

NITROUS OXIDE-OXYGEN
ANESTHESIA, WITH A DESCRIPTION OF
A NEW APPARATUS.

By WALTER M. BOOTHBY, A.M., M.D.
OF BOSTON.

Read at the Annual Meeting of The Massachusetts Medical Society,
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I.—HISTORICAL REVIEW.

In December, 1844, or January, 1845, Dr. Horace Wells* of Hartford, Conn., on the invitation of Professor John Collins Warren, addressed the latter's class in surgery on the subject of rendering the system insensible to pain during the performance of surgical operations; at the close of his remarks Wells invited the students to witness in the evening in a public hall, on Washington Street, an administration of nitrous oxide gas for this purpose to a boy whose tooth was to be extracted.

The exhibition took place, and although not entirely successful in abolishing pain, yet it deserves commemoration as being the first public attempt to demonstrate the fact that the body could safely be rendered insensible to pain for operative procedures. You will note that this trial preceded by nearly two years the public demonstration of the

* Wells, Horace: A History of the Discovery of the Application of Nitrous Oxide Gas, Ether, and other Vapors to Surgical Operations. Hartford: J. Gaylord Wells, 1847. (The Boston Medical Library contains a copy which belonged to and was evidently annotated by W. J. Morton: 82. C. 87.)

anesthetic properties of ether by Morton* at the Massachusetts General Hospital on October 16, 1847.

I will delay you a moment with the very interesting account of the accidental discovery of the anesthetic properties of nitrous oxide: G. Q. Colton, a traveling entertainer of the type then common in New England, was giving an exhibition of the effect of "laughing gas" in the City of Hartford on December 10, 1844, of which he has given the following account: † "Among those who inhaled it was a young man by the name of Cooley, who, while under its influence, in jumping about, ran against some wooden benches or settees on the stage, bruising his legs badly. After taking his seat, he was astonished to find his legs bloody; and said he did not know that he had run against a bench, and felt no pain until after the effects of the gas had passed off. Dr. Wells, who sat next to him, noticed the circumstance; and, as the audience was retiring, asked me why a man could not have a tooth extracted without pain while under its influence. . . . The next morning—Dr. Riggs having been called in—I administered the gas to Dr. Wells and Dr. Riggs extracted a molar tooth for him. Dr. Wells on recovering, exclaimed: "It is the greatest discovery ever made! I didn't feel so much as the prick of a pin!"

In the next few days Wells used the gas successfully on ten or twelve cases; elated with his success he then went to Boston to demonstrate it with the result noted. On account of his practical failure in Boston his discovery attracted little attention. However the anesthetic property of nitrous oxide was recorded in literature in 1845 by the following statement of Ellsworth‡ in a comprehensive article "On the

* Warren, J. Mason: Inhalation of Ethereal Vapor for the Prevention of Pain in Surgical Operations. *Boston Medical and Surgical Journal*, 1846, XXXV. 375-379. Trustees Report Mass. Gen. Hosp., Boston, 1848.

† Colton, G. Q.: Anesthesia, Who Made and Developed this Great Discovery? Sherwood & Co., New York, 1886. (esp. pages 4 and 5.)

‡ Ellsworth: On the Modus Operandi of Medicine, page 396. *Boston Medical and Surgical Journal*, 1845, XXXII, 369-377; 389-400.

Modus Operandi of Medicine": "The nitrous oxide gas has been used in quite a number of cases by our own dentists, during the extraction of teeth, and has been found, by its excitement, perfectly to destroy pain. The patients appear very merry during the operation, and no unpleasant effects follow."

In spite of the attention attracted to it by the controversy* over the discovery of anesthesia, which started after Morton's demonstration of ether no one seems to have attempted to confirm the value of nitrous oxide, and it passed into practical oblivion. For its revival we are indebted to our friend Colton, the traveling entertainer, from whose account I will again quote: "When in New Haven, in June, 1863, I was preparing to give an exhibition of the amusing effects of the gas, and invited a number of gentlemen to attend a private preliminary entertainment at which I gave a history of the discovery of anesthesia, and detailed the experiments of Wells; stating that I had never been able to induce a dentist to try the gas. Dr. J. H. Smith, a distinguished dentist of New Haven, who was present, said to me that he would be very glad to try the gas, provided I would administer it. I replied that I would be very glad to do it, as I wished to demonstrate what could be done with it. . . The first patient who came in was a wealthy old lady, for whom we extracted seven teeth with the gas. On recovering she was so pleased with the result, that she said I might mention her name to my audience. . . I did so. In three weeks and two days, we extracted a little over three thou-

* Ether Controversy: Report of Special Committee of House of Representatives, 1849, Thirtieth Congress—Report No. 114.

Jackson: First Practical Use of Ether in Surgical Operations—A Manual of Etherization. Mansfield, Boston, 1861.

Sims: The Discovery of Anesthesia. Being a statement of the claims of Crawford W. Long to its first use in 1842. *Virginia Medical Monthly*, 1877, May.

Morton: Original depositions of sworn testimony deposited before Judge Putnam. Boston Medical Library, 1853.

sand teeth. This success induced me to abandon the 'Exhibition' business, and to establish an institution in New York called the Colton Dental Association. . . I have given it to over 150,000 patients without a single death. I have the autograph signatures, all numbered, of every patient in my office."*

From this beginning the use of nitrous oxide for the painless extraction of teeth spread rapidly in America, but very slowly in Europe until Colton demonstrated its value in Paris to Dr. Evans† in 1867; the latter, after a series of a thousand cases, visited England where he was invited to demonstrate its use at the Dental Hospital of London. Its use now spread with great rapidity, and naturally the best methods of administration were much discussed; in this connection I will quote to you the directions as given by Colton‡ to the editor of the *British Journal of Dental Science*: "Let a bag containing eight gallons of gas be used, and anesthesia is reached before the oxygen is absorbed and no ill effect attends the operation. The presence of a small amount of carbon dioxide in the bag, produced by breathing into it, produces no harm, *so long as there is an excess of oxygen.*"

The next year, 1868, Professor Andrews§ of the Chicago Medical School, appreciating the advantages of nitrous oxide as an anesthetic, proposed to substitute pure oxygen instead of air, thus rendering prolonged anesthesia possible. His article is very interesting as it consisted of an extended series of animal experiments which showed that nitrous oxide, to which one fifth part of oxygen had been added, could successfully maintain anesthesia for an extended time.

* Colton: *ibid*, pages 9 and 10.

† Evans, Parkinson, and others: Nitrous Oxide. *British Journal of Dental Science*, 1868, XI (see index).

‡ Colton: Experience in the Use of Nitrous Oxide. *British Journal of Dental Science*, 1868, XI, 253-257.

§ Andrews: Oxygen Mixture, A New Anesthetic Combination. *Chicago Medical Examiner*, 1868, IX, 656-661.

However the paper attracted little attention and was apparently soon forgotten.

Not for ten years was another serious attempt made to use nitrous oxide for prolonged anesthesia; then in 1878 Professor Paul Bert* of Paris reasoned as follows: "The fact that nitrous oxide must be administered in a state of purity, signifies that in order to impregnate the organism with a sufficient quantity of the gas, its tension must be equal to the pressure of a single atmosphere . . . hence if we suppose the patient placed in an apparatus where the pressure can be raised to the equivalent of two atmospheres, the necessary tension will be secured by respiration of a gaseous mixture containing 50% nitrous oxide and 50% of air. . . Therefore as a consequence of the presence of a normal quantity of oxygen in the blood, all the natural conditions of respiration are maintained. . . Entering the cylindrical chamber, and increasing the atmospheric pressure by one fifth, I compel a dog to breath a mixture containing five sixths of nitrous oxide and one sixth of oxygen—a mixture in which it is evident that the tension of the gas is exactly equal to the tension of an atmosphere—which gives . . . a good anesthesia."

In 1881 Klikowitsch† demonstrated the value of nitrous oxide to relieve the pangs of labor; he combined nitrous oxide with oxygen in a large gasometer with the oxygen at about 20%, and administered it direct to the patient without increasing the pressure. Döderlein‡ in 1886, and

* Bert: Sur la possibilité d'obtenir à l'aide du protoxyde d'azote, une insensibilité de longue durée et sur l'innocuité de cet anesthésie. Comtes rendus, 1878, Nov. 11, p. 728.

Gazette medicale de Paris, 1878, 108, 498, 579.

Lutand: L'anesthésie par le protoxyde d'ozote sous tension. Méthode de M. Paul Bert. *Gaz. hebdom.*: 1879, XXVI. 14, 213-214; 39, 613-614.

† Klikowitsch: Ueber das Stickstoffoxydul als Anaestheticum bei Geburten. *Arch. f. Gynakologie*, 1881, XVIII. 81-108.

‡ Döderlein: Ueber Stickoxydul-Sauerstoffanästhesie. *Arch. f. Gynakologie*, 1886, XXVII. 85-101.

Hillisher* in 1887 continued the work and confirmed the results of Klikowitsch. At the same time Hewitt† was studying nitrous oxide anesthesia in England, and in 1886 published a study of the question of rebreathing so strongly advocated by many users especially Coleman‡ (1868); his conclusion was that it was permissible only to a slight extent. Somewhat later, becoming acquainted with the work of Hillisher, Hewitt studied the "Effects produced in the Human Subject by the Administration of Definite Mixtures of Nitrous Oxide and Air, and of Nitrous Oxide and Oxygen"; this he published in 1889, followed in 1892 by a more extended account, with the description of a very satisfactory apparatus.

From this time on nitrous oxide and oxygen have been used in some clinics more or less frequently for general surgical work. Wherever such use has been at all extended, the most favorable reports of the great value of this form of anesthesia have been made. Its use seems to depend on the availability of an anesthetist willing to master the mechanical difficulties of producing a smooth surgical narcosis by means of any of the existing apparatuses. Gatch§ of Johns Hopkins has so far obtained the best results largely because he understands the physiology of breathing as demonstrated by Haldane and his co-workers in England and also appreciates the importance of carbon dioxide in its relation to shock as shown by Henderson of Yale.

* Hillisher: Ueber die Verwendung der Stickstoffoxydulsauerstoff gemenges zu Narkosen. *Deut. Monatschrift f. Zahnheilkunde*, 1887 (Sept.); *Centralblatt f. Chir.*, (1888, XV. 115).

† Hewitt: An Inquiry into the Several Methods of Administering Nitrous Oxide. *British Dental Assoc. Jour.*, 1886, VII. 86-90; 152-160; 208-215.

Hewitt: On the Anæsthetic Effect of Nitrous Oxide with Oxygen at Ordinary Atmospheric Pressures. *Transactions Odontological Soc.*, 1892, XXIV. 8, 194-244.

‡ Coleman: Re-inhalation of Nitrous Oxide. *British Med. Jour.*, 1868, I. 410; II. 114-115. *St. Bartholomew's Hosp. Reports*, 1869, V. 153-164.

§ Gatch: Nitrous Oxide Anæsthesia by the Method of Rebreathing. *Jour. Am. Med. Ass.*, 1910, LIV. 775-780.

Likewise Miss Hodgins,* the anesthetist to the Lakeside Hospital, Cleveland, under the direction of Crile, has been successful. Her success I attribute in a large part to the use of gases under moderate tension, and at room temperature; this is due to the fact that the gases are manufactured in the cellar of the Hospital and piped to the operating room under moderate pressure (about 30 lbs.).

II.—SUMMARY OF THE PHYSIOLOGICAL AND CLINICAL FACTS TO BE CONSIDERED IN MODERN SURGICAL ANESTHESIA.

To-day, nitrous oxide-oxygen anesthesia is generally credited as being the method of choice provided it be found practicable from a mechanical standpoint by those who have made a study of the subject. The physiological and clinical facts forming the basis of this opinion may be summarized under the following seven heads:

- (1) Safety of the patient.
- (2) Complete surgical relaxation.
- (3) Agreeableness and rapidity of induction.
- (4) Agreeableness and rapidity of recovery.
- (5) Tendency to the avoidance of shock.
- (6) Tendency to the avoidance of post-operative distension or ileus.
- (7) Absence of post-operative complications.

(1) Statistical studies lead us to the conclusion that nitrous oxide is the safest of anesthetics and is recommended even where ether cannot be used. Ether is the next in safety.

(2) Complete surgical relaxation can usually be obtained by gas and oxygen alone; however, it can always be obtained by the addition of very minute quantities of ether vapor; the quantity needed is so small that it has hardly an appreciable after-effect; that is, it does not produce post-operative nausea.

* Hodgins: Personal communication to Dr. F. J. Cotton, Boston.

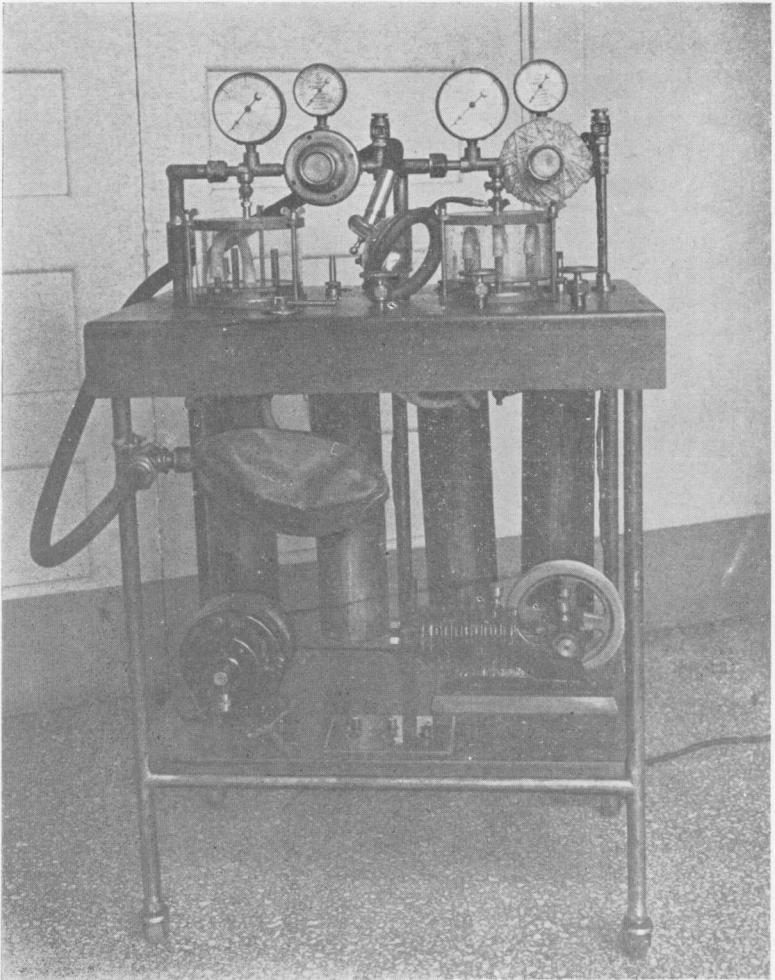
(3) The agreeableness and rapidity of the induction of nitrous oxide anesthesia are too well known to need more than mention.

(4) The rapidity as well as the minimal discomfort of recovery are also known to you all, at least by heresay, to be convinced of the great difference from that of the recovery from an ether anesthesia; all that one needs to do is to talk with some patient who has experienced both methods. In this connection Dr. Cotton, who instigated my work on this subject, informs me that in Cleveland, according to Dr. Crile,* the patients are actually beginning to demand its use.

(5) The question of shock is of such importance that I wish time allowed me to do more than mention the points to be considered: As you know, the most generally accepted hypothesis of shock is that of exhaustion of the vasomotor centre; perhaps you also know that this hypothesis has been shown experimentally to be untenable because the clinical picture of shock and the characteristic fall of blood pressure may be present while the vasomotor centre still gives a normal reflex response to the stimulation of afferent nerves. Moreover, it has been shown that the peripheral vessels are not dilated in shock, as they would be were the vasomotor centre exhausted; on the contrary they are constricted.

Coincidentally Haldane and his colleagues in England have shown the importance of the carbon dioxide content of the blood in regard to the regulation of respiration. Very recently Henderson, of Yale, has shown that the CO_2 content of the blood is also, probably, an important element in the regulation of blood pressure, perhaps by its influence on the tonicity of the veins; that is, as Henderson maintains, a decrease of the CO_2 content of the blood by excessive respiration causes the veins to dilate and the production of the picture of shock. The point here to be made is that ether as it is usually given does cause excessive respiration, and excessive respiration causes a reduction of the CO_2 content

* Personal communication to Dr. Cotton.



of the blood. One advantage of nitrous oxide anesthesia is that the respiration is less disturbed; however, if deep and frequent respirations are caused by the peripheral irritation of the operative procedures their tendency to produce an injurious reduction of the CO_2 content can be offset by means of a slight but constant rebreathing.

The much decreased tendency to the production of shock by an operation under nitrous oxide-oxygen anesthesia can easily be demonstrated to any one who will carefully watch a few cases. I here wish to emphasize the point that I do not imply that a skilfully conducted ether anesthesia produces a picture of profound shock; what I do mean is that the picture of ether recovery as represented by an increase in the pulse rate, wet clammy skin, marked pallor with most distressing nausea and vomiting lasting twenty-four to forty-eight hours, producing an almost absolute loss of morale, are all reduced and ameliorated when nitrous oxide-oxygen has been the anesthetic.

(6) Henderson has also shown that peristalsis is decreased by lowering the CO_2 content of the blood; if this observation is confirmed it would explain the clinical fact that after a nitrous oxide-oxygen anesthesia the patient suffers less from gas-pains, distension, and abdominal distress than after the ordinary administration of ether.

(7) Post-operative complications, so far as we can judge, will be greatly reduced. This will be especially true of those of the lung on account of the practicability of efficiently warming the gases.*

III.—DESCRIPTION OF A NEW APPARATUS WHICH ELIMINATES THE MECHANICAL AND OPERATIVE DIFFICULTIES OF ADMINISTRATION.

One of the chief reasons why nitrous oxide-oxygen anes-

* References to the literature on which the above is based can be found in the recent articles of Henderson in the *American Journal of Physiology*.

thetia has not in the past been more generally used has been the mechanical difficulties attending the same. For when I took up this subject last year, I could find no apparatus described in literature or on the market (aside from the manufacture of the gases on the premises) which would meet the fundamental requirement: a smooth even flow of the two gases. That this even flow is essential even a brief consideration of the matter renders evident, for only by such an even flow can one obtain a uniform mixture to administer to the patient. Further, the flow of the respective gases must be regulated easily in order to bring the mixture to the desired proportions of nitrous oxide and oxygen. Likewise it is essential that adequate provision be made for the addition of ether vapor to be able in all cases to obtain complete relaxation. A less vital though still important point is warming the gases.

My interest in taking up this matter practically as a surgical method was first focused by the enthusiasm of Dr. F. J. Cotton on his return from an observation (of some days duration) of the surprising results daily shown in Crile's clinic in Cleveland. Accordingly, at the suggestion of Dr. Cotton and with his help and that of Dr. Albert Ehrenfried, I designed and had built an apparatus which meets all these conditions. The important points I will now go over in more detail.

In the first place both gases are taken from high pressure steel cylinders, which in the case of nitrous oxide have a pressure of about 700 pounds to the square inch, and in the case of oxygen the pressure is sometimes as high as 2,000 pounds to the square inch; truly excessive pressures from which to attempt to give a smooth flow of gases to a human being and expect an even surgical anesthesia. To obviate this difficulty it is necessary to reduce this pressure automatically by means of a reducing valve to a working pressure of about twenty pounds to the square inch; a pressure

from which the volume of each gas desired can be easily regulated by means of a hand valve.

In the second place the use of reducing valves introduces a mechanical complication which has to be overcome; namely the formation of a connection between the tanks and the apparatus without leakage; also provision must be made for the renewal of tanks without interrupting the use of the apparatus. This is obtained by a specially designed casting consisting of four yokes arranged in pairs so that two nitrous oxide and two oxygen tanks can be clamped on together with appropriate cutout valves and drill holes leading to the reducing valves. To insure the nitrous oxide reducing valve from freezing it is surrounded by an electric heating coil.

Thirdly, it is essential to be able to judge of the amount of each gas that is being used, for otherwise it is impossible to even approximate a correct mixture. This knowledge is obtained by passing the gases through water into a mixing chamber; the rate of the bubbling of the gas through the water gives a very accurate index of the percentages of the two gases as administered to the patient. In addition, this procedure adds a desirable degree of moisture to the gases.

The fourth important point is the arrangement for the addition of the desired amount of ether vapor that is necessary in some cases to obtain complete relaxation. As the amount varies within wide limits there is provided an ether chamber of large evaporating area and a three way exit valve. This valve is so arranged that when closed no ether is added to the gas mixture going to the patient. By opening it gradually, an increasing amount of the nitrous oxide-oxygen mixture can be made to pass over the surface of the ether; should occasion ever arise for an extremely strong ether percentage the valve when pushed still further causes the gases to bubble through the ether. This valve is placed very handily beside the oxygen valve, as these two are the only ones that need attention during the progress of an anesthesia.

The fifth consideration is that of efficiently warming the anesthetic mixture just before inhalation. This is conveniently obtained by passing the mixture through an electric heater which delivers the gases at a temperature about half-way between the room temperature and the body temperature.

Lastly, the question of rebreathing is taken into account by arranging the inspiratory or inlet valve on the mask so that its action can be partly or entirely eliminated, while at the same time the expiratory or outlet valve is arranged with a spring which, by an increase in tension, partially or completely closes the valve. Thus we may control rebreathing to any proportion of the respiratory volume. By this means each expiration may be partly rebreathed; the amount of the gases that escape through the expiratory valve are replaced by a corresponding amount of fresh gases; by this partial method of rebreathing a smoother CO_2 regulation is maintained than when the intermittent complete rebreathing method is used. This point is very important in the prevention of CO_2 loss from an excessive respiration due to peripheral irritation as pointed out in the previous section. It is also of direct benefit in the production of a relaxed anesthesia under nitrous oxide, because a large amount of this gas as well as oxygen must be absorbed for this purpose. As Haldane and others have pointed out, a slight increase in the CO_2 percentage of the inspired air doubles the volume of the air or mixture inhaled by stimulation of the respiratory center, consequently this increased depth and rate of respiration renders more nitrous oxide and oxygen available to the blood. (This must not be confused with an increased depth and rate of respiration which is a reflex result of peripheral irritation and which causes an undesirable reduction of the CO_2 content, unless provision is made to offset the same by rebreathing.)

In addition the apparatus is equipped with an electric motor and air pump for use when air is desired as a carrier for

ether in such cases as are found unsuitable for gas-oxygen anesthesia. Whether or not, for intratracheal work, the the gas-oxygen ether or the air ether mixture will be found most suitable is yet to be determined. For the use of the intratracheal method there is a separate connection from that to the mask, in the circuit of which is placed a mercury safety-valve to prevent the danger of undue intrathoracic pressure; a danger which without question must be efficiently overcome.

At first glance this apparatus may look complicated and difficult to use, and therefore like its predecessors appear impracticable. Such is, however, not the case, as these seeming complications remove from the anesthetiser all operative difficulties; in fact they need no attention, thus leaving him free to give his whole thought to the patient. After becoming acquainted with the nitrous oxide-oxygen ratio of the patient the hand valves need not be touched for intervals of 5 or, sometimes, 10 minutes. The details of operative technic I will reserve for a future paper.

IV.—CONCLUSIONS.

(1) The first attempt to give a public demonstration that the body could be safely rendered insensible to pain for surgical procedures was made in Boston by Dr. Horace Wells, a dentist of Hartford, Conn., with nitrous oxide in December, 1844, or January, 1845, nearly two years before the demonstration of ether by Morton at the Massachusetts General Hospital, on October 16, 1846.

(2) Nitrous oxide-oxygen anesthesia, with the addition of such minimal quantities of ether vapor as may be needed, is the anesthetic of choice.

(3) The general use of this anesthetic is dependent on the perfection of an apparatus which overcomes the mechanical and operative difficulties attending its administration.

(4) Such an apparatus is described.

