ANESTHESIA FOR PNEUMONECTOMY IN MAN *

WILLIAM NEFF, M.D., WILSON PHILLIPS, M.D., AND GRACE GUNN, M.D.†

San Francisco, Calif.

THE conduct of anesthesia for pneumonectomy in man will be greatly influenced by the anesthetist's knowledge of the physiology of respiration. Simplification of the apparatus required for the administration of the anesthetic is highly commendable. The result of any attempt to render the technic of the operation or anesthesia so elementary as to be safe in less skilled hands is bound to be disappointing. It is useless to try to simplify that which is complex, and the physiology of respiration is complex. As our knowledge of the mechanism of breathing increases, the more we will be guided by physical laws and physiological principles and the less we will rely upon mechanical appliances. These remarks are pertinent as regards anesthesiology in general, but there is no other field where they can be as well demonstrated as during the conduct of anesthesia for operations within the thoracic cavity.

This presentation will primarily be directed toward a consideration of anesthesia for operations on the lung. The general principles of conduct are the same whether the site of operation be the lungs, the esophagus, or the heart itself.

PULMONARY VENTILATION

There are a number of physiological factors regarding pulmonary ventilation which directly concern the conduct of anesthesia for pneumonectomy. Many of these principles were known before the advent of anesthesia, while others antedate the discovery of the circulation of the blood. A brief reference to this historical background will aid in presenting a rational basis for the management of anesthesia in the presence of pneumothorax.

Vesalius (1) in 1543 discovered that inflation of the lungs was necessary to life when the chest was widely opened. He was able to keep animals alive by rhythmically inflating their lungs.

More than a century later (1667) Robert Hooke (2) demonstrated that ventilation could be efficient with the lungs maintained in a state of continuous inflation. He concluded that satisfactory ventilation depended not on the movements of the lungs, but rather upon the delivery of a sufficient quantity of "fresh air" to them.

* Read before a meeting of the American Society of Anesthetists, Inc., Montreal, October 30, 1941.

† From the Department of Surgery (Anesthesia), Stanford University School of Medicine, San Francisco, California.

Matas in 1901 (3), working with his assistant John Smyth, perfected a modification of the Fell-O'Dwyer intraglottic cannula and insufflating bellows (the "Matas Smyth Pump" for artificial respiration in medical and surgical practice). With this apparatus he was able to confirm the findings of physiologists that a positive pressure of 6–10 mm. Hg, and usually 8 mm. Hg, was sufficient to overcome the elastic retractility of the human lung when collapsed by the admission of air into the pleura. They also determined the extent of the traumatizing or pathologic effects on the lungs when the positive pressure was carried to excess, as often happened when the bellows were used in the closed chest for artificial respiration in cases of asphyxia from suffocation, drowning or opium narcosis and other non-surgical conditions.

Sauerbruch (4) in 1903 devised a method for ventilating the lungs by a negative pressure system ("Unterdruck"). In his original experiments the open thorax of a dog was enclosed in a glass cabinet from which the air was partially exhausted to produce a negative pressure of 7 mm. Hg. This simple apparatus was gradually developed through various stages until the final stage was reached with the construction of the elaborate chamber in the Munich Clinic. This chamber was large enough to contain a patient and a full operating team. The anesthetist remained outside at the patient's head.

Meltzer and Auer (5) in 1909 confirmed the observations made by Hooke more than two hundred years earlier regarding continuous respiration without respiratory movements. They supplied the lungs with air delivered under 15 to 20 mm. Hg pressure through a tube having a diameter two-thirds the lumen of the trachea. Their method thus caused the lungs to be continuously inflated and allowed air to escape between the tube and the wall of the trachea. Hooke effected the escape of air through holes cut in the lung. It is readily understood why the method of Meltzer and Auer was so enthusiastically received by surgeons who were interested in thoracic surgery. The authors considered three points to be essential factors in the success of their method: (1) "The lungs are kept in a continuous inspiratory state of distention which facilitates the exchange of gases. (2) The fresh air reaches the lowest part of the trachea. (3) The air escapes by another path than by the one it enters. Under these conditions the supply of oxygen and the removal of carbon dioxide take place apparently in physiological fashion without the aid of other rhythmic antagonistic movements." Although these observations of Meltzer and Auer were widely acclaimed and extensively quoted, another finding of as great importance, which they reported in the same paper, regarding the effect of damming back carbon dioxide went relatively unnoticed. They stated, "If air is made to enter the lungs through a short tube tied firmly into the trachea, curarized animals die in a very short time from asphyxia. . . . The difficulty in this method consists mainly in the fact that the removal of carbon dioxide has to take place against the stream of air within the tube."

The control of differential pressure, whether positive from within the tracheo-bronchial tree (Fell-O'Dwyer) or negative from without (Sauerbruch), was always independent of the administration of the anesthetic.

Sterling Bunnell (6) in 1909, then a recent medical graduate from Stanford University, was interested in the rapidly developing field of thoracic surgery. After visiting the various clinics in the United States, he was impressed with the cumbersomeness of the apparatus required for effecting differential pressure. He believed that it could be so simplified that the pressure of the anesthetic gases, nitrous oxide and oxygen, could be utilized for the pressure required to inflate the lungs and for the maintenance of anesthesia as well. On his return from the East he stopped off at Cleveland, and after discussing the matter with Crile, he was given the use of the latter's laboratory in which to work out his problem. It occurred to him that the simplest thing to do would be to apply the pressure by adding a resistance to exhalation. Accordingly, he experimented with the use of water displacement in a U tube as a resistance against the exhalation valve of the Teter gas machine. He found the use of water to be somewhat difficult to handle and substituted a calibrated spring resistance for the U tube manometer. This principle has been in use ever since for the purpose of producing constant positive pressure simultaneous with the administration of the anesthetic. Not all manufacturers of anesthetic apparatus took advantage of the adjustable maximum feature. However, the adjustable water manometer of Foregger, the graduated weights of Connell, and the calibrated spring of McKesson are all based on Bunnell's principle.

In this connection it is interesting to note that F. J. Cotton in a letter written to Bunnell in 1911 referring to the maintenance of positive pressure anesthesia stated, "I have seen both the Teters use it in this way and more unsatisfactory anesthesia I have never seen. The difficulty it seems to me is that the positive pressure so hinders expiration that the patient has to strain to get rid of his air. These patients are always cyanotic and I think in some cases the strain of respiration is due to an over-accumulation of carbon dioxide and its well-known reflex effect in causing forced respiratory movement. This difficulty can be avoided rather than met in using the intratracheal method because it does not make any particular difference in this method whether the lungs are inflated or not. If for any reason temporary inflation is desired, of course it is easily accomplished by partially occluding mouth and nose with the fingers. I am not ready yet to advocate the use of nitrous oxide and oxygen through the tube very strongly. It is perfectly practicable enough and seems safe enough, but I think that all the intratracheal methods are a little bit empirical until we know better about this method on the ventilation of carbon dioxide."

CONTROLLED RESPIRATION

Controlled respiration is a term applied to a condition wherein pulmonary ventilation is under the control of the anesthetist. Respiration is passive on the part of the patient and active on the part of the anesthetist. There are three factors essential to its attainment: (1) the production of apnea by over-ventilation through soda-lime, (2) the continued suspension of all automatic respiratory movements by the maintenance of efficient ventilation, (3) the ability to effect a return to normal breathing at will.

(1) The production of the initial apnea is brought about by overventilating the patient through a canister of soda-lime. Manual compression of the breathing bag during the inspiratory phase of respiration will hasten the deepening of narcosis and render more efficient the removal of carbon dioxide. Over-ventilating tends to weaken the stimulus to the respiratory center and anesthetics tend to make the center less irritable. Within a short while all respiratory movements cease. Respiratory arrest may also be caused by a sudden high concentration of the anesthetic. Guedel believes this is due to furnishing the brain with a sudden, but very transient, high concentration of the anesthetic and thereby depressing the respiratory center directly. We have used the hyperventilation method exclusively for the production of the initial apnea during anesthesia for pneumonectomy.

(2) The continued suspension of all respiratory efforts is accomplished by manually, rhythmically and intermittently compressing the breathing bag to effect inspiration. Expiration is accomplished by the elastic recoil of the lungs. The amount of pressure required during the inspiratory phase to insure adequate ventilation will usually be between 5 and 8 centimeters of water.

(3) Unless anesthesia has been allowed to drift to an unduly deep level, restoration of normal automatic breathing will not require more than one or two minutes. Simply removing the soda-lime and continuing the ventilation will cause automatic breathing to be resumed. The speed with which this occurs will depend upon the existing depth of anesthesia. Deep anesthesia should be lightened before the soda-lime is withdrawn.

The physiological effects produced by an unduly low carbon dioxide tension of the blood, as in the studies on hyperventilation by Seevers, Stormont, Hathaway, and Waters (7), are not in any manner comparable to the effects of controlled respiration. The two situations are so dissimilar as to render comparison impossible. The object of the investigations of the Wisconsin group was to determine the effects of extreme carbon dioxide depletion. There is no evidence that a state of alkalosis exists during controlled respiration.

PREMEDICATION AND PREPARATION FOR ANESTHESIA

It seems advisable to prescribe a rapidly acting barbiturate to insure sleep on the night before the operation. The administration of the barbiturates on the day of operation has not been our practice. Moderate doses of morphine and scopolamine have generally produced the desired tranquillity without undue respiratory or circulatory depression. Only in rare instances has the dose of morphine grain 1/6 (0.01 Gm.) combined with scopolamine grain 1/150 (0.0004 Gm.) been exceeded.

The selection of a late morning hour for the operation is preferable to the "early start" if the patient has a large daily output of sputum. This permits the respiratory passages to be cleared by postural drainage and by coughing before the preanesthetic medication has become effective. When extraordinary amounts of sputum are encountered, primary bronchoscopic drainage may be indicated.

The anesthetist should anticipate the need for intravenous fluids in all cases and for a transfusion of blood in most. He should make certain that the patient has been typed and that suitable blood is available. We favor starting an intravenous infusion of 5 per cent glucose in saline before anesthesia is induced. If a vein on the leg or foot is used, the already crowded area around the arms and chest is not further encroached upon. After the intravenous solution has started to flow, the rate of its injection is reduced to a point where it is barely moving. This very slow administration will not overload the circulation. The set-up having been made, a sudden demand for additional fluid or blood may immediately be met. There is no doubt that the anesthetist must exercise great caution in the control of intravenous fluids to a patient undergoing pneumonectomy.

THE ANESTHETIC AGENT

Cyclopropane, which, in our hands, has been a most satisfactory agent for extra-pleural thoracic operations, such as thoracoplasty, was considered likely to be well indicated for pneumonectomy. Subsequent experience gained in the conduct of anesthesia for lobectomy and pneumonectomy has seemed to confirm the correctness of this belief. The condition of the patients remained remarkably good during the course of pneumonectomies lasting between four and five hours. The surgeons, some of whom received their training in thoracic surgery elsewhere, have been highly pleased with the manner in which their patients withstand the operation and the satisfactory way in which they react after operation. We are well aware that the term "perfect anesthetic" applied to any known agent is a gross overstatement of fact. Nevertheless, we do believe that cyclopropane anesthesia possesses certain qualities which indicate its use for pneumonectomy in man.

The impotency, and therefore the inadequacy, of nitrous oxide for lung surgery has frequently been emphasized. The use of tribromethanol and nitrous oxide continues to be advocated by some surgeons and anesthetists.

The danger of the irritant action of ether to patients about to undergo pneumonectomy has doubtless been over-emphasized. We have frequently noticed during the course of closed endotracheal anesthesia for abdominal operations of long duration that although an enormous amount of secretions could be recovered by suction from the upper respiratory passages, the tracheo-bronchial tree was usually quite clear. In a large measure the increased secretions incident to ether anesthesia seem to emanate from the salivary glands. The bronchial glands appear to be affected only to a minor degree, providing the respired atmosphere is humid and warm.

Cyclopropane anesthesia administered by the Waters "to and fro" carbon dioxide absorption technic was used in all of our cases. This method is especially suitable for the conduct of anesthesia for pneumonectomy because of its simplicity, high efficiency and minimum resistance to respiration. The heat loss incident to the open chest is appreciably reduced. The heat loss with the open chest is estimated to be three times as great as when the peritoneum is open for an extensive abdominal operation. Under these circumstances any conservation of body heat is important. Because changes in gas concentration are almost immediately effective, the "to and fro" method is more flexible and permits minute-to-minute control of the inspired mixture.

LOCAL INFILTRATION ANESTHESIA

A local injection of procaine .5 per cent to 1 per cent or intracaine of similar strength without epinephrine is a most useful adjuvant to the management of the anesthesia. Intracaine, while slightly more toxic than procaine, has the advantage of a more sustained action. We do not believe it is necessary to use local anesthesia until the thorax has been opened. Crafoord's (8) technic of infiltrating around the lower portion of the trachea, the main stem bronchus on the affected side and the hilus region is employed. If the block is perfect, the cough reflex is obtunded and circulatory disturbances of reflex origin are prevented. If the block is not complete it will be necessary to deepen the narcosis in order to eliminate the reflex disturbances. It is imperative that the surgeon desist from making traction on the bronchus or exploring the mediastinum until the pathways of the harmful stimuli are blocked by local anesthesia, or until narcosis is rendered more profound.

ENDOTRACHEAL INTUBATION

While extra-pleural thoracic operations rarely require endotracheal anesthesia, when the chest is to be widely opened intubation is almost essential.

The endotracheal tube provides an unobstructed passage for the transport of oxygen, carbon dioxide and the anesthetic gas. It affords a means whereby pressure may be applied directly to the lungs. It facilitates the prompt recovery by suction of secretions and blood. The Magill tube with its thin wall, large lumen and freedom from kinking or collapsing has proved satisfactory. The distal end of the tube is surrounded by an inflatable cushion, although it is not in all instances inflated. It is pertinent to point out that an attempt is always made to use the largest tube which will fit the trachea and therefore very little air is required to inflate the cuff. It is not unusual to have the endotracheal tube fit so well that leak-proof conditions exist without the inflation of the cuff.

Beecher (9) has pointed out the undesirable features of sealing off the trachea with an inflatable cuff when a tube measuring one-half its diameter has been used. In addition to the dangers, such as interference with the recovery of secretions and of over-inflation of the cuff, to which he has called attention, we feel that the unphysiological nature of such a procedure is sufficient to cause it to be discredited. Through such a tube, by means of pressure on the breathing bag, the inspiratory phase of respiration can be made efficient simply by forcing more atmosphere through a narrowed orifice. The expiratory phase, however, is impeded and the elimination of carbon dioxide is thereby hampered. The large bore, snug fitting Magill tube is in no manner comparable to one which occupies only one-half of the trachea. When the head-down position is used, secretions drain into the tube where they may be effectively recovered by suction. An ordinary urethral catheter lubricated with petrolatum may be easily and quickly introduced through the endotracheal tube and thus affords an ideal way for the application of suction. The diameter of the suction catheter selected depends upon whether the secretions are thin and watery or thick and tenacious. Usually a 14 or 16 French catheter is suitable. A sterile catheter is used for clearing the trachea and bronchi. Another one clean but unsterile is used to remove secretions from the respiratory passages above the inflated cuff. We have frequently recovered large amounts of thick muco-purulent material from the upper respiratory passages while the secretions removed from the trachea were scanty, watery and clear.

Technic of Endotracheal Intubation

Satisfactory relaxation of the muscles of the jaw is a prerequisite to the introduction of an endotracheal tube of the calibre recommended for pneumonectomy. Second or third plane of the third stage of anesthesia will be reached before relaxation is adequate for this procedure in the average individual. When the patient is ready to be intubated, his head is extended and, by means of a pillow, his occiput is raised about 10 centimeters above his shoulders. Such a position favors optimum visualization of the glottis when the teeth are widely separated by a laryngoscope having the large bore which is essential for the passage of a tube with a large lumen. After the necessary relaxation and the proper position have been attained, the anesthetist separates the jaws with the right hand and introduces the laryngoscope blade with the left hand and advances it until the epiglottis is reached. The tip of the epiglottis is elevated and the glottis is thereby exposed. At this point, and not infrequently prior to it, the use of suction to recover secretions is indicated. After a brief examination of the condition of the glottis the endotracheal tube is introduced. Any abnormalities, such as inflammation or edema, should be immediately recorded. The anesthetist should not permit himself to reap the rewards of someone else's bronchoscopic trauma. Neither should he be unaware of a small polyp on the vocal cords which has so far been asymptomatic, the occasional paralyzed cord, and so forth.

After the tube has been placed in position and the connections between it and the canister with attached breathing bag have been established, gentle manual compression of the bag is made to test the leakproofness of the assembly.

TECHNIC OF SEALING THE TRACHEA

Should this test reveal a leak around the endotracheal tube, it will be necessary to inflate the cuff. This may best be accomplished by a method suggested by Guedel. He recommends the introduction of air into the cuff while simultaneously exerting moderate pressure on the breathing bag. Inflation of the cuff is discontinued immediately after the leak is eliminated. This affords a safeguard against over-inflation of the cuff.

TERMINATION OF THE ANESTHETIC

The depth of anesthesia should gradually be lightened as soon as the pleura has been closed. It is desirable to have the patient begin to resist the endotracheal tube toward the end of the operation. The respiratory passages, both above and below the cuff, should be cleared by suction before the cuff is deflated. After this has been done, the air in the cuff is evacuated with a syringe and the tube is withdrawn.

POSTOPERATIVE ADMINISTRATION OF OXYGEN

The routine postoperative administration of oxygen to all patients who have undergone pneumonectomy is a good practice. The oropharyngeal catheter method provides a means whereby the insufflation of oxygen may be instituted in the theater and continued on the ward. It has seemed beneficial to commence the administration of oxygen immediately after the anesthetic has been discontinued.

The catheter should first be properly placed in the oropharynx. An "A" cylinder of oxygen fitted with a suitable regulating valve permits the delivery of an easily controlled flow of oxygen. The desired rate of flow should be obtained before the delivery tube is connected to the oropharyngeal catheter. This will insure against the forcing of a sudden blast of oxygen into the pharynx. After the patient is returned to the ward the administration of oxygen is continued by connecting the catheter to a standard flowmeter humidifier unit. The rate of flow, at first allowed to be excessive, is later adjusted to the oxygen demands of the patient.

Thirty-four cases consisting of 19 pneumonectomies and 15 lobectomies have been operated upon under the described conduct of anesthesia. There were 2 hospital deaths in the pneumonectomy series and 1 hospital fatality in the lobectomy group, the percentage of deaths therefore being 10.5 and 6.6, respectively. A discussion of the deaths is beyond the scope of this paper. It may be of interest, however, to note that one of the pneumonectomy deaths was caused by a rupture of the atria of the right auricle of the heart forty-eight hours postoperatively. The atria were accidently punctured one hour after the commencement of the operation, the rent was sutured, and the patient's condition immediately improved. This improved condition continued throughout the operation and afterward until the rupture which caused his sudden death.

SUMMARY

Anesthesia for pneumonectomy in man has been discussed from the standpoint of the physiological factors involved. A discussion of differential pressure methods has been preceded by a brief historical review. The details of a suggested technic of anesthesia using cyclopropane have been presented. Attention to the physiological control of ventilation has been given greater emphasis than the selection of the anesthetic agent.

REFERENCES

1. Vesalius, Andreas: De Humanis Corporis Fabrica, 1543.
2. Hooke, R.: An Account of an Experiment Made by M. Hook of Preserving Animals Alive by Blowing Through Their Lungs with Bellows, Phil. Trans. Roy. Soc. 2: 539–540, 1667.
3. Matas, R.: Value of Artificial Aids to Respiration in "Acute Operative Collapse of Lungs," Arch. Surg. 5: 110, 1922.
4. Sauerbruch, F., and O'Shaughnessy: Thoracic Surgery, Edward Arnold & Co., 1937, p. 25.
5. Meltzer, S. J., and Auer, J.: Continuous Respiration Without Respiratory Movements, J. Exper. Med. 11: 622, 1909.
6. Bunnell, Sterling: The Use of Nitrous Oxide and Oxygen to Maintain Anesthesia and Positive Pressure for Thoracic Surgery, California State J. Med. 10: 11–14 (Jan.) 1910.
7. Seevers, M. H.; Stormont, R. T.; Hathaway, H. R., and Waters, R. M.: Respiratory Alkalosis During Anesthesia, J. A. M. A. 113: 2131–2137 (Dec. 9) 1939.
8. Crafoord, Clarence: On the Technique of Pneumonectomy in Man, Stockholm, Tryeckeri Aktiebolaget Thule, 1938, p. 77.
9. Beecher, H. K.: Some Controversial Matters of Anesthesia for Thoracic Surgery, J. Thoracic Surg. 10: 202–212 (Dec.) 1940.