springfield, Illinois, Charles C Thomas, 1947, pp. 72–83.
5. Cole, F.: Water Accumulation as Hazard of Rebreathing in Anesthesia, J.A.M.A. 151: 910–913 (March 14) 1953.
6. Adriani, John: The Chemistry of Anesthesia, Springfield, Illinois, Charles C Thomas, 1947, pp. 94–95.
7. Mousel, L. H.; Weiss, W. A., and Gilliom, L. A.: Clinical Study of Carbon Dioxide Absorption During Anesthesia, Anesthesiology 7: 375–398 (July) 1946.
8. Beecher, H. K., Some Current Problems of Anesthesia, Surgery 7: 931 (June) 1940.
9. Adriani, J.: Some Hazards of Anesthesia, New Orleans M. & S. J. 98: 324–330 (Jan.) 1946.
10. Potter, G. J.: Physiology of Anesthesia and Resuscitation, Ann. West. Med. & Surg. 1: 114–118 (May) 1947.
11. Noble, A. B.: Anaesthetic Emergencies, Canad. M. A. J. 56: 490–496 (May) 1947.
12. Etsten, B., and Himwich, H. E.: Management of Anoxia During Pentothal Anesthesia, Am. J. Surg. 76: 268–271 (Sept.) 1948.
13. Failing, J. H.: Anesthetic Disasters, Ann. West. Med. & Surg. 6: 293–296 (May) 1952.
14. Beecher, H. K.: Severe Acidosis Associated with Trans-Thoracic Surgery, N.I.H. Bull. (Jan.) 1950.
15. Beecher, H. K.; Quinn, T. J., Jr.; Bunker, J. P., and D'Alessandro, C. L.: Effect of Position and Artificial Ventilation on Excretion of Carbon Dioxide During Thoracic Surgery, J. of Thoracic Surg. 22: 135–148 (Aug.) 1951.
16. Taylor, F. H., and Roos, A.: Disturbances in Acid-Base Balance During Ether Anesthesia with Special Reference to Changes Occurring During Thoracic Surgery, J. Thoracic Surg. 20: 289–295 (Aug.) 1950.
17. Young, W. G., Jr.; Sealy, W. C.; Harris, J. S., and Botwin, A.: Effects of Hypercapnia and Hypoxia on Response of Heart to Vagal Stimulation, Surg., Gynec. & Obst. 93: 51–55 (July) 1951.
18. Brown, E. B., Jr., and Miller, F.: Ventricular Fibrillation Following a Rapid Fall in Alveolar Carbon Dioxide Concentration, Am. J. Physiol. 169: 56–60 (April) 1952.
19. Brown, E. B., Jr., and Miller, F.: Tolerance of Dog Heart to Carbon Dioxide, Am. J. Physiol. 170: 550–554 (Sept.) 1952.
20. Draper, W. B.; Whitehead, R. W., and Spencer, J. N.: Studies on Diffusion Respiration; Alveolar Gases and Venous Blood pH of Dogs During Diffusion Respiration, Anesthesiology 8: 524–533 (Sept.) 1947.
21. Patrick, R. T., and Faulconer, A.: Respiratory Studies During Anesthesia with Ether and with Pentothal Sodium, Anesthesiology 13: 252–274 (May) 1952.
22. Dripps, R. D.: Immediate Decrease in Blood Pressure Seen at Conclusion of Cyclopropane Anesthesia; "Cyclopropane Shock," Anesthesiology 8: 15–35 (Jan.) 1947.
23. Crowley, J. H.; Faulconer, R. A., and Lundy, J. S.: Certain Factors Influencing Percentage of Oxygen in Mixtures of Nitrous Oxide and Oxygen, Anesth. & Analg. 27: 255–261 (Sept.–Oct.) 1948.
24. Milowsky, J., and Betcher, A. M.: Postoperative Recovery Unit, New York Med. 9: 248–251 (March 20) 1953.
25. Stephen, C. R.: Technics in Pediatric Anesthesia—Nonrebreathing Method, Anesthesiology 13: 77–85 (Jan.) 1952.
26. Stephen, C. R.: Relation of Light or Deep Anesthesia to Shock, Anesthesiology 13: 540–544 (Sept.) 1952.
27. Cassels, W. H.; Becker, T. J., and Seevers, M. H.; Convulsions During Anesthesia; Experimental Analysis of Role of Hyperthermia and Respiratory Acidosis, Anesthesiology 1: 56–68 (July) 1940.