THE TECHNIC OF TOTAL UNILATERAL PNEUMONECTOMY

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Total removal of one lung in the human is a much earlier operation than one would think. Haight, in a recent article, has given a satisfactory and useful review of all the cases recorded in the literature up to January, 1934. The first reported instance of complete removal of one lung in man goes to the credit of Kuemmell. This was in November, 1910. He employed a one-stage procedure. The pedicle was simply clamped, the entire lung amputated, and the clamp left in place, without ligatures. The patient died on the sixth day, from œdema and bronchitis of the other lung. The operation was done for diffuse carcinoma of the lung, and was unjustifiable as the condition was obviously hopeless from the start, inasmuch as the pleural cavity and diaphragm were infiltrated with carcinomatous nodules, and the axillary glands were involved.

In 1915, Willy Meyer lost a patient on the table, from hæmorrhage due to a tear of the pulmonary artery, while he was endeavoring to pass a ligature around the artery. This was, therefore, only an attempted pneumonectomy, not a completed one.

In 1919, Lilienthal resected the right lung, which was the seat of an extensive bronchiectasis, in one stage, by the chain ligature method. This patient also had a sudden hæmorrhage from a large vein during division of the pedicle, which was secured by clamps, and death occurred six hours later from œdema of the remaining lung.

In 1920, Lilienthal resected the whole left lung in two stages, for post-tonsillectomy suppurative pneumonitis. Death occurred from secondary hæmorrhage from the pedicle after the ligatures had sloughed off. In 1920, Willy Meyer amputated the right lung for bronchiectasis, in one stage, and the patient died of œdema of the other lung.

On November 8, 1922, Hinz removed the whole of the left lung for a carcinoma of the lower lobe, involving the hilus. The patient died about sixty hours post operationem from emphysema of the mediastinum and the remaining lung.

In 1923, Sauerbruch reported a total removal of the left lung, which, however, was not a planned operation. In the course of removing a large posterior mediastinal tumor, he must have in some unexplained way interfered with the vascular supply to that lung without knowing that he had done so. After four weeks large sloughs of necrosed lung came away and later inspection of the pleural cavity revealed the absence of the entire left lung.

Apparently during the eight years following, that is, from 1923 to 1931,

no further cases of this operation were recorded. In the latter year, Nissen, of Sauerbruch's Clinic, performed the first successful operation. The case was one of diffuse suppurative bronchiectasis of the left lung, which had resulted from a tear in the left main bronchus, following a crushing injury to the thorax. A stenosis of the left main bronchus ensued as a result of healing, but suppuration developed behind the block. The whole left lung was removed in two stages, the second stage being rendered necessary by a temporary cardiac block, presumably due to traction on the hilum. The pedicle was ligated with silk, and the lung was allowed to slough off, which it did in fourteen days.

Haight, as I think rightly, gives the credit to Nissen for the first successful total pneumonectomy. In this respect he sets aside the two earlier cases of Sir William Macewen (1895) and of Sauerbruch (1923). Macewen's celebrated case was one of practically total tuberculous excavation of the left lung, and Macewen did little more than drain this enormous cavity, and in successive stages remove shreds of surrounding lung tissue, at the same time excising portions of the fourth to the seventh ribs, also, later, portions of the third, eighth, and ninth ribs. All this was done in 1895, but not reported until 1906. It was not, properly speaking, a planned pneumonectomy; Nature indeed had already carried out the greater part of the work.

The next case after Nissen's of planned removal of one entire lung was the one which the writer reported briefly at the meeting of the Association of Thoracic Surgeons, at Ann Arbor, in April, 1932. This patient died of a septicæmia four days after operation. The first stage of the operation was done December 2, 1931, the second stage February 10, 1932; and the case was one of carcinoma of the left stem bronchus.

November 8, 1932, Doctor Haight, of Ann Arbor, did the first stage of a total left pneumonectomy for diffuse bronchiectasis, and did the second stage November 14. The patient made a perfect recovery.

On the same date, November 8, 1932, Doctor Windsberg (personal report to Doctor Haight) carried out a successful multiple-stage removal of the right lung for bronchiectasis. This, as Haight remarks, is apparently the second instance of successful pneumonectomy in man, and the first in this country. It would appear that Doctor Haight (although not so claimed by him) has an equal claim in the matter of priority.

April 5, 1933, Evarts Graham operated on a patient with carcinoma of the bronchus, removing the entire left lung in one stage, and this represents the first case of successful removal of the entire lung for carcinoma of the bronchus.

I need hardly go on to give a detailed report of other cases, most of which are mentioned by Haight, but it is noteworthy that, following the earlier discouragements of the years up to 1923, which apparently led to eight years of inertia, there has occurred since Nissen's successful case, in 1931, a regular spate of total pneumonectomies. My own case in the late fall of 1931, though ending in death from an infective complication, demonstrated the

possibility of removing the whole lung from in front, without serious upset of the respiratory and cardiac functions. These were the only two cases reported belonging to 1931.

In 1932, three further cases were operated on, while in 1933 ten more cases are listed by Haight; and in addition I know by correspondence of eight more that have been done in 1934.

During the years from 1910 to 1923 seven cases were reported, with six post-operative deaths and one cure, while in the years from 1931 to 1934 twenty-three cases have been operated on with sixteen operative cures and seven deaths. Such a record constitutes another milestone of progress in surgery, and another evidence of the beneficent results of specialization, for by far the greater number of these patients have been operated on by surgeons who have made thoracic surgery their hobby or their exclusive specialty. There can be no doubt that the foundation of the Association for Thoracic Surgery by the late Dr. Willy Meyer has contributed largely to such a record of encouraging progress as is represented by the statement which I have just given you. We are now able to say that the operation in its main lines is firmly settled on a scientific foundation, although variations in technic still remain to be discussed.

It is this question of technic which I wish to bring before you today, and the chief object of this paper is to propose a new line of approach, that from the front through the anterior mediastinum. We have to consider the following main points: anæsthesia; the line of approach to the lung; the liberation of pleural adhesions; the method by which the pulmonary arteries and veins are to be secured; the closure of the bronchial stump or stumps; the question of immediate or delayed amputation of the lung; the avoidance of disturbances of the cardiac and respiratory functions; the question of drainage; and the obliteration of the empty side of the thorax.

Before proceeding to take up these questions in detail, a few general remarks upon the pathological conditions which may be held to justify the entire removal of one lung, and upon the bearing which such pathological condition may have upon the choice of operation, may not be out of place.

All the reported cases, save two, have concerned one of two conditions—generalized suppurative bronchiectasis with or without abscess, and malignant disease. The two exceptions are, first, Macewen's case of 1895; and second, a recent patient of my own, who was suffering from very advanced pulmonary tuberculosis, upon whom a four-stage thoracoplasty had been performed, leaving a residual cavity in the apex, with positive sputum and extensive generalized bronchiectasis in the collapsed lung. I shall refer to this case later.

On the pathological side, the essential difference between the conditions of widespread infection and malignant tumor lies in the fact that in the former pleural adhesions may be so dense as to be almost impossible of separation without danger of rupturing the lung, while inflammatory œdema and adhesions around the hilus may make difficult and dangerous any attempt to

secure the hilar structures outside the lung. On the other hand, in the latter, that is malignant disease, so long as this is uncomplicated by lung infection, neither of these difficulties has to be met. It is obvious, therefore, that, other things being equal, it will usually be easier to secure the vessels of the lung outside the lung, between it and the heart, in cases of carcinoma than in cases of bronchiectasis and lung abscess.

The anatomy of the heart-lung system has also a bearing upon the type of operation, in the sense that any dissection of the vessels and bronchi outside the lung, between it and the heart, is very much more difficult on the right side than on the left. On the left the stem bronchus measures about two inches before giving off the upper lobe branch. On the right it may be extremely short. The eparterial, or upper lobe bronchus, comes off frequently less than one inch from the bifurcation; and the middle lobe and lower lobe bronchi within an inch below that. Consequently any extrapulmonary ligation on the right side can hardly be done in the stem bronchus, but only after its division into two or perhaps three separate branches, and these are already covered by lung tissue. Likewise with the vascular supply. On the left side the pulmonary artery can easily be ligated outside the lung before it divides, so that one has only one vessel to take care of. On the right side the artery divides very quickly into two or three branches, each of which has to be separately isolated and ligated. The same is true of the veins. Moreover, on the right side there are three lobes as against two on the left; and consequently three sets of vessels demanding separate ligation. And, finally, the inner edge of the right lung comes in farther towards the mid-line than does the left lung, and, therefore, covers the pedicle much more completely than on the left side. If, in addition, this edge of the lung is adherent through old infiltration to the right side of the heart, the difficulty of dissection and the danger of wounding the lung or vessels in any attempt to uncover the hilus is by so much increased. Consequently, as a general principle, total pneumonectomy on the right side will, in the majority of cases, be more safely and easily carried out by using mass ligatures including a small area of the lung tissue proper, together with the hilar structures, than by endeavoring to secure the pedicle between lung and heart; whereas on the left side it will often be found that the one is as easy as the other and in many instances the extrapleural ligation may even be easier than mass ligatures through the base of the lung.

Anæsthesia.—The anæsthetic is certainly a matter of the greatest importance. To prevent shock, Shenstone in the operation of lobectomy uses as a routine a high spinal anæsthesia, with novocaine, and has had no ill results from the side of the medullary vital centres, in particular from excessive fall of blood-pressure. He goes so far as to declare that he no longer concerns himself with the blood-pressure record. He admits that it may fall to a degree alarming to the inexperienced, but that the patient always recovers a normal blood-pressure in due time. However, he takes care to give a continuous intravenous infusion of Ringer's solution throughout the operation, and, if

necessary, adds a blood transfusion. This must contribute to prevention of shock. The anæsthesia must be pushed quite high. I have attempted only one operation of lobectomy under spinal anæsthesia, and while I found the skin insensitive as high as the third dorsal vertebra, the arteries in the underlying muscles were still sensitive. The pleura was opened without pain, but immediately one began, at about the level of the sixth rib in the scapular line, to separate pleural adhesions, the patient complained of intolerable pain, so that a general anæsthesia had to be added. It was clear that the fibres of deep sensation enter the cord higher up than the third dorsal root, and it is to be presumed that Shenstone, and others, who report themselves satisfied with this form of anæsthesia, must push the drug up to the lower cervical region at least. I cannot but feel that this involves some danger.

Another indication for the use of spinal anæsthesia is to preserve the cough reflex, so that pus from the diseased lobe, expressed during manipulation, or running out of the lobe by gravity, may be coughed up by the patient and not run over into the opposite lung, and there set up an acute septic process. That this preservation of the cough reflex does not always prevent the complication just mentioned, which is frequently a fatal one, is shown by the fact that several of Shenstone's patients died of it. And, in fact, considering the large amount of fluid pus, which is present in any of the advanced types of bronchiectasis, and considering also the fact that the act of coughing may splash a portion of such thin pus into the other lung (as we have seen in lipiodol observations) it is obvious that the preservation of the cough reflex does not of itself sufficiently safeguard us from this danger.

Doubtless the great majority of lobectomies, both in this country and in Europe, have been done under a general anæsthetic, either nitrous-oxide gas with oxygen, or ethylene, or ether. One must admit that a general anæsthetic of this sort does not prevent shock, nor does it prevent the accident of contralateral infection through flooding. An acute infective pneumonitis, in my own series of cautery pneumonectomy, and of a portion of the one-stage lobectomies, has been the most frequent cause of death, and the most dreaded complication. I came to the conclusion some three years ago that, in one way or another, the pus contained in the affected lobe had to be prevented from running out of it during the operation, and at that time Doctor Griffith and Doctor Howell devised for me an instrument consisting of a very long coudé catheter, bearing at its end an inflatable balloon of a size to fit the stem bronchus. This has been of great help in the ordinary one-stage lobectomy, and is equally applicable to the cases of total unilateral pneumonectomy, when the condition of a considerable amount of pus retained in the lung is present. This is, of course, the case in bronchiectasis of both lobes, and is also frequently the case in carcinoma, especially when situated near the hilum and causing bronchial stenosis. I have, therefore, in dealing with such conditions adopted in principle the following procedure. The patient is first deeply anæsthetized with chloroform, in order to allow the introduction of this rubber balloon into the stem bronchus of the lung or lobe which is to be removed.

Quiet induction and deep anæsthesia is necessary in order to prevent coughing, and the expulsion of pus at the start, before the balloon is properly placed and blown up. As soon as this is accomplished anæsthesia is continued with nitrous-oxide gas, run in through an intratracheal catheter, which is pushed part way down the trachea beside the coudé catheter. This has in six cases prevented any exit of pus, and satisfactory oxygenation of the blood has been maintained through the sound lung. In the case of carcinoma without lung suppuration, this manœuvre is not necessary, and I am then satisfied with gas-oxygen anæsthesia through a mask, or through the intratracheal catheter, with provision made for positive pressure, if necessary.

Morriston Davies recommends in addition the intrathoracic injection of the vagus nerve with novocaine, just above the hilum, as soon as that nerve can be exposed, claiming that it prevents shock almost completely. This may well be a valuable aid, but when extensive pleural adhesions are present, the separation of these adhesions will usually have caused a very definite degree of shock before the vagus can be exposed.

Line of Approach.—The approach in Kuemmel's first case seems to have been through a long oblique lateral incision. Since then, in all recorded cases except five, the incision has been postero-lateral, running from close to the vertebral border around to the axillary line or beyond, and at a level of the fifth, sixth or seventh ribs.

In the fall of 1931 I attempted a total pneumonectomy in a case of carcinoma of the left stem bronchus, with dense adhesions from secondary pneumonitis, through this approach, but found after separating these adhesions that the access to the hilum was insufficient, and the lower lobe alone was removed. This experience led to the idea that an anterior approach through the mediastinum, on the left side, would render the operation easier, and would give better control for the ligation of the important hilar vessels. Therefore, in February, 1932, I removed through the anterior incision (for the first time, I believe), the upper lobe, together with the stump of the lower lobe and the stem bronchus, without serious difficulty. Since then I have used the same approach for another total pneumonectomy on the left side, in a case of sarcoma of the upper lobe, situated close to the hilum, with success. Doctor Rienhoff, of Baltimore, has also independently used the same method in two cases with success (July and November, 1933), and is strong in its favor. He had been employing this line of approach for several years in experimental work upon the œsophagus (verbal communication). It seems to me that for all cases of carcinoma involving the stem bronchus, or close to it, in which obviously the bronchus has to be cut across below the bifurcation, and in which early and accurate control of the pulmonary artery and veins is naturally desired, this access through the anterior mediastinum will, at any rate on the left side, be found the most convenient. It permits early dissection of the vessels, clean and accurate ligation and division, and subsequently an easy approach to the long stem bronchus. It seems to me a more surgical operation than to attack the hilum from behind, from which position, though access

to the bronchus may be easy, the subsequent visualization and accurate ligation of the vessels may be difficult. Another advantage lies in the recumbent posture of the patient on the table, which allows freer respiration.

One can imagine a regular bogging of the extrapulmonary hilar tissues in a chronic inflammatory exudate, though I have not yet seen such a condition; and in such circumstances this approach would not be so suitable. Here there would seem to be better reason to gain access from behind and use mass ligatures around the stem of each lobe separately, or through the hilum as a whole. But this condition, if it occurs at all, can not be foreseen; and the anterior approach is not thereby invalidated.

On the right side, judging from one experience in a case of chronic advanced tuberculosis, I feel sure that the anterior approach and dissection through the mediastinum is too difficult for the reasons above mentioned, and that here a postero-lateral approach and mass ligatures are better. Hilar infiltration by carcinoma naturally forbids any operation.

Pleural Adhesions.—The tightness and extent of pleural adhesions make a great difference. If there are no adhesions, the operation becomes really simple, and Rienhoff completed one such operation in a child in thirty minutes. In contrast with this, where, following lung infection, either primary, or secondary to neoplasm, adhesions are dense and universal, the mere act of separation and division may provoke such shock that a two-stage operation is imposed. Traction on the lung hilus also may cause cardiac stoppage (Nissen), and interrupt the operation.

Securing of the Pedicle.—Here two methods have been used; mass ligation through lung tissue, close to the hilus; and separate ligation of vessels and bronchus, outside the lung. The earlier operations were all done by mass ligation. I believe that whenever reasonably normal conditions are present in the mediastinum, extrapulmonary ligation is better. This has to be determined at the moment of operation. In all cancer cases that have remained clean, it should be the method of choice. But when dissection through the anterior mediastinum comes upon difficult inflammatory thickening, mass ligation should be safer, because of the danger of wounding the hilar vessels. Whether mass ligation through the anterior approach is as safe as when done from the postero-lateral aspect I do not know. It should depend on the extent and nature of the posterior adhesions. One must keep in mind the danger of wounding large veins outside the lung during the process of separation of the spinal gutter adhesions. For this, clear vision is safest.

The condition of carcinoma arising in the stem bronchus on the right side, or in the primary divisions of the stem bronchus, close to the hilus, presents theoretically a most difficult problem. I have not yet had occasion to operate for this lesion. It is obvious that mass ligation would be here impossible, as it would be applied through involved tissue or, at any rate, too close to the growth. On the other hand, separate ligation of the vessels and of the stem bronchus is exceedingly difficult, and may also be dangerous. Any carcinomatous infiltration outside the lung and in the hilus forbids any such dissec-

tion. Where the hilus is still free of the disease, the dissection and separate ligation of the vessels immediately outside the heart and of the short stem bronchus would be the only thing left to do; but the point is, as I have found in cadaver dissections, that dissection is extremely difficult, for the reasons above mentioned, and I believe that it is equally difficult whether attempted from behind or from in front.

Closure of the Bronchial Stump.—The various experimental methods devised do not help us much in the operation in man. Elaborate methods are out of place as being time-consuming, and the presence of infection has usually defeated them. On the other hand it is remarkable how little trouble, on the whole, the failure to secure closure of the bronchus or bronchi, has caused. The fistula nearly always closes spontaneously by granulations in due time, if only it lies deep (a principle which Brunn emphasized in describing his operation for lobectomy). Nevertheless there is a real, even if nowadays infrequent danger from emphysema of the mediastinum, or of the opposite lung (Sauerbruch, Hinz). I think it unwise to use any method which crushes the stump, as this may create a way of escape for air into the mediastinum. Ordinary gut, or silk ligatures, fail to effect permanent closure. The method of inducing fibrosis and an occluding scar by use of caustics, recently advocated by Livingstone and Adams, and by Cutler, is one which seems definitely established and frequently successful. Silver nitrate has been used for many years to close the openings of small bronchi in the bed of an opened lung abscess, but the large bronchi, even the largest, can also be closed in this way, although infection may prevent it. In two recent cases I have escaped fistula by cauterizing the mucosa with phenol over a length of three-quarters of an inch or more, and ligating not too tightly both with chromic gut and a silver wire. The bronchus remained closed in spite of the presence of infection in the lung. It is clear that, as between the two competing methods of mass ligation and the extrapulmonary operation here proposed, it will be easier in the latter method, which is one of clean dissection, to cauterize the bronchial mucosa and apply ligatures, and therefore there will be a better prospect of securing primary permanent closure without fistula. Mass ligation is practically always followed by fistula.

Immediate or Delayed Amputation of the Lung.—In the first three successful cases (Sauerbruch, Nissen, Haight), the mass ligation method was used (in Sauerbruch's case accidentally), and the lung was left *in situ* and allowed to slough away. In a few others the same method has been followed by death. Alexander has advised it as a matter of principle in two-stage lobectomies. I am inclined to consider it dangerous on account of toxic absorption, particularly when the pleural surfaces have not been prepared by previous aseptic pleuritis, with granulations, to resist absorption. Practically all of the successful cases in the last three years have had immediate amputation. In serious conditions of extensive bronchiectasis, with abscess and dense adhesions, or in advanced chronic tuberculosis uncured by thoracoplasty, it may be wiser, after mass ligation, to leave the lobe and await sloughing.

Drainage.—It is remarkable that in five cases operated on within the last six months (Churchill, Overholt, Rienhoff), all drainage was omitted, and in four of these no fistula resulted; and in all five there was quite satisfactory recovery from the operation. Aspiration of fluid, naturally, may be necessary. In all these cases, however, the condition appears to have been carcinoma without any complicating infection. Indeed, in one case the tumor was benign. Under such ideal conditions the omission of drainage may be justified, although for myself I can see no objection to leaving a closed drain at the bottom to take care of the inevitable serosanguinolent effusion. But there is one danger in closing the chest completely, and that is tension pneumothorax. Sauerbruch lost three cases in this way, after lobectomy, and many others have been reported. It is always possible that the bronchial closure may open after a few days, and that the stump should become loosely covered by mediastinal tissues, or pleura, in which case the valve action may come in and induce a tension pneumothorax, or emphysema, which may be fatal. Tube drainage for the first week or two is, in this respect, a measure of safety, and I can see no objection to its use.

Physiological Disturbances.—In quite a few cases death has been due chiefly to failure of the heart, with coincident œdema of the remaining lung. This danger is clearly due to two main causes, of which the first consists in a too sudden and too great suppression of oxygenating surface, and the second in a lack of care in respect of the flapping mediastinum of open pneumothorax during or after operation. Both these dangers can be avoided by a preliminary stabilizing of the mediastinum and gradual compression of the diseased lung by artificial pneumothorax, slowly induced and maintained for about a fortnight. This will be possible chiefly in cases of tumor unaccompanied by infections of the lung and pleural adhesions. In cases of diffuse bronchiectasis adhesions will frequently make it impossible. Kuemmel, in 1910, was the first to employ this measure of preliminary pneumothorax and to recommend it, and Eloesser pointed out some seven or eight years ago that all thoracic operations were rendered safer by this measure. I used it in 1931, in my first case. Ivanissevich and Ferrari used it in October, 1932. Rienhoff, in 1933, makes a strong point of it. Two weeks of pneumothorax seems to be quite sufficient, so that the later operation can be done even without a differential pressure apparatus. This method also is useful in accustoming the other lung to take up the extra work.

Infection.—As regards infection of the other lung, where there is any amount of purulent sputum coming from the affected lung, I consider it important to use the inflatable balloon, which occludes the stem bronchus, and prevents flooding of the other lung. In this sense the anterior approach, the patient lying on his back instead of on the good side, ought to help in preventing this complication.

Infection of the pleura constitutes a very definite danger when chronic infection of the lung is present. Such infection is almost inevitable, if the stem bronchus shares in the infection, but I believe that the separation of

pleural adhesions can of itself light the fire of empyema. After all, they are the result of preëxisting infection and possibly contain living bacteria. Certainly in a series of peritoneal adhesions which I examined bacteriologically, positive cultures were obtained in two-thirds of the cases. To prevent or lessen the danger of such pleural infection is one of our most difficult tasks. Every effort must be made while cutting across the root of the lung to protect the pleura by extensive gauze packing, or rubber tissue, properly placed; and in all infected cases I consider a gauze pack surrounding the stump and brought out through the wound to be a necessary part of the operation. My first patient died of a streptococcus septicæmia arising in such a pleural infection.

In a few cases one gets the impression that the heart muscle is itself unequal to the strain imposed by the anæsthetic and the operation, and against such dangers we have to guard by means of a very careful pre-operative investigation of the patient's circulation and his general resistance, by the use of blood transfusions and of cardiac tonics, by the avoidance of dragging on the mediastinum during operation, and if possible by infiltration of the vagus with novocaine.

Obliteration of the Cavity Left.—Experience has shown that the hemithorax is frequently obliterated spontaneously by an emphysematous expansion of the sound lung with displacement of the heart and by a rise of the diaphragm. A phrenicectomy, either preliminary or late, is usual. In the pre-operative period of closed pneumothorax, that can hardly be of value. In the child it may never be necessary. I incline to the opinion that its proper place is after operation, if found necessary. The same is true of thoracoplasty. In one case (Overholt) it was necessary to do later a limited thoracoplasty. Evarts Graham did a preliminary thoracoplasty and went on immediately to remove the lung, with success. I cannot feel that it is necessary to do such a preliminary thoracoplasty, and believe it must add to the dangers of a one-stage operation. The sequence in Overholt's case seems to me the proper one. In my second case, however, it was shown by the second operation that no obliteration of the left side of the thorax could be hoped for. There was a dense fibrous partition between the two halves of the chest, and thoracoplasty would have had to be an absolutely total one to close the space. But I contemplated such a condition with equanimity and expected a permanent sterile hydropneumothorax. As a matter of fact such was the condition found four months after operation (except for the presence of some blood in the small amount of fluid present, coming from the recurrent sarcoma); and such I believe will be in many cases a quite acceptable alternative condition.

A brief report of my three cases of total unilateral pneumonectomy is appended, leaving the complete record for a later communication. In this place I propose to do no more than describe the operation as carried out through the anterior approach, which I think is the most advantageous under certain conditions.

In the preceding remarks I have indicated the conditions which in general permit an attack from the front. I might summarize these conditions by saying that this operation would seem to be best employed in all left-sided pneumonectomies, certainly for tumor, but also for diffuse lung suppuration. I admit that the one condition which may give us pause is the presence of extensive and dense pleural adhesions between lung and posterior mediastinum. Here the separation of adhesions in the process of freeing the lung pedicle should be done more or less under direct vision, because of the danger of wounding the large mediastinal veins, including the main pulmonary vessels. This can be done through the anterior opening, if sufficient ribs are excised (third, fourth and even the fifth) to allow of pulling the lung forward and medially so as to afford direct vision. It cannot be done safely through any relatively small opening. It can possibly be done more easily through a long postero-lateral incision, but in this case the section and individual ligation of the pulmonary artery and veins is less easy than from in front, as they lie anterior to the stem bronchus. Consequently I should prefer, in principle, to go in first from in front, secure the vessels, and then, if necessary, enlarge the thoracic opening sufficiently towards the posterior axilla to allow access to the posterior surface. In my two left-sided pneumonectomies for tumor, both complicated by a serious lung infection, such adhesions were present, and yet it was possible to complete the operation safely in the way described. In the case of diffuse lung suppuration, where it is not necessary to cut through the stem bronchus outside the lung, the method of mass ligation, including a stump of lung, has much to be said for it, and has a number of successes to its credit. (Nissen, Haight.)

In cases of tumor uncomplicated by adhesions I feel that there is no doubt that the anterior approach is the easiest and safest.

On the right side I should favor, on the whole, the postero-lateral incision, coming well round to the anterior axillary line, and mass ligatures, both for the condition of diffuse bronchiectasis and for that of carcinoma situated in the body of the lung but not in the stem bronchus or in its first divisions. This latter condition has already been discussed above, as regards operation.

The procedure then, on the left side, by the anterior approach, is as follows:

Anæsthesia.—Nitrous-oxide gas with oxygen, plus local. If the lung is infected, and copious purulent sputum is being expectorated, the rubber balloon is used. *Position on the Table.*—The patient lies on his back, with the left side slightly raised by pillows. *The incision* runs from the mid-sternum, opposite the second intercostal space, downwards below the nipple and up into the mid-axillary line, going through muscles as far as the ribs. The musculocutaneous flap is retracted upwards, exposing the third, fourth and fifth ribs. The third rib is excised with its cartilage from the sternum to the anterior axillary line. Part of the sternum may be rongeured away. If necessary a portion of the fourth rib and cartilage is later excised, if access to the lowermost pulmonary vein proves difficult. The pleura is then opened freely in its

whole length into the pneumothorax, which should be, if possible, previously established. There follows careful palpation in order to ascertain the extent of eventual adhesions, and also the presence or absence of metastases in the mediastinum, in cases of carcinoma. So far the operation may be considered an exploratory one. If the condition is found operable, one may then proceed immediately to carry out the radical operation. The pleura, opened as far as the edge of the sternum, is now pushed back laterally so as to expose the anterior mediastinum, and is held back by retractors. The left edge of the heart and the medial edge of the lung are defined and carefully pushed back and lightly held by retractors. The pulmonary artery is found usually in front, and at this point has not ordinarily divided into its branches. It is carefully dissected free, which can be done over a distance of nearly an inch, and is ligated doubly and cut between. Beneath the artery there will be found the upper pulmonary vein, and lower down the inferior one. These are treated in the same way. Under these one will have to dissect rather more deeply to expose the left stem bronchus, which can easily be felt. It runs obliquely upwards in the wound to the bifurcation, and one can isolate it easily over a length of a good inch, without invading the lung. In cases of bronchiectasis there may be some inflammatory infiltration of the adventitious tissue surrounding it, but this offers no serious obstacle. With a curved Macewen needle, carrying No. 2 chromic gut, passed behind the bronchus, it can be lifted towards the operator and can be securely held. It is doubly ligated and then severed. If possible, the proximal stump should be left open for half an inch beyond the ligature. The mucosa of this stump is then cauterized with pure phenol and finally a silver-wire ligature is tied snugly around this projecting stump, the ends twisted and cut short. No attempt is made to cover the stump with pleura or connective tissue.

The pedicle of the lung being thus cut across, it remains to deal with eventual adhesions, and with the reflection of the lower posterior pleura constituting the pulmonary ligament, and also with the reflection of the pleura above the pedicle. This can best be done by sweeping the hand around the interior of the thorax, and lifting the lung forward into the opening, thus rendering the posterior surfaces accessible to direct vision and dissection. When pleural adhesions have to be cut around the periphery of the lung, the Cameron light, with curved end, will be found most useful. It can be inserted under adhesions and the transillumination shows exactly the boundary between the lung and the adhesion, the lung surface showing pigmented, while the adhesion is a clear pink. This prevents blind cutting into the lung substance. The operation then is completed from behind by cutting the pleural reflections and entering the space of loose tissue behind the cut bronchus. In this way the lung is not invaded at all, the whole operation proceeding between the lung and the heart.

Rienhoff has done a similar operation without resection of any ribs, with the help of rib retractors, but such I imagine could be possible only with a lung almost entirely collapsed by the pneumothorax. In both my cases exten-

sive adhesions and an uncollapsed lung had to be dealt with, and, as a matter of fact, in the first case three ribs, the third, fourth and fifth, had to be excised before the lung could be delivered. In the second case only the third rib and an accessory third rib, about three inches long, needed excision.

After this, no attempt is made to resuture the opening in the pleura, and the musculocutaneous flap is replaced and accurately closed with two layers of interrupted catgut reuniting the muscles. A stab drain is previously placed just above the diaphragm, posteriorly; and closed drainage with slight suction is maintained.

There follows a brief report of the three cases in which total unilateral pneumonectomy was done.

CASE I.—S. F., aged thirty-four, male, admitted to the Surgical Department of the Royal Victoria Hospital October 5, 1931, with a diagnosis, proved by bronchoscopy and biopsy, of carcinoma situated in the left stem bronchus, about one and three-quarter inches below the bifurcation, together with left lower lobe pneumonitis and bronchiectasis. An artificial pneumothorax was first instituted in preparation for a total left pneumonectomy. October 23, an exploratory thoracotomy was done, no enlargement of the mediastinal glands was found, and a few adhesions were cut. The lower lobe was densely adherent. November 13, the left phrenic nerve was avulsed. December 2, the main operation was undertaken. It was intended to attempt the complete operation through a long posterolateral incision at the level of the seventh interspace. The separation of the very extensive adhesions of the lower lobe induced marked shock, and it was found also that access to the hilus at the high level necessitated by the position of the tumor in the stem bronchus was insufficient. Consequently only the lower lobe was excised. Bronchial fistula developed on the sixteenth day, and empyema followed, which, December 24, was drained. February 10, 1932, the removal of the upper lobe, together with the stump of the lower lobe, and the stem bronchus, was undertaken, although there still persisted a very small empyema pocket. This was done through an anterior incision according to the technic above described. Moderate shock was relieved by a blood transfusion. During operation there had occurred no physiological disturbance of moment, the remaining lung and the heart carrying on very well because of the firm mediastinum. On the day after operation there was no air hunger, color was good, and respiration, though a little hurried, was free. At the end of the fourth day the patient died of a streptococcus septicæmia (proved by blood culture), but complicated by a terminal œdema of the right lung, the signs of which first appeared only about twelve hours before death. Both pleural exudate and heart blood showed a hæmolytic streptococcus, the origin of which was undoubtedly the small residual empyema.

CASE II.—J. G., aged thirty-one, male, admitted June 5, 1933. Referred by Doctor Mayhew, Malone, N. Y. The condition was one of sarcoma of the left upper lobe, invading the tissues of the hilus, and confirmed by bronchoscopic biopsy. During the previous two weeks there had arisen the complication of an acute lower lobe pneumonitis, with foul sputum and fever. By June 16 his temperature was normal. June 19, an exploratory thoracotomy was done, and no definite metastases could be felt in the mediastinal glands, nor any nodules on the pleural surface. July 7, the whole left lung was removed by the technic described, through the anterior incision. Spinal anæsthesia was used, but had to be supplemented with gas and oxygen. There was some shock which was relieved by blood transfusion. Closed drainage was established. The cardiorespiratory mechanism withstood the operation quite well. Convalescence was uneventful except for the development of an empyema, which yielded to irrigations of gentian violet and salt solution. No bronchial fistula occurred. He was discharged September 22.

November 7, 1933, he was readmitted. Doctor Mayhew, on taking an X-ray film,

had discovered a metastasis at the apex of the pleural cavity. He had been feeling well, had gained twelve pounds, had no cough, no sputum, no fever, and no shortness of breath, except upon going up an incline. November 13, the chest was reopened, and a very soft, dark red, pear-shaped tumor, with a pedicle in the posterior mediastinum, was removed, and a radium pack inserted. The left pleural cavity appeared much reduced in size, but would still contain probably about a litre of fluid. There was no trace of the stump of the lung. The whole medial aspect was a blank wall of smooth fibrous tissue. He was discharged November 24.

He was readmitted January 27, 1934, with a very extensive recurrence filling the pleural cavity, and he finally died March 16 with progressive anæmia and exhaustion.

CASE III.—This case was one of far-advanced chronic tuberculosis of the right lung, the patient being left, after a four-stage total thoracoplasty, with a residual apical cavity, generalized bronchiectasis, and positive sputum. Here I attempted a complete pneumonectomy through a long postero-lateral and anterior incision, with elevation of the scapula. In this place I may say only that the separation of adhesions necessary to isolate the lung pedicle was extremely difficult, and apparently dangerous, because of the fibrotic contraction which drew the lung itself and the right side of the heart, vena cava, and azygos vein, tightly together; in fact soldering them to each other. Separation, however, was successfully accomplished and the lung stump was tied off with mass ligatures of heavy silk. The patient died of shock two hours later. Post-mortem showed enormous thickening of the root bronchi, so great as to make one doubt whether any effort at bronchial closure could succeed. This subject is reserved for later discussion.

BIBLIOGRAPHY

A full bibliography is contained in Dr. Haight's paper on "Total Removal of Left Lung for Bronchiectasis," Surg. Gyn. & Obst., April, 1934.

DISCUSSION.—DR. WILLIAM F. RIENHOFF, JR. (Baltimore, Md.).—I was very much interested in the presentation by Doctor Archibald of his operative technic which corresponds somewhat to the procedure described by me in the December number of the Johns Hopkins Hospital Bulletin, vol. 53, No. 6, pp. 390–393, 1933. About five years ago, at the suggestion of Dr. Dean Lewis, work was begun on the operative procedure for the removal of the thoracic œsophagus in man. A number of patients were operated on and it was at once apparent that a gradually induced artificial pneumothorax was mechanically of great advantage in removing the lung from the field of operation and reducing it to the smallest volume. This had the added advantage of enabling the patients to adapt themselves to breathing with the non-collapsed lung, and also adjust themselves to the altered conditions of intrathoracic pressure which would exist during and after the operation. The relative simplicity of removing a lung thus collapsed was at once realized and thus artificial pneumothorax was employed as a part of pre-operative preparation at the first opportunity. Two successful cases of total pneumonectomy are described and demonstrated.

The approach to the hilus of the lung through an incision in the anterior thoracic wall was selected, because from the anatomical as well as the surgical standpoint, it is the most rational and simplest route. The hilus of the lung is thus completely exposed so that an anatomical dissection may be deliberately and carefully performed. Thus the pulmonary artery and veins may be independently and securely ligated. Those vessels lying essentially ventral to the main or primary bronchi are dispensed with in the beginning of the operation, thus insuring against the loss of any considerable amount of blood, and undoubtedly decreasing the probability of air emboli via the pulmonary veins. A secondary but still an important consideration is the ligation of the pulmonary veins before the lung is handled, preventing of course the escape of carcinomatous emboli into the peripheral arterial circulation through the left auricle. An excellent exposure to the mediastinum may be obtained at the level of the third interspace anteriorly which

permits of a dissection of not only the lymph-glands of the hilus but also those of the posterior mediastinum as well. (Two neuromata of the mediastinum on the right and left side have been removed recently using this approach with excellent exposure.) The antero-lateral incision in the third interspace, from the parasternal line to the anterior axillary line, permits without even so much as fracturing or cutting a rib, by simple spreading of the incision, ample exposure from the diaphragm to the apex of the thoracic cavity. In this manner not only is time saved but the somewhat shocking procedure of resecting ribs and dividing muscles is done away with.

The closure of the bronchus was done in these cases in a simple way with as little damage to the tissues as possible. The left primary bronchus was cut completely across with a scalpel in the first case just distal to the bifurcation of the trachea. The spring-like action of the cartilaginous rings was done away with by cutting the ring at several points in its circumference. The mucosa was sutured with a continuous suture of No. 1 plain catgut while the wall of the bronchus was sutured with interrupted silk sutures. The bronchial stump healed per primam. In the second case, the tumor being located just distal to the first ventral branch of the left primary bronchus, the incision was carried through the inferior portion of the first ventral branch and then across the descending primary bronchus: the idea being that the small first ventral branch might be closed independently of the large descending one. Proceeding thus on the hypothesis that a small bronchus would more readily heal than a larger one. As a matter of fact the size of the large descending branch is very little reduced on the left side by the departure of the first ventral branch, remaining about the size of one's index finger and being equal in size to the bronchus in the first case. The result shown by the lipiodol injection is almost self-explanatory. The large bronchus healed per primam while in the smaller one remained an opening the size of a thread. The same technic of closure was used on both the first and second case. The second case was infected due to a bronchiectasis distal to the tumor and as a result of fulguration of the tumor through the bronchoscope. Slide demonstrates the walling-off pocket-forming process about the end of the bronchus which has been described. These results at least suggest that the bronchus may be securely closed in the human being and further if a small opening should occur after some days or weeks, that a walling-off process may take place which makes this opening into the bronchus inconsequential. A small bronchus should probably not be left attached to the primary bronchus for the reason that the circulation in the bronchial artery to such a small bit of tissue is more than likely disturbed in the closing of the main bronchus. Cauterization of the bronchial stump in any form is apt to cause a slough and prevent primary healing, or become a nidus of infection and should therefore be abandoned. Mass ligatures or tourniquets about the hilus are also harmful in that the bronchial artery is blocked far proximal to the point at which the bronchus is cut across and thus the bronchus for some distance is deprived of its circulation. Healing is thus retarded to say the least, if not entirely prevented. In cases in which the primary bronchus is invaded toward the trachea as in the first case, it would be impossible to cut across the bronchus proximal to the growth if the hilus were tied off in a mass ligature.

Thoracoplasty is certainly unnecessary in pneumonectomy. The first case, a child, has fortunately had the juvenile resilience to compensate completely for the loss of an entire lung. This case may be considered from every point of view the ideal result which for an older person would be unobtainable, or only approximately so as in the second case. Nevertheless, the maintenance of the normal shape and rigidity of the thoracic cage is a most important factor in the compensatory restitution. It serves somewhat as a sheet anchor to which the heart and mediastinum are attached by fibrous bands. Probably profoundly influencing the intrathoracic pressure relations by maintaining the patency of the chest cage. What could be more upsetting to the cardiorespiratory mechanism than a flail wall to one side of the thoracic cage that moved in a large excursion with each respiration? Surely the ultimate effect of such a fluttering chest-wall must be eventually deleterious. A sterile small pneumothorax is harmless, yet even that condi-

tion will be rare for the cavity remaining in the thorax after the maximum compensatory dilatation of the remaining lung will gradually obliterate itself by the formation of multiple fibrous bands creating a veritable fenestrated labyrinth of many small spaces. In six consecutive cases of one-stage obectomies for bronchiectasis, without a fatality, in the presence of infection the same process of obliteration has been observed to occur. In none of these has a thoracoplasty been found to be necessary. Likewise in such cases should interference with the function of the phrenic nerve be given up for the piston action of the diaphragm and its effect on intrathoracic pressure is a valuable adjuvant in the compensatory restitutional mechanism.

As far as could be ascertained from clinical examination, X-ray and thoracentesis the compensatory restitutional mechanism consisted of the following steps. The remaining thoracic cavity, after removal of the lung, gradually fills after a period of forty-eight to ninety-six hours with an effusion of bloody serum possibly mixed with some old blood, clotted and unclotted, from the operation. This semi-fluid or fluid medium in addition to the entrapped air approximately fills the chest cavity. The latter rises to the apex of the cavity. Displacement of the mediastinum is by this means prevented in the first few hours or even days following operation. If the fluid in the cavity is sterile or even mildly infected, *i. e.*, ability to obtain a growth but not pus formation, organization begins immediately and fibrous tissue strands develop from the costophrenic sinus and pericardium from below up much like the "sealing off" process occurring after prolonged pneumothorax in cases of pulmonary tuberculosis. These strands of fibrous tissue can be seen running from the pericardium and mediastinum to the lateral thoracic wall. The bands divide the thoracic cavity into many small spaces which are lace-like in appearance and form a veritable labyrinthian network. Different fluid levels can be seen in these spaces. Undoubtedly as these fibrous bands contract they have a tendency to immobilize the diaphragm in a high fixed position, but also to limit any respiratory movements of the chest-wall and to pull the entire mediastinum and heart to the affected side. This readily explains the retraction of the interspaces and the ribs themselves thus narrowing not only the lateral but also the antero-posterior diameter of the chest. Following the mediastinum evacuating its central position the volume of the right thoracic cage is by this much increased and a compensatory dilatation of the remaining lung occurs simultaneously. If the mechanism ceases at this point the vital capacity is increased but moderately as in the second case but if a negative pressure is developed in the affected thoracic cavity the remaining lung will undergo further compensatory dilatation and fill the remaining empty space in the operated side, as in Case I. With this filling the respiratory movements seem to return. Whether or not the remaining lung advances to fill the empty space left by the operation seems to depend entirely on the pressure conditions in the remaining space; if negative the remaining lung will expand and fill the remaining space; if positive the remaining lung will not hyperexpand or advance.

In treating malignant disease of the bronchi and lungs it is to be recalled that the spread of the growth may be: (*a*) Along the bronchi by continued growth or by bronchial embolism; (*b*) into the pulmonary veins and then carried into the left heart and peripheral arterial system without passing through the lung capillary system; (*c*) by direct extension of the growth from one lobe to another due to an incomplete anatomical fissure; (*d*) antero- and retrograde invasion of the lymphatics along the bronchi, involving the intra- and interlobar glands as well as those of the hilus; if the fissure is incomplete, involving the lymphatics of the adjoining lobe.

For these reasons it would seem likely that total pneumonectomy would be followed by a higher percentage of ultimate cures than partial pneumonectomy, while at the same time in many instances technically less difficult.