EXPERIMENTAL PNEUMECTOMY; THE APPLICATION OF DATA SO OBTAINED TO THE SURGERY OF THE HUMAN THORAX.

BY WILLIAM C. QUINBY, M.D., AND GEORGE W. MORSE, M.D., BOSTON.

(From the Laboratory of Surgical Research of the Harvard Medical School.)

Since the advent of experimental work on the various forms of apparatus to control operative pneumothorax, total one-sided pneumectomy in the dog has come to hold the position of a test operation. It has been of more value than merely to demonstrate the feasibility of apparatus, however, for the principles underlying its successful performance in the dog apply also in a large degree to the thoracic surgery of man. These principles have accumulated through the combined work of many experimenters, so that now, by their observance, the removal of the dog's lung should have a very low mortality. The contrast between this and the very high mortality of many of the earlier workers, is striking.

Experimental observations. — Two main difficulties have been encountered in attempting excision of the lung in the dog; the first, that of handling the stump of the bronchus so that it will not leak air; the second, that of providing for the compensatory filling of the empty half of the thorax by the remaining chest organs. Various methods have been proposed to accomplish these ends. In an attempt to come to a decision as to the most successful method of excising a lung, as well as to gain familiarity with the intratracheal insufflation method of Meltzer and Auer, concerning which a report has already been published,[1] the writers have done a series of experiments in the Surgical Research Laboratory of the Harvard Medical School. All the animals were operated on under ether anesthesia administered by the intratracheal method. Large dogs were given morphia before operation to facilitate handling them, small dogs were etherized without this.

Treatment of bronchus: The methods of air tight closure of the bronchus which have been advocated are as follows:

(1) A single mass ligature about bronchus and vessels with or without cauterization of stump.

(2) An elastic mass ligature about hilus with removal of lobe at a second operation.

(3) Single ligature of bronchus as in (1), followed by stitching over it a lappet of lung tissue.

(4) Double ligature of bronchus after curetting its mucous membrane.

(5) Inversion of crushed bronchus stump as is done in appendectomy. Meyer.[2]

Though the most accurate and generally successful method is undoubtedly the infolding one of Meyer, a tight closure may be had with any of the other methods in an occasional case. By far the easiest and quickest way is to ligate the hilus of each lobe *en masse*, and then amputate the lobe. But though this method is successful in a fair number of instances in the laboratory animal, it is by far too unsurgical and uncertain a procedure to apply to man. It has seemed to the writers to depend for its success entirely on the amount of peribronchial tissue which happens to be present, for we have never been able to secure airtight closure of a bronchus which has been isolated thoroughly before tying. This is in accord with the point brought out by Tiegel,[3] that bronchial wounds heal best when the stitches are placed only in the peribronchial tissues. Early in our experimental work, therefore, we adopted the crushing and inverting method of Meyer. This is not always easy to do, however, for an early division of the main bronchus, especially on the right, where the bronchus to the upper lobe is *eparterial*, may make a mass of tissue which even when crushed is so large that it enters the uncrushed portion with difficulty. This can usually be met by reserving as long a portion of each of the primary bronchi as possible before amputation, so that each one can be separately crushed and inverted.

When the proper technic has been observed, this infolding should suffice. We have had one death due to leakage of a bronchus so treated, however, so that it has seemed better in our later work to employ a lappet of lung which is apposed by a stitch to the hilus denuded of pleura. As is well known, the lung has adhesive and walling-off power quite like the omentum. In two unsuccessful experiments dealing with esophageal suture the lung was found firmly adherent, surrounding a small leak in the gullet wall, and preventing infection of the general pleural cavity. As an added precaution, therefore, it seems wise to retain a small portion of one lobe with its vessels intact, though with ligated bronchus.

Obliteration of the remaining cavity: After the proper removal of the dog's lung, the space left empty is gradually filled in by a change of position of the remaining organs. The heart and single lung, with the mobile mediastinum, move over toward the operated side; the diaphragm rises, and, in most instances, especially in young dogs, the ribs flatten.[4] Thus at a longer or shorter period after operation, the space is entirely filled. To bring this about, however, a *minus* pressure must exist in the empty side of the thorax. Workers with positive pressure, especially Robinson,[5] had a large mortality due to a serous effusion into the operated side which reached a fatal amount in from three to five days. Those who did not experience this operated with negative pressure. Though at first this difference in results was put down to the credit of the negative pressure, it was soon demonstrated to be in no way due to the form of pressure apparatus used, but dependent entirely on the conditions left behind after closure of the chest wall. Either during or after closure of the thoracic wound the pressure within the chest must be reduced at least to the normal physiological amount. This is about −9mm. Hg. for dogs; about −7mm. Hg. for man. While tying the last of the muscular stitches in closing the chest wall, the remaining lung can be over-inflated. Then when the thorax has been made airtight, the elasticity of the lung so treated will create a sufficient negative pressure,

Still another way to bring this about is to close the chest carefully and follow this immediately by aspiration through a needle or tube till the required amount of negative pressure, as measured by a manometer attached to the aspirator, has been reached.

The operation of pneumectomy: Observing these points in the treatment of the bronchus and the closure of the chest, the operation of pneumectomy as now done by us is as follows:

Strict asepsis is indispensable. This should be the same in all respects as when operating on the human being. Besides wearing sterile gowns, the hands should be covered with cotton gloves, which greatly facilitate handling the lung. If thought necessary, these can be worn over the usual rubber glove. The thorax of the animal, lying on its back and etherized with the intratracheal tube, is carefully shaved and scrubbed with soap and water. This is followed by $HgCl_2$, 1–5000, and alcohol. An intercostal incision is made over the fifth rib, beginning about an inch from the border of the sterum, and with a slight convexity caudalward, extending to within about two inches of the spine. The pectoral and scapular muscles are divided one space lower and reflected upward. The intercostal muscles of the fifth space are separated gently with the knife from the upper border of the lower rib, over an extent of an inch or so, till the parietal pleura is laid bare, through which can be seen the lung. After careful attention to hemostasis, the pleura is incised by the point of the knife cutting upward, and the lung allowed partially to collapse. The remainder of the intercostal space is then opened by scissors, guided by the left forefinger within the cavity, and cutting always on the top edge of the inferior rib so as to avoid the intercostal artery. When the incision is of sufficient length, both front and back, the upper ribs will easily be swung upwards and outward, where they are held by the rib spreader. The lung is then drawn into the wound and the periphery of the lobe destined to cover the bronchial stump is resected down to within about one and a half inches of its base, by clamp and inverting mattress stitches. This lobe will usually be the middle one on the right, the upper one on the left. Its bronchus is then freed, with care not to injure the vessels, and cut between double ligatures. The remaining vessels going to the other lobes are then separately surrounded by double ligatures and divided. The bronchus is then freed by blunt dissection from the vagus branches and peribronchial tissue and glands, as far back as the bifurcation of the trachea. Just distal to this is placed a temporary right-angled clamp with jaws protected by rubber. At the first bifurcation of the primary bronchus a stout ligature is tied, and the lung then removed. The treatment of the bronchus by crushing and inversion, as done by Meyer, is then carried out. The region of the lung root is then carefully dried and painted with tincture of iodine, and the remaining lung lappet, deprived of its bronchial connections, but not of its blood supply, held upon it by a couple of stay sutures.

To expedite the obliteration of the thoracic space left empty, the diaphragm has been paralyzed in many instances by division of the phrenic nerve as it passes over the pericardium. As demonstrated by several successful operations where this has not been done, this step is not entirely necessary. It is probable, however, that it hastens the compensatory filling of the space. The spreader is withdrawn, and the ribs then approximated by three or four stout pericostal sutures. The scapular and pectoral muscles are united, and as the last stitches are being tied, all possible air is driven out of the chest cavity by over-inflation of the remaining lung, together with inward pressure on the ribs. Accurate approximation of the skin wound is followed by a dressing of gauze and a many-tailed bandage applied quite snugly.

The technic of separate ligation of the vessels of the right side is somewhat more difficult than of those of the left, because of the eparterial position of the bronchus going to the upper lobe, and also because the pulmonary artery coming from the left side branches earlier. This, together with the fact that the dog's right lung with its infracardiac lobe is considerably larger than the left, makes a right pneumectomy somewhat more severe a procedure than is a left one. In spite of this, we have had equally good results on each side.

Numerically stated, our results have been as follows: Thirty-eight dogs have been subjected to a unilateral pneumectomy. Of these there have been thirty recoveries and eight deaths. The right lung was excised in seventeen instances with three deaths; the left in twenty-one instances with five deaths. There has been no mortality in the last nine cases.

Physiological observations. — Though it is true that the total excision of a lung in man will almost never be necessary or wise, it is of interest to study the process of physiological compensation following such a sudden diminution in the blood oxygenating surface of the organism. For it may fairly be argued that those events which follow the removal of a whole lung will also occur, only in lesser degree, when a smaller portion is excised or otherwise excluded from its share in the process of ventilation.

The compensatory filling of the empty thoracic space is brought about by the surrounding structures as described above. But this is a readjustment which is not completed for a number of days at least. Nevertheless, respiration is seen to be performed almost without any alteration from the normal during this time. In the beginning this is made possible by an increase in the heart-rate together with a less marked increase in the rate and amplitude of respiration. Physiological and histological changes in the alveolar space soon appear, and with their occurrence the increase of heart-rate and respiration subside. These alveolar changes are described by Möllgaard [6] as follows:

"When one lung is removed, and it is suddenly demanded of the right heart that it pump

the whole of the blood through the other lung, this one becomes distended and the alveolar spaces dilate, but without atrophy of their partitioning walls. Therefore the residual air increases and the animal breaths from now on with a lung which is more filled. There follows dilatation of the capillaries and the work of the heart thus becomes lessened. If the heart does not change (and here, not only the time after operation, but also the age of the animal plays a part) the distention of the lungs persists, and we have a chronic, compensating emphysema. If the heart is strong, the distention is so much the less; but if it is weak, the emphysema may reach a marked degree."

Histological preparations of our material have been studied in many instances, the specimens coming from animals allowed to survive the operation for periods of time varying from three or four days up to two months and over. In no case was any abnormality to be seen, there being no emphysema or breaking down of the alveolar partitions. In the earlier specimens, the blood vessels seemed somewhat dilated.

Thus we find that besides the compensatory filling of the space left empty, there is also compensation called forth on the part of the heart and remaining lung tissue. The degree to which each will participate in the process depends on the strength of the heart, the amount of lung tissue excluded and the time after such exclusion. By such changes the respiratory function is preserved, even after the removal of over half of the normal breathing surface of the organism.

In speaking on the "Factors of Safety in Animal Structure and Animal Economy," Meltzer[7] makes these pertinent remarks: "Next we shall consider the lungs, an organ of supply and elimination of the first order. We all know that life may continue, though a great part of the lungs be destroyed, if only the disease which caused the destruction comes to a standstill. We know that in some cases of pneumonia one lung can be entirely consolidated without seriously impairing the process of ventilation. Furthermore, a patient whose thorax was freely opened to evacuate a one-sided pleural abscess has, after the opening, less dyspnea than before. In empyema, as in pneumonia, it is essentially the infection and intoxication, with their reactions, which cause the apparent disturbance in the respiratory mechanism, and not so much the mechanical interference with the ventilation of the corresponding lung. Since the classic experiments of Regnault and Reiset, many investigators have stated that compression of one lung, or a unilateral pneumothorax, exerts very little influence on the exchange of gases. Hellin reported recently a series of experiments on rabbits in which the right lung was completely removed. The right lung of the rabbit has four lobes and is much larger in volume than the left; that means that more than one half of the lung tissue was removed. Most of the animals survived the operation, and some lived a year and longer. Except for a temporary moderate dyspnea, lasting only an hour or two, the animals were in a normal condition, and the respiratory quotient continued to be, after the removal of the lung, exactly as it was just before the operation. We see, then, that the normal process of respiration can be carried out with at least one half of the lung tissue, and probably with a good deal less. We have here, with regard to the quantity of tissue, a factor of safety equal at least to two, which does not appear to be an excessive margin, considering the importance of the function which that tissue has to carry out."

Clinical observations. — Having seen that experimentally a lung may be excised with safety, and having examined the physiological factors which underlie such successful removal, it remains to discuss the application of such data to the human being. At the outset we find that any operation which includes the resection of any considerable amount of lung tissue must be planned with full recognition of the fact that, because of its firmer structure, the human mediastinum cannot be displaced nearly to the extent possible in the dog. The very important factor of obliteration of the remaining space in the thorax must thus be met almost wholly by resection of ribs. But such resection must be relatively limited in its extent, else support of the vital organs contained in the thorax is lost. Therefore, successful excision of lung tissue in man has been limited to one lobe at the most, and in such conditions as localized bronchiectasis a number of cures have followed this operation. But it is in the exploratory operation on the human thorax, especially in cases of non-pyogenic origin, that the points above brought out will find their widest application.

Thanks to our newer appreciation of the physiological factors, to the intercostal incision with rib spreader devised by Mikulicz and to differential pressure, or preferably the intratracheal insufflation method of Meltzer and Auer, an exploratory thoracotomy can now be approached with the assurance that no harm will be done, since the physiological and anatomical conditions present before operation may all be re-established. This being the case, it is to be earnestly hoped that such operations will be done with increased frequency, for by this means our surgical knowledge of thoracic diseases will benefit, in much the same way as our knowledge of abdominal disease has been enlarged by exploratory laparotomy.

In outline, the operation of exploratory thoracotomy consists of the following steps: After etherization and the introduction of the tracheal tube, the patient is placed with the operative side somewhat higher than the other, and the pillows and sheets so arranged that this side of the chest is accessible from sternum to the angles of the ribs. A rigid asepsis is imperative; therefore, so soon as the skin and thoracic muscles have been divided, the cut edges of these should be protected by fastening towels to their circumference by means of skin clips. The skin and muscle in-

cision will vary somewhat according to the portion of the thorax which it is desired to open. It should begin well forward, however, and, curving downward *below* the intercostal space, which will later be opened, reach nearly to the rib angles. By thus making the skin-muscle incision fall below that of the intercostal space, subsequent airtight closure of the thorax is made more sure. The intercostal muscles are next divided, and the pleura opened. With a sufficiently long incision the ribs can be forced apart without undue pressure, and held so by the spreader. A wound large enough to admit the hand easily is thus obtained, through which the thoracic contents can be carefully and completely inspected. If an operation of any duration is to be attempted, it will be wise to wall off or cover those portions of the cavity outside the immediate field with rubber dam, or a sheet of oiled Chinese silk. Loss of heat and drying of the serous surfaces, which is quite rapid in such large chest exposures, are thus controlled, and considerable shock avoided. Hemostasis should be given minute attention, because vessels which have contracted and ceased to bleed during the operation may become patent again after closure of the chest and restoration of negative pressure. Before closure of the wound, the pleural cavity should be dry and free from blood clots. The spreader is next removed and the ribs above and below the incision surrounded by stout sutures of silk or kangaroo tendon placed about 2 or $2\frac{1}{2}$ inches apart. If time affords, these may pass through holes drilled in the ribs after the manner of Friedrich.[8] It is unnecessary to attempt suture of the pleura or intercostal muscles, but restoration of the other muscles and skin should be accurate and painstaking. At the completion of the operation the air should be withdrawn from the cavity by an aspirator attached to a needle of good caliber, and suction continued till the manometer attached to the aspirating tube registers a minus pressure of about 7 or 8 mm. Hg. This latter step cannot apply, of course, to instances where it is found necessary to drain the cavity; but in such cases every effort should be made to keep the drainage opening as small as is consistent with the purpose for which it is used, thus making re-expansion of the lung quicker and easier.

In concluding, the writers wish to call attention again to the great value of practical laboratory experience as an aid in acquiring knowledge and technic in this increasingly important branch of surgery.

REFERENCES.

[1] Quinby: Surgery of the Thorax; Intratracheal Insufflation by the Method of Meltzer and Auer. Surg., Gynec. and Obstet., Nov., 1910, p. 482.
[2] Meyer: Pneumectomy with the Aid of Differential Air Pressure. Jour. Am. Med. Asso., Dec., 1909, p. 1978.
[3] Tiegel: Experimentelle Studien ueber die Chirurgie des Bronchus. Beitr. z. klin. Chir., 1910, lxviii, s. 584.
[4] Friedrich: Die Raumausgleich in der Brusthoehle nach einseitiger Lungenamputation. Arch. für klin. Chir., 1908, lxxxvii, s. 647.
[5] Robinson and Leland: Surgery of the Lungs under Positive and Negative Pressure. Surg., Gynec. and Obstet., March, 1909, p. 255.
[6] Möllgaard: Ueber Emphysem und Herzhypertrophie nach Exstirpation der einen Lunge. Skandin Arch. für. Physiol, 1909, xxii, s. 101.
[7] Meltzer: The Harvey Lectures, 1906–07, p. 144 *et seq.*
[8] Friedrich: Die Chirurgie der Lungen. Arch. für klin. Chir., Bd. lxxxii, Heft. 4.

INTERLOBAR EXUDATES.*

BY ARTHUR K. STONE, M.D., BOSTON, MASS.

THE presence of free fluid exudate in the thoracic cavities, in amounts of over half a liter, presents certain very definite physical signs which, for the most part, make easy its recognition. It is only when adhesions are formed and encapsulation of the exudate occurs that the problem becomes complex. Every one who has the opportunity to see many chest cases has encountered difficulties in the way of making an absolute diagnosis of pleurisy with effusion, or of empyema. Many have been in the habit of using long exploring needles to find the hidden exudate, and almost all of us have a number of "dry taps" to our debit account, and that, too, in cases when the signs and symptoms have seemed to point clearly to the presence of fluid in the pleural cavity.

It is my intention to discuss only those collections of fluid which occur in the spaces which are formed between the lobes of the lung. The formation of such spaces presuppose sufficient fibrous inflammation to cause the edges of the lobes to adhere, while the formation of a fluid exudate takes place from the usually approximated surfaces, forcing them apart. Another form of interlobar exudate is found near the costal surface of the lungs and is formed by forcing apart the lobes so that small pockets are made along the sulci, with the lateral boundaries the separated lobes of the lung and the parietal pleura for a base, the edges of the lobes bring adherent to the chest wall so as to surround the exudate.

Very little regarding the encapsulated exudates has been said in the textbooks or monographs that will help one who really wishes to understand the problem and to act intelligently in the presence of perplexing signs. Musser[16, 17] has been the American author to call attention to the frequency of the presence of purulent exudates being located between the lobes of the lungs; and the recent advances made by the surgeons in operations upon the thoracic conditions have also emphasized the importance of understanding the position of the interlobar spaces as places where pus must be sought.

A. Fränkel in Germany has written several papers upon interlobar exudates and is the one man in Germany who has laid emphasis on the importance of the subject.[3, 4, 5] The pathologists have made singularly few observations regarding this condition. Of course, there is nothing new in the recognition of the interlobar spaces as the lurking places of exudates. The presence of fluid, both serous and purulent, was recognized by early observers, and Laennec[1] gives a good and satisfactory account of the pathological condition as he observed it in his large experience with post-mortem material, and his explanations of the pathological processes leading to the formation of the condition are perfectly sound to-day.

It is necessary for the diagnostician to hold in mind the general anatomical position of the sulci forming the boundary between the lobes of

* Presented at the meeting of the American Climatological Association in Montreal, June 14, 1911.