ANESTHESIA FOR THORACIC SURGERY IN THE UNITED STATES ARMY

LIEUTENANT COLONEL LLOYD H. MOUSEL,* MEDICAL CORPS,
ARMY OF THE UNITED STATES

THE results obtained in seven thoracic surgical centers in the United States during World War II reflect the advances made in the field of anesthesia in relationship to the altered physiologic conditions of the open chest. During World War I many emergency thoracic surgical procedures were carried out and at that time it was determined by the end result that most procedures were dependent largely upon the anesthesia. It was obvious that many patients died during or soon after operation due to collapse of pulmonary tissue and paradoxical respiration during major operative procedures. The anesthesia equipment available during the years 1914 to 1918 was, in most instances, inadequate for thoracic surgical anesthesia. Nitrous oxide and oxygen were the agents used most often, although in some instances the anesthetist was forced to resort to the use of open drop ether. Methods were devised for the administration of intermittent positive pressure but these means were not particularly satisfactory. The carbon dioxide absorption method of anesthesia had not yet been developed. The high flow of gases necessary to maintain positive pressure without the accumulation of a dangerous amount of carbon dioxide proved extremely wasteful of anesthetic gases. Following the development of the carbon dioxide absorption method of anesthesia with rebreathing of anesthetic gases, equipment became available which has been in most instances quite satisfactory for the maintenance of anesthesia during open thoracotomy.

Prior to 1940 very little had been written on the subject of anesthesia for thoracic surgery. During 1940, Phillips, Livingstone and Engel[8] reported the anesthetic results in over 500 thoracic surgical operations. Ethylene oxygen anesthesia was used in 73.2 per cent of all thoracic operations. Eight of their patients developed severe shock on the operating table and were treated by means of blood transfusions. Preoperative transfusions were given to three patients at the beginning of operation. Eight patients were given blood the same day as operation. Less than 10 per cent of all patients received blood later. Postoperative oxygen therapy was required in only ten instances. Pneumonectomies were done under ordinary mask anesthesia without the use of endotracheal tubes. Eleven lobectomies were carried out without the use of either face masks or endotracheal tubes. The authors stated that positive pressure mask anesthesia was used only once and was seldom required.

In 1940, Beecher[1] recommended the use of ether and oxygen as the anesthetic of choice in major thoracic surgery patients. He stated that oxygen must be available in high concentrations because of reduced vital capacity and that ether allows more oxygen to be used than can be used with cyclopropane.

Received for publication Aug. 29, 1946.

*Now Clinical Professor of Anesthesiology, George Washington University, Washington, D. C.

He further stated that cyclopropane may interfere with oxygen uptake in the cells and that this agent has a toxic effect upon the heart in a relatively high percentage of patients. Whether toxic cardiac effects are responsible or not, the mortality rate seemed to be higher if cyclopropane was used than if ether was used as the anesthetic agent. He also condemned the use of avertin with nitrous oxide for thoracic surgical patients. Beecher stated that positive pressure is necessary at times in some cases and almost constantly in others so that endotracheal intubation is important. He condemned the use of inflatable cuffs, stating that they are not necessary and may cause severe irritation of the trachea. He also stated that controlled respiration is neither necessary nor advisable and that the production of respiratory failure removes the greatest safeguard against overdose. He stresses the importance of simplicity in anesthesia.

Wiggin and Schultz,[10] in 1941, recommended the use of cyclopropane in major thoracic surgery, although at times procaine infiltration was used in combination with the inhalation agents. Endotracheal catheters with inflatable cuffs were used routinely for lobectomy and pneumonectomy, without untoward effects from either intubation or pressure from the inflated cuff. Positive pressure administration was resorted to only when indicated.

Phillips, Livingstone, and Adams,[7] in 1941, stated that they seldom used endotracheal anesthesia because of the desire to avoid trauma of the tracheobronchial tree. Ethylene and oxygen were used in the majority of cases. Supplemental ether was avoided as much as possible because of increased irritation of the respiratory tract. All agents which inhibit the cough reflex were avoided if possible. They stated that operations on the heart, pericardium, and mediastinum may be successfully performed under local anesthesia.

Moyer,[4] in 1941, condemned the use of pentothal sodium and evipal soluble with simultaneous administration of a high concentration of oxygen. He found that in experimental animals, the barbiturates caused the response to 12 per cent carbon dioxide to change from an intense stimulation of breathing to a very minor stimulation, followed by serious depression of respiration as shown by cessation of respiration and asphyxial rise in blood pressure. Breathing during moderate evipal or pentothal anesthesia is likely to be largely and even entirely dependent upon reflex drives for maintenance. Any reduction of these reflex drives is apt to result in respiratory failure as is shown by changing from room air to oxygen during deep anesthesia. Dogs whose respiration was not greatly depressed while breathing room air showed a slowing of respiration and finally complete cessation following the administration of oxygen.

Nosworthy,[6] in 1941, advocated the use of controlled respiration. He brought about control by depressing the respiratory center with sedatives and anesthetic drugs. He advocated the use of one lung anesthesia for pneumonectomy. This he obtains by means of an endotracheal airway with bronchial tamponage on the affected side or by endotracheal intubation on the sound side. He is convinced that all thoracic surgery should be done under anesthesia deep enough to abolish all reflexes since coughing may tend to spread

the infection. He stated that chest patients commonly have a low vital capacity and the lateral position on the operating table handicaps them still further. Therefore, the anesthetic technique should make use of all alveolar membrane for gaseous exchange and permit a high oxygen concentration. He stated that controlled respiration with ether or cyclopropane fulfills this requirement. "Paradoxical respirations will at times develop under local anesthesia for thoracoplasty and have been a common cause of death in the past, especially if too many ribs were removed at a single operation." The lung on the sound side discharges part of its contents into the collapsed lung. The to-and-fro movement of air makes the movements of the lung on the affected side paradoxical since it expands with expiration and collapses with inspiration. Nosworthy also stated that the anesthetist must be prepared to supervise continuous circulatory resuscitation and, second, he must make sure that efficient respiration is taking place. He must not wait for signs of circulatory depression to develop but must institute resuscitative measures early. He advocated a constant drip transfusion during all thoracoplasties.

Neff and associates[5] recommended the use of cyclopropane for pneumonectomy and lobectomy. Small doses of premedication were used. Apnea was produced by overventilating the patient's lungs through a canister of soda lime. Controlled respiration was maintained throughout the course of operation. They reported a hospital death rate of 10.5 per cent following pneumonectomy and 6.6 per cent following lobectomy.

In 1940, Beecher advocated positive pressure anesthesia and did not find a rise in blood carbon dioxide. He disapproved of rhythmic ventilation or controlled respiration on the grounds that with the abolition of active breathing, the anesthetist lost his chief guide to the depth of anesthesia.

Randolph and Kober[9] in 1943, reported 123 thoracoplasties done satisfactorily under pentothal anesthesia.

Esten[3] stated that although the cough mechanism has a supposedly spreading action, the incidence of spread of infection in patients with a cough reflex prior to surgery is extremely low. He stated that spontaneous respirations, if allowed to persist, result in increased oxygen demand, exhaustion of the respiratory muscles, and a diminished elimination of carbon dioxide, and that the to-and-fro canister is a more efficient carbon dioxide absorber giving less resistance than the circle type filter. He further stated that positive pressure anesthesia interferes with the bellows action of the lungs and the mixing of the gases. The elimination of carbon dioxide from the alveolar spaces is entirely dependent upon this mixing action. An increase of carbon dioxide, without notable clinical signs, may occur.

Bourne and co-workers[2] recommended the use of nupercaine spinal anesthesia for thoracic surgery. He reported an anesthetic death rate of 3.9 per cent.

During the recent war years, seven thoracic surgical centers* were set up in the United States for the purpose of providing the best possible care for

*One center was closed in 1944.

soldiers who required surgery of the chest. These centers were organized in such a way that the personnel originally selected to staff these institutions were able to remain in most instances throughout the duration of the war. In this way, surgical and anesthesia teams were formed and, in their close cooperation over a long period of time, became intimately associated in their common problems. Close cooperation of all personnel was to a large extent responsible for the low mortality figures reported here. All types of surgical conditions pertaining to diseases of the thorax were treated in these centers. However, this paper deals only with that group which gives rise to the major anesthetic problems, namely, lobectomy, pneumonectomy, and mediastinal tumor.

By Dec. 1, 1945, 559 lobectomies had been reported. A 1.9 per cent over-all mortality rate was reported in this series of cases. Three of the deaths were definitely related to anesthesia. One of the patients died immediately after surgery and following the aspiration of a large amount of vomitus into the tracheobronchial tree. The second died approximately one hour after operation, due to cerebral anoxia. This patient developed profound shock during surgery and the treatment of shock was delayed because of the difficulty in administering whole blood. The third patient died twenty-four hours after operation due to inability to obtain complete oxygenation during the last part of surgery. This death probably could have been prevented by early complete bronchoscopic aspiration during the operation.

There were 109 mediastinal tumors. Of this group, eighty-three tumors were removed and exploration was carried out in twenty-six patients for biopsy diagnosis. In this series, one patient died, giving a 0.9 per cent over-all mortality rate. This patient died as the result of cerebral anoxia on the third postoperative day. Massive hemorrhage occurred during the operation, the patient became pulseless and blood pressure was unobtainable. The condition was relieved by massive blood transfusion but anoxia had apparently been sufficient to cause irreparable damage to the higher centers.

In the series of pneumonectomies carried out in our thoracic surgical centers eight deaths could be associated with anesthesia, four of them being definitely anesthetic deaths. Two patients were reported as having died from cardiac failure and two were found to have died of obstruction of the main stem bronchus on the unoperated side. Four of the patients died of pulmonary edema,* one eight hours, two twenty-four hours, and one seventy-two hours postoperatively. In all four of these patients, large amounts of fluid, consisting of blood, plasma, and saline, had been given on the operating table, and during the first few hours postoperatively.

Of the patients reported in this entire series, all operations were done under endotracheal anesthesia. During the early part of the war a few patients were anesthetized with cyclopropane. However, well over 95 per cent of the patients reported on were anesthetized with nitrous oxide, oxygen and ether with ether and oxygen maintenance. No serious complications were reported following

*These cases were reported as being related to anesthesia because it is thought to be the responsibility of the anesthetist to prevent shock by replacing all blood loss, as it occurs, with whole blood.

the use of endotracheal tubes. In approximately 80 per cent of all endotracheal procedures, an inflatable cuff was used to insure a completely tight airway. In approximately 20 per cent, no cuff was used. A face mask was placed directly over the endotracheal airway in order that a tight seal could be obtained.

In five centers, intermittent positive pressure anesthesia was used. In two centers, the apneic technique of controlled respiration was practiced routinely. The over-all anesthetic mortality study leaves room for conjecture regarding the wisdom of using controlled anesthesia. All deaths related to anesthesia occurred in centers where the apneic technique of controlled respiration was used routinely for lobectomies, pneumonectomies, and removal of mediastinal tumors.

In the study of the over-all mortality figures, several pertinent points become obvious. In the first place, the anesthesia has been relatively simple but it has been carried out by men who have been extremely interested in the subject of anesthesia for thoracic surgery and have given their personal attention to these patients. I have been impressed with the fact that the more toxic anesthetic agents have not been used to any great extent and that by far the large percentage of patients were not carried on the apneic technique as has been suggested by some writers. Careful observation of all patients on the operating table with the prevention or early relief of tracheobronchial obstruction, prevention of anoxia, and prevention of shock by adequate replacement of blood as hemorrhage occurs has been responsible for this excellent record.

Major thoracic surgical proceedures can be carried out successfully using the closed method of ether-oxygen administration through a circle type of filter. Postural drainage immediately before induction will minimize the amount of foreign material in the tracheobronchial tree of patients suffering from suppurative disease of the lung. Bronchoscopic aspiration immediately before operation may cause hemorrhage into the tracheobronchial tree. Patients usually become somewhat apprehensive during and immediately following bronchoscopy, making them unfit subjects for smooth anesthetic induction. It is my belief that bronchoscopic aspiration should not be carried out immediately before surgery in the elective case. Conservative amounts of premedication are administered to these patients approximately two hours before operation.

The primary anesthetic induction is carried out using 80 per cent nitrous oxide and 20 per cent oxygen. After the patient's reflexes have been dulled by the action of nitrous oxide, ether is gradually added to the system and the administration of nitrous oxide is discontinued. Endotracheal intubation with a McGill endotracheal catheter equipped with an inflatable cuff is now carried out. The endotracheal catheter is connected directly to the anesthesia machine and the equipment carefully checked to assure a completely leakproof system. The patient is placed in position on the operating table in such a manner as to assure maximum respiratory excursion. Sandbags under the dependent portion of the chest or breaking of the operating table in such a manner as to interfere with respiratory excursion should be avoided. A large bore needle is placed into a convenient vein and a very slow drip of whole blood is started be-

fore sterile drapes have been put in place. It is essential in all major thoracic surgical procedures to prevent the onset of shock. This can be done by an accurate estimation of blood loss and the replacement of such loss as it occurs. If blood loss is not replaced as it occurs, the patient may go into a state of shock which will necessitate the administration of large quantities of fluids postoperatively, resulting in some instances in pulmonary edema.

The tracheobronchial tree is aspirated frequently, using a soft rubber urethral catheter in order to prevent tracheobronchial obstruction. These patients are carried without positive pressure in the anesthesia machine until a few minutes before the pleura is opened. Approximately two or three minutes before the pleural cavity is entered, positive pressure of approximately 8 cm. of water is built up in the system in order to prevent a sudden collapse of the lung following the opening of the pleura. Positive pressure is gradually reduced over a period of five or six minutes' time, allowing the lung to collapse slowly. If this technique is carried out, paradoxical respiration will rarely develop. Should interference with respiratory excursion develop after the lung has been deflated, enough positive pressure is added to control the mediastinal shift. This amount of pressure will rarely exceed 5 cm. of water. Occasionally the patient will be encountered in whom a slight amount of positive pressure will be required throughout the duration of surgery, but these cases are rare. Most patients will develop a stable mediastinum provided initial decompression of the lung is carried out slowly. These patients will rarely require positive pressure to maintain adequate pulmonary and cardiovascular circulation. If the lung is allowed to collapse completely the surgeon may carry out his work without the interference of an inflated lung protruding into the wound.

It has been found on measurement of the tidal volume of thoracic surgical patients, that the average case of open pneumothorax, where one complete lung is collapsed, is between 400 and 500 c.c. The color of these patients remains good. The normal blood pressure and pulse rate would indicate that anoxia does not exist. In cases of lobectomy, it is believed that reinflation of the uninvolved lung tissue on the side operated upon should be carried out every twenty to thirty minutes. This procedure probably minimizes the danger of postoperative atelectasis and may prevent unintentional ligation of a bronchus in the uninvolved lobe. Tracheobronchial aspiration must be carried out at frequent intervals with a catheter long enough to reach the terminal portion of the tracheobronchial tree. One must not wait until mucus can be heard in the airway before carrying out aspiration. It is possible for a large amount of foreign material to gravitate from the diseased lung to the contralateral side, producing partial or complete obstruction without changes in the audible tone of respiration.

If the patient is draped in such a manner that the anesthetist can see into the chest at all times, bronchial obstruction can be detected frequently by noting increased diaphragmatic movements several minutes before clinical symptoms of anoxia can be recognized from the color of the patient or from changes in pulse and respiration. It is essential that the anesthetist be alert at all times

in order that instantaneous diagnosis of complications may be made and corrective measures instituted at once. Otherwise, tracheobronchial obstruction may terminate in death on the operating table or death from cerebral anoxia several hours or days postoperatively. Rarely is there reason for carrying these patients on controlled respiration.

At the termination of operation, a sufficient amount of positive pressure is gradually built up in the machine to reinflate the remaining lung tissue. This pressure is maintained until the chest wall has been completely closed in order to avoid the possibility of pneumothorax. At the time of chest wall closure, pulse and blood pressure must be watched carefully, for occasionally the pressure required for re-expanding the lung will be great enough to interfere with return of circulation to the heart once the chest wall is closed. If increased pulse rate and decrease in blood pressure takes place soon after the chest wall has been closed, positive pressure in the anesthesia system must be reduced at once.

It has been the policy in most thoracic surgical centers in the Zone of the Interior to carry out routine bronchoscopic procedures immediately after the operation and before the patient is returned to his room. If an x-ray is made of the patient's chest at this time, conditions such as atelectasis, pneumothorax, or hemothorax can be detected and corrective measures taken immediately. It is believed that if this routine is adopted by all thoracic surgical clinics, many serious postoperative complications can be avoided. If pulmonary edema is to be avoided, great care must be exercised in the administration of fluids during operation and in the immediate postoperative period. Mortality figures impress us with the necessity of extreme caution in fluid therapy, particularly during and following pneumonectomy. The average patient undergoing lobectomy seems to tolerate rather large quantities of intravenous fluids without difficulty. However, slight overloading of the circulation with intravenous fluids during and following pneumonectomy is apt to produce fatal pulmonary edema. If on-the-spot replacement therapy using whole blood is carried out during operation, there is usually little need for large quantities of intravenous fluids postoperatively in an attempt to elevate a seriously reduced blood pressure.

I am impressed with the low mortality and morbidity figures following the use of ether in major thoracic surgical cases, particularly in the group of patients suffering from suppurative disease of the lung, for it is in this group that many writers have condemned the use of ether because of its irritating qualities.

CONCLUSIONS

1. Ether is a safe anesthetic agent when used in a closed system with a high concentration of oxygen in major thoracic surgical procedures.

2. Endotracheal catheters are essential for the maintenance of a clear airway for frequent tracheobronchial aspiration and for the administration of positive pressure when indicated. The use of endotracheal catheters and inflatable cuffs have produced no harmful effects in this series of patients.

3. Continuous positive pressure anesthesia is not required in most patients. Intermittent positive pressure is essential.

4. Intermittent positive pressure anesthesia and the method of controlled respiration have both been carried out in a large series of major thoracic surgical procedures.

5. All deaths related to anesthesia occurred in centers where controlled respiration was carried out routinely during anesthesia.

6. Re-expansion of collapsed pulmonary tissue for the purpose of preventing pneumothorax can be safely carried out using measured positive pressure at the termination of the operation.

7. Uninvolved lung tissue should be re-expanded frequently during the course of operation in an attempt to minimize the dangers of postoperative atelectasis and to assist the surgeon in locating lines of demarcation.

8. Care must be exercised in the administration of large amounts of fluids during operation and during the immediate postoperative period.

9. On-the-spot replacement therapy using whole blood will prevent the onset of shock in most instances.

10. Patients undergoing pneumonectomy are apt to develop fatal pulmonary edema if excessive quantities of fluids are given intravenously.

11. Immediate postoperative bronchoscopic aspiration and x-ray examination of the patient before he leaves the operating table will reduce the incidence of postoperative pulmonary complications.

The figures used in this study were taken from the records of General Hospitals through the courtesy of the following chiefs of Anesthesia Sections: Baxter General Hospital, Major Leonard M. Taylor, Brooke General Hospital, Lieutenant Colonel J. W. Winter, Bruns General Hospital, Captain Carl F. Mast, Fitzsimons General Hospital, Major Bryce Stearns, Kennedy General Hospital, Captain Frank Galiato, Percy Jones General Hospital, Major Edward B. Tuohy, Walter Reed General Hospital, Lieutenant Colonel Harold F. Bishop, and Lieutenant Colonel Lloyd H. Mousel.

REFERENCES

1. Beecher, Henry K.: Some Controversial Matters of Anesthesia for Thoracic Surgery, J. THORACIC SURG. 10: 202, 1940.
2. Bourne, Wesley, Leigh, Digby M., Inglis, A. Nelson, and Howell, G. Rennie: Spinal Anesthesia for Thoracic Surgery, Anesthesiology 3: 272-281, 1942.
3. Esten, Benjamin: Anesthesia for Thoracic Surgery, New York State J. Med. 43: 1980, 1943.
4. Moyer, C. A.: Major Changes in the Fundamental Relationships of the Respiratory Drive Mechanisms During Evipal and Pentothal Anesthesia, With Special Consideration of Possible Applications to Transpleural Surgery, J. THORACIC SURG. 11: 131, 1941.
5. Neff, William, Phillips, Wilson, and Gunn, Grace: Anesthesia for Pneumonectomy in Man, Anesthesiology 3: 314-322, 1942.
6. Nosworthy, M. D.: Anaesthesia in Chest Surgery, With Special Reference to Controlled Respiration and Cyclopropane, Proc. Roy. Soc. Med. 34: 479-506, 1941.
7. Phillips, Francis, Livingstone, H. M., and Adams, W. E.: A Clinical Consideration of Anesthesia in Intrathoracic Operations, Anesth. & Analg. 20: 78-87, 1941.
8. Phillips, Francis J., Livingstone, H., and Engel, R.: Anesthetic Results in Over 500 Thoracic Surgery Operations, Anesth. & Analg. 19: 11-18, 1940.
9. Randolph, Howell S., and Kober, Leslie, R.: The Use of Pentothal Sodium Anesthesia in Thoracic Surgery, J. A. M. A. 121: 1215-1217, 1943.
10. Wiggin, Sidney Cushing, and Schultz, Philip E.: Anesthetic Procedures in Thoracic Surgery, Am. J. Surg. 54: 4-17, 1941.