THE DEVELOPMENT OF ANESTHESIA

(Conclusion)

THOMAS E. KEYS, A.B., M.A.* †

Washington, D. C.

ENDOTRACHEAL ANESTHESIA AND MISCELLANEOUS SUBJECTS

It is well known that Vesalius (128) in 1542 passed a tube into the trachea of an animal, the thorax of which had been exposed; by blowing into the tube he was able to maintain artificial respiration. According to Gillespie (128), Robert Hook performed a similar experiment before the Royal Society in 1667. After these early experiments, intubation of the trachea was employed as a therapeutic procedure in asphyxia and drowning, often with dire results. John Snow (23), whose contributions to anesthesia have been mentioned previously herein, apparently was the first to produce endotracheal anesthesia in an animal. He performed tracheotomy on a rabbit and into the resultant opening he inserted a wide-bore tube. The animal was made to breathe through this tube and into and out of a bag filled with the vapor of chloroform.

Apparently, Friedrich Trendelenburg (129) was the first to use this procedure on man. In 1871, to prevent aspiration of blood into the lungs during an operation on the upper air passages, Trendelenburg performed preliminary tracheotomy and passed a wide-bore tube into the trachea. Attached to the tube was an inflatable cuff. This provided watertight contact with the tracheal wall. The tube was connected by a length of rubber tubing to a gauge or flannel-covered funnel. Anesthesia was accomplished and continued by the dropping of chloroform onto the gauze or flannel.

William MacEwen (130) in 1880 found it possible to obtain endotracheal anesthesia without resorting to tracheotomy. He desired to maintain continuous anesthesia, and also to protect the respiratory tract from the possible aspiration of blood in the removal of a malignant lesion situated at the base of the tongue. To do this he inserted a metal tube into the trachea by way of the mouth. Chloroform was administered through the tube, the laryngeal opening was packed off and the operation was successfully performed.

To meet the needs of anesthesia in otolaryngologic operations, Karel Maydl, professor of surgery at the University of Prague, in 1893, modified the apparatus O’Dwyer (131) had invented for intubation of

* Reference Librarian, The Mayo Clinic, on leave of absence.
† Capt., Sanitary Corps, A.U.S., Assistant to the Librarian, Army Medical Library, Washington, D. C.
the larynx for the relief of patients suffering from diphtheria. Maydl (132) connected a Trendelenburg funnel to an O'Dwyer tube, and the result apparently was satisfactory.

Using Maydl's technic, Victor Eisenmenger (133) constructed an apparatus which he described in the same year (1893) as that in which Maydl's work was done. This consisted of a wide-bore semirigid tracheal tube in which was carried an inflatable cuff modeled after that of Trendelenburg.

According to Matas (134), Truehead of Galveston, Texas, reported in 1869 on an apparatus of which the purpose was to insufflate air into the lungs by means of an intubating cannula. The mouthpiece of this apparatus was connected to a bellows which automatically injected and aspirated air in and out of the trachea. In this machine Truehead anticipated the Fell-O'Dwyer apparatus.

In 1880, according to Matas (134), O'Dwyer published his preliminary article on intubation of the larynx for the relief of asphyxia caused by acute or chronic laryngeal obstruction. Some time later, George H. Fell, of Buffalo, New York, invented an apparatus for artificial respiration. This he demonstrated at the International Medical Congress held in Washington on September 7, 1893. It consisted of a hand bellows connected to a tube which was inserted into the trachea. Fell modified his original apparatus by substituting a face mask for the trachectomy tube. This mask fitted closely over the nose and mouth. Air was forced into the larynx through the natural passages, and expired air was allowed to escape by a side outlet in the injecting tube.

Because of the disadvantages of the oronasal apparatus of Fell, O'Dwyer made a much needed modification of it. O'Dwyer's improvement consisted of a long intubation cannula fitted with a conical tip graduated so that it would fit variations in the size of the larynx. The external end consisted of two branches; one branch received the ingoing air from the bellows; the other branch served as an exit for the air (fig. 30). Although O'Dwyer's apparatus had been anticipated by many experimenters, his machine was remarkable for its simplicity and efficiency.

Matas devoted much time and work to attempts to improve thoracic surgery. The chief difficulties encountered in surgery of the thorax previously had arisen from the making of large surgical openings in the thorax. These permitted the rapid and free entrance of air, followed by collapse of the lungs. This in turn led to cyanosis, defective oxygenation and arrested respiration. Older surgeons afforded some relief to their patients in cases of penetrating wounds of the thorax by sealing the opening. But when they were confronted by tumors of the thorax or mediastinum, most surgeons of the eighteenth and nineteenth centuries refused to operate, because of the notoriously poor results of surgical intervention in such cases.

Matas, in 1897, read of the experiments of Tuffier and Hallion (135).
These men inserted a long copper tube attached to a bellows into the larynx of a dog. Artificial respiration being established by this means, the pleura was freely incised through an intercostal space. The edges of the wound were kept apart to allow free circulation of air. The pleural cavity was illuminated by a small incandescent lamp. It then became easy to operate on the esophagus and pneumogastric nerve without interfering with respiration.

At about this time Matas also read in the *Medical and Surgical Reports of the Presbyterian Hospital* of New York for 1896 an article on the use of the Fell-O'Dwyer apparatus for the treatment of opium narcosis in nonsurgical conditions. In these cases, artificial respiration was prolonged by the use of the Fell-O'Dwyer apparatus and re-
spiratory failure was overcome. His reading of the aforementioned two papers suggested to Matas a method for the solution of the problems of surgery of the thorax. He elaborated his ideas before the Louisiana State Medical Society in 1898 (136), recommending use of the Fell-O’Dwyer apparatus to prevent the disastrous results of acute pneumothorax in thoracic operations. Dr. F. W. Parham (137), a colleague, profited by these remarks; using the suggestions of Matas, he successfully resected the wall of the thorax for a sarcoma.

Matas not only was the first to advocate intralaryngeal insufflation for intrathoracic surgery, but he also modified the Fell-O’Dwyer apparatus for the maintenance of anesthesia while artificial respiration was

![Fig. 31. The Matas modification of O’Dwyer's intubating apparatus with anesthesia attachment. (From Matas, Rudolph: Intralaryngeal Insufflation, J. A. M. A. 34: 1465-1473 (June 9) 1900.)](image)

being applied (fig. 31). He altered the laryngeal cannula by furnishing a branch and stopcock to which a rubber tube and funnel were connected. The funnel was covered with flannel and was used as an inhaler.

Franz Kühn of Kassel, Germany, published his first communication of a series on endotracheal anesthesia in 1900, and in 1902 he published a paper on nasal intubation. At about this time, to abolish the idiosyncrasy of a patient to chloroform, Rosenberg recommended the local application of cocaine to the nose. Kühn also advocated the use of cocainization as a very helpful adjunct to intubation.

In 1907, Barthélemy and Dufour (138) of Nancy advocated use of the insufflation principle of endotracheal anesthesia. This study anticipated, to a large extent, the work of S. J. Meltzer and John Auer (139).
The last-mentioned investigators published the results of their researches in 1909: they demonstrated that if air were blown into the trachea of an animal whose respiratory mechanisms had been paralyzed, full oxygenation of the blood could be maintained. Not long afterward (1910) Charles A. Elsberg (140) succeeded in clinical application of the work of Meltzer and Auer. In 1912 Charles H. Peck (141) and later many others also demonstrated the application of this principle to clinical anesthesia. Meanwhile, in 1911, F. J. Cotton and

![Fig. 32. Dennis E. Jackson (courtesy of Dr. Jackson).](image)

Walter Boothby (142) had advocated the endotracheal insufflation of mixtures of oxygen and nitrous oxide. Chevalier Jackson's invention of the direct-vision laryngoscope also contributed to the success of endotracheal anesthesia. By its use intubation was made more nearly certain and more nearly accurate.

In 1915, Dennis E. Jackson (143) (fig. 32) published a remarkable article in which he described a method for the production and maintenance of prolonged anesthesia or analgesia by means of nitrous oxide, ethyl chloride, ether, chloroform, ethyl bromide, somnoform, and others, with oxygen. Jackson's method involved the continuous process of rebreathing by the experimental animal of gaseous or volatilized anes-
thetic agents from which the exhaled carbon dioxide had been removed. Sodium hydrate and calcium hydrate were used to absorb the exhaled carbon dioxide. Oxygen was constantly added in proportions suitable to maintain the animal in good physical condition. Jackson did not have an opportunity to try his experiments on human beings, but suggested that human patients could be anesthetized by his method. He demonstrated his equipment at the sixty-seventh annual meeting of the American Medical Association in Detroit in 1916. There Jackson stated that the cost of this nitrous oxide-oxygen anesthesia should be approximately thirty-two cents per hour. This was considerably less expensive for patients than other techies had been, since at that time the usual cost of nitrous oxide-oxygen anesthesia was about $2.50 per hour. Very few members of his audience thought his method was practicable. At the Washington University School of Medicine in Saint Louis, however, Dr. Otto Henry Schwarz and his son Dr. Otto Henry Schwarz, Junior, and Dr. Willard Bartlett, gave Jackson some encouragement. The Drs. Schwarz performed a number of examinations in the obstetrics department of that university, using nitrous oxide-oxygen anesthesia produced with Jackson’s machine (fig. 33). Dr. Pessl successfully produced anesthesia a number of times by the employment of Jackson’s machine. Once he anesthetized a patient for Dr. Bartlett, who removed a thyroid gland. In the summer of 1918, Dr. Jackson offered his machine to the Medical Corps of the United States Army, but nothing came of this.

Dr. Ralph M. Waters, then of Sioux City, Iowa, however, became very much interested. In 1920, he wrote to Jackson, asking for reprints and suggestions. Jackson cooperated and Dr. Waters (144) demonstrated clinically the work Jackson had done so well experimentally. Waters’ apparatus was somewhat simpler than Jackson’s. It consisted of a face mask, a container for granulated soda lime which opened into a large rubber bag, and a rubber tube leading from the bag to the nitrous oxide and oxygen tanks. The great advantage of this type of anesthesia was of course the remarked reduction in expense to the patient, as had been predicted by Jackson.

Further improvement in insufflation anesthesia was achieved during the first World War. At this time, I. W. Magill and E. S. Rowbotham were serving with the British Army Plastic Unit as anesthetists. For their type of patient, insufflation endotracheal anesthesia was well suited. They also found it possible to improve upon the technic. It was found desirable to pass a second tube into the trachea to act as a return airway for the escaping vapor. For operations involving the mouth, they learned to pass the tube through the nose into the pharynx and thence, by the help of a guiding rod or forceps, into the trachea. After more experience, Magill and Rowbotham found it possible to intubate the trachea “blindly” without the use of other instruments.

It then occurred to these anesthetists that anesthesia possibly could
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be more economically produced if only one wide-bore tube were inserted into the trachea and the patient were allowed to inhale and exhale through it. This arrangement they called the "semiclosed" method.

Fig. 33. Model of Dennis Jackson's first anesthetic apparatus (courtesy of Dr. Jackson).

In function it resembled the function of normal respiration, and was highly successful. Gwathney and McKesson, in the United States, and Boyle in England, found it feasible to produce this type of anesthesia in
many cases. Other advantages of inhalation endotracheal anesthesia were that true asepsis and undisputed possession of the operative field were assured the surgeon in operations on the head and neck.

In 1924, as has been mentioned, Waters perfected Jackson’s carbon dioxide absorption technic. Guedel (145), working with Waters, wrote concerning the importance of the inflatable cuff in 1928. The absorption technic, with the use of the inflatable cuff, as mentioned by Gillespie, made possible the development of true inhalation endotracheal anesthesia.

Brian C. Sword started to investigate the possibilities of a circle filter about 1926. According to Sword (146), the apparatus gener-

![Fig. 34. Arthur E. Guedel (courtesy of Dr. Lundy).](image)

ally employed for the carbon dioxide absorption method of anesthesia, consisting of a canister and bag at the face, was awkward in that it was too close to the field of operation. In an effort to surmount this difficulty, Sword consulted Professor Yandell Henderson, of the Yale University School of Medicine. Richard v. Foregger aided in the construction and, in 1928, the first apparatus was built. The apparatus was so made that the inspiratory and expiratory phase ran in the same direction. This required a separation by means of valves and two tubes: one for inspiration and one for expiration. The two tubes were connected by a “Y” so that they could be applied to a mask. The canister and rebreathing bag were attached 2 feet (61 cm.) away and, when this “circle” type of respiration was used, it made little difference where the bag was placed. It was thus removed from the field of operation.
In this connection it is interesting to note that J. A. Heidbrink's first machine, an improvement of the original Teter gas machine, provided for rebreathing. Dr. Heidbrink (147) improved on the Teter machine in 1906. The Teter machine had two bags, one for nitrous oxide and one for oxygen. Dr. Heidbrink added a third bag for rebreathing.

In 1927, Dr. Heidbrink developed a "round trip" absorber. This he displayed that year at a medical meeting in Minneapolis. He withheld it from the market for some time, believing that the absorber prin-

![Fig. 35. Wesley Bourne (Courtesy of Dr. Bourne).](image)

ciple would complicate anesthetic technic. In the meantime, "round trip" absorbers were brought out by Mr. Richard Foregger and Dr. Ben Morgan. This required that the Heidbrink machine be supplied with an absorber; hence, their two-chamber absorber was designed and built.

Arthur E. Guedel (fig. 34) in the fall of 1941 was the recipient of the third award of the Henry Hill Hickman Medal. So that the reader may gain some idea of the importance of this award, it can be said that on November 17, 1931, the Royal Society of Medicine accepted from the Henry Hill Hickman Memorial Committee the sum of 200 pounds for the creation of a bronze medal in commemoration of Hickman. The
24th May 1935.

Dear Sir,

It is my pleasant duty to inform you that the Council of the Royal Society of Medicine has unanimously decided to make the first award of the Hickman Medal to you upon the recommendation of the Council of the Section of Anaesthetics of this Society.

The Hickman Medal was founded in 1931 and its award is made for original work of outstanding merit in anaesthesia or in subjects directly connected therewith. The Deed of Foundation lays down that the first award should be made in 1935 and subsequent awards at intervals of not less than three years. The award is open to any person of any nationality. I enclose a reproduction of both sides of the medal which is struck in bronze.

I am having the Medal prepared and despatched to you as soon as possible.

May I ask you to accept my personal congratulations on this first Award.

Believe me,

Yours faithfully,

P.R. Edmunds
Secretary,
Royal Society of Medicine.

Wesley Bourne Esq., M.D.,
Royal Victoria Hospital,
Manchester.

enclo.
24th June 1935.

Dear Sir,

Thank you for your kind letter which I will lay before my Council at its next meeting.

I am to-day sending you under separate cover the Hickman Medal.

This Medal is carried out in bronze, is designed by R. Paget and is struck for us at the Royal Mint. On the one side is a portrait of Henry Hill Hickman and on the other side is an allegorical representation of Pain being banished by Anaesthesia. For this purpose we have personified Anaesthesia as a beautiful woman, Pain as a kind of devil who has held the patient by his chain. Anaesthesia has, as you will see, broken the chain binding the patient to Pain and is banishing him with an imperious gesture. He scowls at her holding his broken chain and his now useless scourge.

Yours faithfully,

[Signature]

Secretary.

Wesley Bourne Esq., M.Sc., M.D.,
32, Holton Avenue,
Westmount,
Montreal, Canada.

Fig. 36. Letters from the Royal Society to Dr. Bourne, a, announcing the first award of the Hickman Medal, and b, explanation of the Hickman Medal.
medal was and is awarded by the Council of the Royal Society of Medicine on the recommendation of the Council on the Section of Anaesthesiology. It is granted not oftener than triennially for original work of outstanding merit in anesthesia or in subjects relating thereto. This medal was first awarded in 1935 to Wesley Bourne of Montreal (figs. 35 and 36a and b). The second award was made in 1938, to Ivan Whiteside Magill, of London, whose contributions already have been discussed.

The interests of Guedel in anesthesia can be traced back for many years. In 1909 he devised the technic of the self-administration of nitrous oxide and air for obstetrics and for minor surgical operations that could be performed in the physician’s office. His first report (148) on this subject appeared in 1911. This type of anesthesia was especially valuable in obstetric cases. As the patient received warning of an approaching pain, she placed the inhaler to her nose and breathed deeply a few times; then began to breathe normally. Intermittent anesthesia was thereby induced with each pain. In his pamphlet (149), “The Self Administration of Nitrous Oxid,” Guedel said that about 75 per cent of the gas is rebreathed. His apparatus contained a respiratory valve which regulated the percentage of air to be mixed with the gas and the amount of the gas mixture to be rebreathed.

Although Dr. Guedel has made important contributions in the development of new anesthetic agents, such as in demonstrating the anesthetic action of divinyl oxide, earlier referred to herein, and his work on cyclopropane, as well as his work on carbon dioxide absorption, his outstanding contribution has been his emphasis on the importance of the physiologic factors in inhalation anesthesia. In May, 1920, his first paper on this subject appeared in print (150). This paper was a reflection of his experiences with the American Expeditionary Forces during World War I. In France he found it convenient to teach his colleagues the significance of certain reflexes under various stages of anesthesia. Guedel’s conceptions of the “signs of anesthesia” have been brought up to date in his recent monograph (151). Accepting the suggestions and observations of others, notably Miller, Waters and Shields, Dr. Guedel divided anesthesia into four stages as follows: (1) stage of analgesia; (2) delirium or “dream” stage; (3) surgical stage; and (4) stage of respiratory paralysis. Dr. Guedel also has classified the various physical reactions which occur at various stages of anesthesia. These include respiration, activity of the eyeballs and the pupils, the eyelid reflex, the “area of swallowing” and the “area of vomiting.”

Albert H. Miller (152), of Providence, Rhode Island, in 1925 published the results of his study of ascending respiratory paralysis as it occurs when the patient is under the influence of general anesthesia. Dr. Miller was able to demonstrate that at the commencement of anesthesia, respiration is of the usual or mixed type. As anesthesia deepens, after a period of delayed thoracic respiration, the abdominal type
of respiration appears. After a few inspirations, thoracic inspiration begins; it commences midway in the period of abdominal inspiration. A little later, thoracic inspiration occurs, but still is further delayed. Finally, abdominal inspiration begins. If the anesthetic dosage is further increased, paralysis of the costal muscles becomes more complete, and the condition of exaggerated abdominal respiration occurs. This is an indication of the presence of profound anesthesia.

J. U. Human (155), of Plaistow, London, England, reported in 1938 a new sign in anesthesia called "chin retraction." The sign consists of a downward movement of the larynx and chin with each inspiration. It occurs in the third stage of anesthesia. According to Human, this sign is sometimes called "tracheal tug."

There are other terms familiar to many anesthetists that deserve an emphasis in this historical study. Such a term is "balanced anesthesia." This was suggested by Lundy (154) in 1926 to indicate the use of a combination of anesthetic agents and methods so balanced that part of the burden of relief of pain is borne by preliminary medication, part by local anesthesia and part by one or more general anesthetic agents. Lundy (155) recently has suggested that as more anesthetic agents become available, the tendency may be to use several agents and methods during a single operation. The advantage of this newer development is that it leads to greater flexibility and more (relative) safety.

"Ether percentages" and "anesthetic tension" are subjects that need some clarification. Dr. Walter Boothby, who was in charge of the metabolism laboratory at the Peter Bent Brigham Hospital for several years and who served as lecturer on anesthesia in the Harvard Medical School from 1914 to 1916, did much work in and developed the aforementioned subjects. He has made important contributions to the physiology of anesthesia, in addition to his assistance of a technical nature. Boothby's interest in anesthesia machines dates back to about 1910. He was stimulated by the enthusiasm of Dr. F. J. Cotton on the basis of Cotton's observations made at the Cleveland Clinic. Accordingly, and with the help of Cotton and that of Albert Ehrenfried, Boothby (156) designed the Cotton-Boothby nitrous oxide-oxygen ether apparatus. As has been mentioned earlier, Cotton and Boothby (142) also developed the use of nitrous oxide-oxygen anesthesia produced by endotracheal insufflation. Karl Connell, with the use of the anesthetometer, which he devised in 1913, showed that anesthetic tension; that is, the tension of ether vapor necessary to produce narcosis in man, is about 50 mm. of mercury. Boothby (157) confirmed Connell's work and found that the optimal dosage of ether vapor for man is between 47 and 53 mm. of mercury. He further demonstrated that patients vary but slightly in their susceptibility to ether.

The anesthetometer of Connell was also found to be useful in the determination of ether percentages. Boothby (158) suggested that
surgical anesthesia depends on the establishment in the blood and tissues of a definite ether tension corresponding to about 15 per cent of ether vapor in the alveolar air. He further demonstrated that in order to induce anesthesia quickly, air containing approximately 30 per cent of ether vapor should be administered for a period of from two to twelve minutes.

Frank Mann (159, 160), using the Connell apparatus, tested the vascular reflexes of dogs with various tensions of ether vapor. He found that the physiologic reactions which occur during anesthesia with ether vary with remarkable constancy. The lowest ether tension that will allow operative work on dogs is about 36 mm. of mercury. Any tension between 36 and 45 mm. of mercury is safe so far as the life of the animal is concerned, but tensions between 48 and 50 mm. are likely to prove fatal.

The honor of being the recipient of the first award of the Hickman Medal belongs, as has been mentioned, to Wesley Bourne, anesthetist to the Royal Victoria Hospital, Montreal, and lecturer on pharmacology at McGill University. Bourne also has the distinction of being the first to receive the degree of Master of Science in Pharmacology, for work on Anesthetics. This was conferred upon him by McGill University. His thesis was entitled, "Heat Regulation and Water Exchange: the Influence of Ether in Dogs (161)." The first degree of Master of Science in Anesthesia to be awarded, and the first to be granted in the United States, so far as the author is aware, was conferred on Dr. Edward B. Tuohy (162) in 1936 by the University of Minnesota.

Dr. Bourne has made many contributions of a physiologic and pharmacologic nature to the development of anesthesia. A few of his outstanding observations will be reviewed briefly. He concluded, on the basis of work carried out in the preparation of his thesis, that dogs, under the influence of ether anesthesia, lose the factor which regulates bodily temperature. In considering the problem of the acidosis which occurs during anesthesia, Bourne (163), working with Stehle, established on the basis of data concerning human beings the fact that phosphoric acid is the responsible factor. Bourne (164) also was able to show that the acidosis of anesthesia could be reduced by the rectal administration of copious quantities of a specially balanced solution of alkaline sodium and potassium phosphate, immediately after operation.

Bourne (165–168) and his associates also studied the effects of anesthetic agents upon the liver. They concluded that ethylene was the anesthetic agent of choice for operations carried out in the presence of severe hepatic disease. Neither sodium amytal nor tribromethyl alcohol in amylene hydrate (avertin) influenced hepatic function, according to them. Stehle and Bourne (169) also made a study of the changes in the activity and appearance of the kidney as brought about by anesthesia.

Although they did not believe that restorative agents should be used
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routinely in anesthesia, Raginsky (170) and Bourne nevertheless found ephedrine to be of value clinically in overcoming profound anesthesia produced with tribromethyl alcohol in amylene hydrate (avertin). In a recent communication, Bourne (171) and his associates in discussing the use of spinal anesthesia for thoracic surgical operations, found the use of analeptic measures justified in instances of anesthesia in which there is a marked decrease in blood pressure, accompanied by an increase in pulse rate.

Another study originating from the Department of Pharmacology at McGill University is that of Bourne (172) and his colleagues on the action of anesthetic and sedative agents upon the inhibited nervous system. These investigators concluded that amytyl, pentobarbital sodium, alcohol, and tribromethyl alcohol in amylene hydrate (avertin) quickly abolish most of the signs of inhibitory neurosis in dogs. They (173) also studied the changes in conditioned reflexes in dogs brought about by anesthetic and sedative agents.

Gas Machines

Perhaps the first modern gas inhaler was the one that James Watts, an engineer, constructed for Thomas Beddoes (174). The first article (175) in the present series contained an illustration (fig. 4) of Humphry Davy’s “gas” machine. According to Miller (176), this, too, was constructed for Davy by Watts.

The ether inhalers in the United States, such as the one perfected by Morton, were soon discarded and replaced by the ether sponge. The sea sponge, probably similar to the sponge of Theodoric of the thirteenth century, was hollowed to fit the face, as mentioned by Miller. It was then saturated with ether. It provided by its extensive surface sufficient ether vapor for the purpose of anesthesia.

In England, closed inhalers were the favored apparatus. In an earlier paper (177) in this series the achievement of John Snow and his inhaler has been mentioned. His successor, J. T. Clover, published in 1862 an account of his chloroform inhaler by means of which the percentages of chloroform and air could be more nearly accurately regulated than heretofore.

According to Archer (1), mixtures of ether and chloroform were used for anesthesia in the late 1860’s. As has been mentioned earlier herein, Colton reintroduced the use of nitrous oxide for anesthetic purposes, during the extraction of teeth. In 1867 D. H. Goodwille’s patented inhaler for nitrous oxide gas, ether and chloroform was advertised. This inhaler was similar to that of John Snow and covered the nose as well as the mouth. It was important in that it permitted the mixture of air with the gas.

In the S. S. White Dental Manufacturing Company’s catalog for 1867, according to Miller (176), is pictured a complete nitrous oxide gas
machine. In the same catalog there is also a picture of an inhaler designed to cover both the mouth and nostrils.

Dr. Edmund W. Andrews, a Chicago surgeon, is said to have introduced the use of a mixture of oxygen with nitrous oxide into the practice of anesthesia in 1868. The feasibility of this method, however, was not demonstrated until Sir Frederick Hewitt many years later adapted it. Hewitt was the first to develop an apparatus that was practicable. By using semi-elastic bags, he overcame the terrific pressures of nitrous oxide and oxygen. The bags were kept almost full from the high pressure tanks by means of an intermittent flow of the gases. The gases were controlled directly by hand valves and the tanks which acted against the high pressures.

Clover (178) in 1876 introduced the gas-ether sequence. To do this he added to the bag of his inhaler a tap through which nitrous oxide could be admitted for the production of anesthesia.

S. J. Hayes, a Pittsburgh dentist, in 1882, patented an apparatus for generating and applying anesthetic agents. Ether and chloroform were mixed and heated by means of a water bath.

The S. S. White Dental Manufacturing Company in 1899 brought out a machine which proportioned the gases. This was their nitrous oxide-oxygen apparatus. It was constructed similarly to a machine that Hewitt had perfected in England.

Charles K. Teter (179), a Cleveland dentist, while practicing his profession in Upper Sandusky, Ohio, became interested in developing an apparatus for administering nitrous oxide and oxygen as well as other anesthetic agents. His first machine was manufactured in 1903 by the Cleveland Dental Manufacturing Company. It was very popular, and it is due to some extent to Teter's influence that the use of nitrous oxide-oxygen anesthesia became widespread. Dr. Teter has administered nitrous oxide and oxygen anesthesia more than 100,000 times for the extraction of teeth and the removal of tonsils, without a single fatality. In 1909, Dr. Teter was appointed chief anesthetist at St. Luke's Hospital in Cleveland. In 1912 he was appointed to the position of special anesthetist at Lakeside Hospital in the same city.

In about 1909, according to Heidbrink (180), Burt Clark, now of Minneapolis, developed a gas machine. By means of this machine the maintenance of constant pressure in the bags was attempted. A central valve with a slot for each gas was supposed to proportion the gases. This did not have fine enough control to give good results in gas anesthesia.

From 1906 to 1910, E. I. McKesson, of Toledo, who in 1907 introduced the practice of making tests of blood pressure during anesthesia, and J. A. Heidbrink, to whom many references have already been made herein, worked independently on an attempt to build a machine which would provide better control of the gases. McKesson invented a machine which produced pressure on the bags individually. This was similar to the Clark machine, but it had a better proportioning valve.
In 1910 McKesson perfected the first “intermittent flow” nitrous oxide and oxygen anesthesia machine. It contained an accurate percentage control for the two gases. In 1911 McKesson (181) introduced the principle of fractional rebreathing. He found it possible to save the first part of each expiration for rebreathing. The expiratory valve made provision for the escape of the last part of each expiration.

Meanwhile, Heidbrink was developing his machines. He perfected a machine called the “OO.” Later, after a few minor changes, this machine was called the model “T.” Heidbrink made use of the reducing valve on his machine as a flowmeter. He was an early exponent of “timed anesthesia.”

Willis D. Gatch (182), in 1910, published his important article on nitrous oxide-oxygen anesthesia produced by his rebreathing method. His apparatus is described therein. Gatch also provided for a sight-feed dropper, and in some cases ether was administered after the gas. Karl Connell also invented a gas machine at about this time. In 1918 a government order for gas machines was divided among McKesson, Connell, Foregger and Heidbrink.

In 1911 J. T. Gwathmey (183) and William C. Woolsey began experimenting with gas machines. They had a nitrous oxide-oxygen apparatus built for them by Langsdorf in 1912. That same year the Ohio (184) monovalue anesthesia machine was put on the market by the Ohio Chemical and Manufacturing Company of Cleveland. This year, too, was the date of the appearance of the Boothby-Cotton sight-feed apparatus (185). To insure an even flow of gas, this machine provided for the use of automatic reducing valves. In 1914, Boothby furnished accurate calibration for the sight-feed valves.

Richard Foregger in 1914 built a nitrous oxide-oxygen machine without a reducing valve. The first Gwathmey apparatus built by Foregger without reducing valves, but with control valves for oxygen and nitrous oxide, appeared in 1915.

As Miller (176) has said, many others during the period from 1910 to 1920 developed gas machines. These included Coburn, Cunningham, Flagg, Guedel, Peariro, Miller and Morgan.

In 1923, John S. Lundy specified the first Seattle model gas machine. This was a four-valve apparatus for the utilization of oxygen, nitrous oxide, carbon dioxide and ethylene. This was the first apparatus to have all four gases. Dr. Lundy in 1925 worked with Dr. Heidbrink on the first Lundy-Heidbrink Model. One of the first machines was delivered to the Mayo Clinic on August 20, 1925. This was followed in 1932 by the Lundy-Heidbrink kinetometer gas machine, which was better adapted for absorber use.

Concluding Comments

In the five papers (175, 177, 186, 187, 188) in this series the progress of anesthesiology throughout the centuries has been charted. It has been the wish of the author to write the story of anesthesia in such a
way that the student, with proper notation of references, might go to the original sources as indicated.

The paper will be concluded with the evidence at hand which suggests that anesthesiology has reached a state of maturity. One development in technic may be mentioned. This is the method for continuous spinal anesthesia as suggested by William T. Lemmon. Lemmon (189) has observed during the past several years that sometimes spinal anesthesia has failed to take effect, and that in many cases the effect, once produced, is dissipated too soon. To remedy this, he devised an apparatus and injected procaine hydrochloride into the spinal fluid. As the effect of the first injection disappears, subsequent injections are carried out. To prevent or ameliorate a toxic condition which sometimes occurs, a 10 per cent solution of glucose is administered intravenously to the patient.

Edwards and Hingson, by virtue of Hingson's (190) familiarity with continuous spinal anesthesia, developed continuous caudal anesthesia for obstetrics, the most recent important contribution to anesthesia.

Two important contributions have been made to increase the safety of the use of anesthetic gases. Because of a fatal anesthetic explosion in Boston in 1938, Philip Woodbridge (191) then of the Lahay Clinic, J. Warren Horton of the Massachusetts Institute of Technology and Karl Connell, late of Branch, New York, made an investigation. The fatal explosion seemed to have been caused by the ignition of anesthetic gases by static spark. These investigators concluded that the ideal method for the prevention of any spark discharge which might ignite an explosive mixture would be to interconnect all objects and persons by conductors between these bodies or from these bodies to a connecting floor. They felt that this method was impracticable, however. They developed "high resistance intercoupling" and by its use in the operating room found it possible to reduce certain specific hazards of frequent occurrence.

G. W. Jones (192), R. E. Kennedy and G. J. Thomas have investigated the explosive properties of cyclopropane. This was a cooperative project between the United States Bureau of Mines and representatives from the School of Mines at the University of Pittsburgh, the American Society of Heating and Ventilating Engineers and various hospitals and industries in and around Pittsburgh. This committee advised that the practice of using a mixture of 20 per cent cyclopropane and 80 per cent oxygen be discouraged because such mixtures are violently explosive and have led to fatal accidents. A satisfactory means of eliminating explosion hazards was found. It consisted in reducing the oxygen content of the anesthetic mixture by the addition of inert gases. With continued dilution of the mixtures with inert gases, a concentration of oxygen is finally reached at which the mixtures are no longer explosive or inflammable.
In this country, two events of significance were the formation in 1937 of the American Board of Anesthesiology, Inc., and in 1941, the first meeting of the Section on Anesthesiology of the American Medical Association.

Perhaps the best evidence in the literature which tends to show that anesthesia has matured is that recently offered by Ralph Waters (193). Waters emphasized the viewpoint that clinical practice in anesthesia is handicapped by failure to correlate and utilize existing knowledge. Such an observation by a mature thinker in this field shows that anesthesiology is now concerning itself not only with new developments in technics and new drugs, important as these are, but also with such matters as the one mentioned by Waters: "Permanent improvement will develop in the future, as it has come in the past, mainly through consideration of scientific facts—laborious learning, imaginative insight and accumulative application."

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