THE IMPORTANCE OF BRONCHOSPIROMETRY AND LUNG FUNCTION TESTS IN RELATION TO THORACIC SURGERY.

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Glasgow.
March, 1957.

I N D E X

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CHAPTER I.

1. Introductory Preface, with Brief Resume of Object and Scope of Work Entailed.

2. Acknowledgements, etc.

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INTRODUCTORY PREFACE.

There is an ever widening scope for thoracic surgery in the treatment of pulmonary tuberculosis, bronchial carcinoma, and other less common intrathoracic conditions. For some time now the inadequacies and shortcomings of assessing a patient for major chest surgery on the clinical and radiological findings alone, perhaps with a solitary vital capacity reading, have been apparent. Particularly has this been so in the Thoracic Unit in Mearnskirk Hospital. Some cases come to mind who following resection of lung tissue (a lobe or a whole lung) developed severe respiratory insufficiency, and whose post-operative course was very stormy and precarious indeed as a result.

Accordingly it was decided to investigate as fully as possible all potential cases for thoracic surgery whose respiratory function was at all suspect (from previous widespread disease, due to previous collapse measures in tuberculous patients, or due to co-existent emphysema in lung cancer patients otherwise suitable for resection). Bronchospirometry, together with certain tests of overall lung function, form the major part of this investigation, and it is with the results of these and their importance that this work is concerned.

Bronchospirometry has till recently been much neglected in this country. In a recent annotation in the British Medical Journal (September 10, 1955), it was pointed out how important "the laboratory assessment of respiratory function in diseases of the lung had been acknowledged for some time in the United States of America, but how appreciation of its importance had lagged in Britain." H. A. Fleming and L. R. West (1954) reported the results of the first large series of patients (125) subjected to bronchospirometry in Britain, and their findings suggested that bronchospirometry was helpful in deciding whether cases of doubtful respiratory efficiency were suitable for pneumonectomy, and whether decortication would help after plerual effusion or empyema. Bronchospirometry was also of assistance in determining the correct sequence of treatment when several surgical operations were required.

K. W. Donald (1952) likewise stressed the importance of bronchospirometry, and urged its more widespread adoption in this country.

It is the object and scope of this thesis to show not only how useful and valuable is bronchospirometry correlated with the clinical and radiological findings, in determining the suitability of doubtful cases for lung surgery; but also to demonstrate clearly the functional loss resultant from each type of surgical procedure (including thoracoplasty, resection, plombage, and phrenic crush). By such means it will be possible to accord to the patient with impaired respiratory efficiency the type of operation which is most conserving of lung function, while at the same time controlling adequately the disease process.

Bronchospirometry is also a very important investigation in the assessment of cases of bronchial carcinoma that are from a clinical, radiological and bronchoscopic viewpoint suitable for resection surgically. Such cases, being on the whole in the older age group, often suffer from concomitant emphysema, and the value of knowing fairly accurately the function of each lung separately when contemplating resection of part or whole of one lung need not be stressed. It is hoped to show how valuable an aid bronchospirometry is in cases of lung cancer that are suitable otherwise to resection, and also the importance of bronchospirometry in assessing any case for resection surgery (be it pulmonary tuberculosis, lung cancer, or bronchiectasis). Such pre-operative assessment of a case for excision of lung tissue is of added value when it is realised that resction, of all forms of surgery (particularly in pulmonary tuberculosis), is the one most liable to post-operative complications (such as: atelectasis of the remaining lobe, lobes, or segments; haemothorax; and fistula). It is also the intention to demonstrate that in cases potentially suitable for bilateral surgery, bronchospirometry is not only an indispensable investigation but in most cases an imperative one, too.

Before proceeding to the actual volume of the work, the author must express his indebtedness to many of his colleagues. Firstly, he would like to thank Mr. R. S. Barclay, Thoracic Surgeon, Mearnskirk Hospital, for his helpful advice, for his encouragement to undertake the work, and for access to patients in his wards. The author is deeply indebted to Dr. J. G. Stevenson, Chest Physician to the Thoracic Unit, Mearnskirk Hospital, not only for many useful suggestions, but for his very able and willing assistance in the actual performance of many of the bronchospirometric examinations. To Mr. T. M. Welsh and again to Mr. R. S. Barclay, Thoracic Surgeons, who operated on many of the patients included in this thesis, he is deeply grateful. The author must also thank Dr. Dale, Surgeon Superintendent, for his interest and help; and in addition all the physicians from other hospitals who referred patients for bronchospirometric evaluation, and who kindly supplied information as to the subsequent course and management of the patients in question. Lastly, he is most appreciative of all the assistance and invaluable aid accorded by the Nursing Staff of Mearnskirk Hospital, particularly those attached to the Thoracic Unit; and to Dr. D. McIntyre, who reproduced the prints of X-ray films and bronchospirometric charts, the author wishes to express his thanks and appreciation.

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Mearnskirk Hospital.
March 1957.

CHAPTER II.

1. History of Bronchospirometry - first used by Bjorkman in 1932.

2. A Review of the Literature on the Subject.

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HISTORY OF BRONCHOSPIROMETRY

The first mention of bronchospirometry as a feasible procedure of investigation appeared in an article in 1932 by Jacobaeus, Frenckner, and Bjorkman. Gaensler (1952) gave a very comprehensive review of the literature on the subject, and much of the ensuing pages is based on this article.

Prior to 1932 studies of differential lung function were confined to experiments on animals, using a "Pfluger" catheter inserted through a tracheotomy opening. Jacobaeus, Frenckner, and Bjorkman in 1932 were the first to report their findings in human patients subjected to bronchospirometry. For their study they used a single-lumen bronchoscope which measured the two lungs separately but not simultaneously. They reported only on the ventilation and vital capacity of each lung in 11 cases. In 1934 Bjorkman published the results of bronchospirometry carried out in several patients who had had thoracoplasty and artificial pneumothorax therapy; in this study he used a double-lumen metal bronchoscope. He listed several contra-indications to the procedure, such as recurrent or recent haemoptysis, severe cyanosis or dyspnoea, myocarditis, aneurysm, and hypertension.

However, these bronchoscopes (both the single-lumen and double-lumen) were very rigid, and caused considerable discomfort to the patient. Accordingly it was only a matter of time before a more flexible tube was devised. Gebauer (1939) was the first to use a flexible double-lumen catheter, this being supported by a steel spring which aided the introduction of the tube through the vocal cords and also enabled the catheter to be seen fluoroscopically. Zavod in 1940 described his own type of catheter for use in bronchospirometry.

Carlens in Sweden (1949) devised a catheter based on the principles of the Zavod and Gebauer types, with several modifications. Being of thinner rubber than the other two, it was possible to have each airway of larger internal diameter without increasing the external diameter. This, in turn, served the dual purpose of decreasing air resistance and also facilitating removal of any secretions by suction. In addition, the tube could be left in position for 20 minutes, allowing exercise tests to be carried out, and no screening of the patient was required while the tube was being inserted.

The Carlens catheter is the one the author of this thesis has used in nearly half of his cases, and it has proved very satisfactory. A fuller description of this tube and of the other common types will be given in a later chapter.

Marsh, in 1953, described a modification of Carlens' catheter, but personal experience with Marsh's tube in 150 cases in the present series has proven it to be inferior in all respects to Carlens' one.

The most recent catheter to be devised for bronchospirometry combined the advantages of the single-lumen and the double-lumen tubes, while minimising their respective disadvantages (Croce, 1954). Croce attempted to overcome the main defect of the double-lumen catheter (namely, air resistance) by having a long tube with a wide diameter which entered the left main bronchus, while a shorter tube of narrower diameter, situated just within the larynx but outside the cords, collected air from the right side.

Other investigators have attempted to analyse differential lung function without recourse to intubation. Fluoroscopy and examination of inspiratory and expiratory films by special grids have been used to show localised "trapping" of air or paradoxical motion of the diaphragm, indicative of unilateral disease of an obstructive nature (Vaccarezza, Benze, Lanari, and Segura, 1943). Labesse (1946) designed an instrument using two thoracometers and a device for the separate compression of each hemithorax and each leaf of the diaphragm. Ordinary spirometry was carried out, while the instrument blocked the respirations of one lung in turn, and then the other. The premise for using such an apparatus in the investigation of differential lung function was that pulmonary insufficiency was always accompanied by a corresponding limitation of motion of the thoracic cage and diaphragm.

During bronchospirometry the patient breathes pure oxygen in most cases, and the carbon dioxide from the expired air is absorbed in a soda lime container which forms an essential part of the closed circuit. However, a number of observers have postulated that breathing pure oxygen in a closed circuit during bronchospirometry may obscure the insufficiency of a diseased lung (Whitehead, O'Brien, and Tuttle, 1942; Wright and Woodruff, 1942; Bjorkman and Carlens, 1951; Gaensler, Maloney, and Bjork, 1952). Bjorkman and Carlens (1951) maintained that the inhalation of pure oxygen was unphysiological, and they made comparative bronchospirometric studies of oxygen intake by each lung during rest, breathing air of high oxygen content, and then breathing ordinary atmospheric air with a constant oxygen content. They found that giving oxygen-enriched air in any condition in which there was a large dead space (generalised emphysema, a large giant bullous cyst) might give a false high oxygen intake, whereas with ordinary atmospheric air no such false high oxygen intake was recorded. They also demonstrated that during ordinary air breathing, the function of the inferior lung deteriorated as compared with the results obtained when pure oxygen was breathed. However, in the present series pure oxygen was breathed through a closed circuit in all cases, as the author is inclined to the view that bronchospirometry itself is not wholly physiological, particularly with the added effect of "resistance breathing" that is an almost inevitable concomitant in some degree of any procedure involving intubation (Gaensler, Maloney, and Bjork, 1952). In addition, any patient prone to bronchospasm who undergoes bronchospirometry which produces a further reduction in the lumen of the airway, will encounter serious distress if made to breathe atmospheric air. Such distress, with its accompanying dyspnoea and cyanosis, can be obviated by breathing pure oxygen during bronchospirometry.

Jacobaeus and Bruce (1940) investigated by bronchospirometry the ability of one human lung to substitute for another. Previous work of this nature had been confined solely to animal experiments, the results seeming to indicate that on occlusion of one lung blood still continued to flow through that lung (as indicated by a distinct fall in the arterial blood oxygen saturation in these animals) (Le Blanc, 1922). Moore (1931) ligated the left main bronchus of dogs, and fixed a cannula through the trachea down into one bronchus. Partial blockage of one bronchus was followed at once by increased ventilation by the other lung, corresponding to the decrease in ventilation on the partially blocked side. Upon complete blockage of one bronchus, the ventilation of the other lung deepened at the very next breath. Despite the decrease in volume of the tidal air moved by the partially occluded bronchus, the proportion of oxygen consumption by the two lungs remained the same before and after occlusion. The authors concluded that marked reductions in the tidal air of one lung were not followed by shunting of blood to the opposite side.

Jacobaeus and Bruce (1940) used three healthy males with no lung disease, and during bronchospirometry one of the lungs was blocked (by simply occluding one of the two lumina of the tube with a pair of forceps). On occlusion of one lung, the oxygen consumption and the minute ventilation and the vital capacity of the respiring lung all increased, but there was a fall in the arterial oxygen saturation (due to deficient oxygenation of the blood flowing through the occluded lung). As there were no subjective symptoms, such as dyspnoea or tightness in the chest, and no cyanosis from such occlusion in healthy subjects, the authors then performed the same procedure in tuberculous patients, particularly in cases of bilateral disease when collapse measures were required on one side. If one lung could withstand the increased strain made on it when the opposite bronchus was occluded, it was considered feasible to undertake collapse measures on the side that had been occluded.

The same authors in a further article in the same journal carried out a further series of investigations during broncho-spirometry, using different gases (1940). Firstly, one lung was made to breathe pure oxygen while the other breathed ordinary atmospheric air, and it was noted that the lung breathing pure oxygen had a greater oxygen uptake but that the ventilation of both lungs remained equal. Next one lung was made to breathe pure oxygen while the other breathed pure nitrogen, and it was found that the former took up oxygen in large proportions while the nitrogen-breathing lung actually gave off some oxygen at first. Both lungs expelled equal amounts of carbon dioxide, but there was a slight fall in the arterial blood oxygen saturation. They concluded that the oxygen-breathing lung took up oxygen equivalent to both lungs respiring together without any increase in ventilation. This they postulated was due to unoxygenated blood from the nitrogen-breathing lung entering the circulation, lowering the arterial oxygen saturation, and thus facilitating the absorption of oxygen more easily from the oxygen-breathing lung. Finally, the authors once again made one lung breathe pure oxygen while the other breathed a mixture of 95 per cent. nitrogen and 5 per cent. carbon dioxide. There was a marked uptake of oyxgen in the former, while the latter gave off carbon dioxide and oxygen at first but later gave off no carbon dioxide when equilibrium was reached. At this point the ventilation of the oxygen-breathing lung was increased. This last investigation demonstrated that one lung can be forced to deal effectively with the entire oxygen intake and carbon dioxide output necessary for the body, while the other lung is prevented from participating in respiration altogether.

Pump (1954) used this method of blocking one bronchus (either by means of forceps applied to one lumen of the tube, or by making one lung breathe pure oxygen and the other pure nitrogen) in the assessment of tuberculous patients for lung surgery. Any increase in the functional residual capacity, the tidal volume, or in the respiratory rate was noted.

The ultimate refinement in differential lung functional analysis combines the use of blockage of one bronchus during bronchospirometry with occlusion of the ipsilateral branch of the pulmonary artery by means of an inflatable cuff attached to a cardiac catheter (Dotter and Lucas, 1951; Carlens, Hanson, and Nordenstrom, 1951; Hanson, 1954). Carlens, Hanson, and Nordenstrom (1951) stressed the importance of these combined procedures where pneumonectomy was contemplated, particularly where the function of the remaining lung was in doubt due to previous disease or collapse measures. The authors experimented first on dogs, then extended the procedures to three human patients who were possible candidates for pneumonectomy. They claimed that by occluding the bronchus of the lung to be removed along with its pulmonary arterial blood supply, they could thus simulate most accurately pre-operatively the conditions that would eventuate following pneumonectomy. The occlusion of the bronchus and pulmonary artery lasted for periods of 20 minutes, and if no untoward results ensued they concluded that pneumonectomy was safe to undertake in such cases.

However, serious complications may follow occlusion of the pulmonary artery (Dotter and Lucas, 1951), such as cardiac syncope, pulmonary infarction (particularly in the elderly), sepsis, and even death. Its adoption as an investigational procedure has not met with any great enthusiasm, particularly in this country.

Gaensler (1952) summarized the clinical applications of bronchospirometry. He stressed its value in the study of bilateral pulmonary disease (particularly tuberculosis), and in assessing the effects of collapse therapy and thoracic surgical procedures on pulmonary function. It is of prime importance before contemplating lung surgery in patients who have had previous medical or surgical collapse measures, before bilateral surgery, and to evaluate "reconstructive" chest surgery (such as decortication, excision of cysts and bullae) (Gaensler, Patton, and Frank, 1953). It can demonstrate conclusively the congenital absence of one pulmonary artery (Smart and Pattinson, 1956), as well as acquired cases of pulmonary artery ligation but with no resultant infarction of the associated lung (Roh, Greene, Himmelotein, Humphreys, and Baldwin, 1949).

Two further incidental uses of the Carlens catheter apart from bronchospirometry are (a) the prevention of spread of secretions during pulmonary resection of grossly infected lung tissue, by applying one lung anaesthesia to the good lung. Continuous suction is applied to the bronchus draining the diseased lung during the resection (Bjork and Carlens, 1950). (b) By means of the Carlens' tube, open closure of the bronchus is facilitated, along with resection of the carina and of the tracheal wall, in cases of neoplastic involvement.

With the recent advances and perfections in general anaesthesia and in the technique of lung surgery, along with the arrival of effective chemotherapy for the control and treatment of pulmonary tuberculosis, the boundaries of thoracic surgery have become almost limitless. However, much time and effort can prove fruitless if a patient manages to withstand a lung resection only to be left a hopeless respiratory cripple ultimately, or even worse, dies several days after operation from respiratory insufficiency. It was with the object of helping in the assessment of doubtful cases for lung surgery that the present series of lung function tests together with bronchospirometry was commenced in February, 1955, in Mearnskirk Hospital. Not only have these proved valuable in the surgical assessment of tuberculous patients who are potential surgical risks (from previous bilateral disease or previous contralateral collapse measures), but their use in the evaluation of lung cancer cases for resection surgery (particularly where there is concomitant disease, such as pulmonary emphysema) is in many cases almost indispensable. Over 316 examinations have been carried out now, and it is with the results of these that this thesis is concerned.

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CHAPTER III.

INDICATIONS AND CONTRA-INDICATIONS TO BRONCHOSPIROMETRY.

A. INDICATIONS.

1. Introductory. Scope and Limitations of Bronchospirometry and of all cardio-respiratory function tests.

2. Particular Disease. (a) Pulmonary tuberculosis.
   (b) Bronchial Carcinoma.
   (c) Bronchiectasis.
   (d) Miscellaneous.

3. Phase of Disease (particularly in tuberculous patients).

4. Site and Extent of Disease. Suitability for specific type of operation.

5. Previous Ipsilateral Disease or Collapse Measures. (particularly in tuberculous cases).

6. Previous Contralateral Disease or Collapse Measures.

7. Bilateral Disease for possible Bilateral Surgery.

8. Age of Patients.

9. General Condition, e.g. presence of exertional dyspnoea is potent indication for investigation.

10. Presence of any concomitant cardio-respiratory disease. (emphysema, bronchitis).

11. Investigational - to find functional loss from various procedures.

B. CONTRA-INDICATIONS.

1. General.

2. Local (laryngitis, gross tracheal or bronchial distortion, etc.)

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INDICATIONS AND CONTRA-INDICATIONS TO BRONCHOSPIROMETRY

A. INDICATIONS.

1. Introductory.

Before proceeding with the indications and actual scope of bronchospirometry together with lung function studies in general, it is necessary to mention and stress several important points.

Firstly it is clear that, with the exception of decortication of lung or excision of obstructive bullae causing dyspnoea, all major pulmonary operations more or less inevitably reduce respiratory function. Many thoracic surgeons have had at some time in their experience the distressing sight of what are more-or-less respiratory cripples, the end result of resection surgery on patients that in retrospect were not fit for such treatment (Birath and Crafoord, 1951). Alternately many borderline cases may be denied chest surgery from which they may benefit unless tests of respiratory and cardiac capacity are carried out. The above mentioned authors described the tests they used for evaluating cardio-respiratory function, including radiology, ordinary spirometry, cardiac catheterisation, and bronchospirometry (citing bilateral surgery in tuberculous patients as their main indication for the latter).

Steele (1943) emphasised the importance of bronchospirometry when contemplating surgery in tuberculous cases with a low or reduced respiratory reserve. He mentioned several difficulties that might be encountered during the procedure, such as the blockage of one of the channels of the tube by secretions, and stenosis of the left main bronchus preventing passage of the tip of the catheter into this bronchus. Maier (1949) stated how important it was in cases of bilateral pulmonary tuberculosis to know the individual lung function, because although the overall lung function might be relatively good, the side requiring collapse or resection might be the one contributing the greater part to the total lung function. This would vitiate, or at least greatly modify, such surgery to the better functioning lung. He further stressed how much a previous pleurisy, resulting in a thickened, fibrous pleural membrane, could impair pulmonary function, and how unreliable X-ray appearances alone could be in assessing lung function.

Bjork (1953), in a discussion of cardiopulmonary function tests in general, stated that only by bronchospirometry could changes in the function of the operated lung and compensatory changes in the contralateral lung be studied. He found marked functional loss as the end result in cases of old pleurisy and in his series of re-expanded artificial pneumothoraces.

Gaensler, Cugell, et al. (1955) found respiratory function tests, including bronchospirometry, very useful in helping to elucidate the role of pulmonary insufficiency in the mortality and invalidism following surgery in tuberculous cases.

However, no matter how accurately and painstakingly lung function tests are measured prior to operation, no test can foretell what may eventuate if any complication (such as a broncho-pleural fistula or an acute respiratory infection) arises post-operatively. Tests of lung function can help in deciding whether a borderline case is fit for operation, and what the probable post-operative function will be. But such tests are of no avail in estimating the effects of any supervening operative complication or post-operative respiratory infection, either of which may swing the balance in these borderline cases, and produce respiratory insufficiency and death. This occurred in three cases in the present series. All three survived the initial operative trauma and the first two succeeding days, but succumbed very quickly from a respiratory infection shortly afterwards. The mechanism in such cases may be that of pulmonary hypertension, as postulated by Bassinger (1955). A respiratory infection developing post-operatively in a patient with a low respiratory reserve increases an already existent anoxaemia, causing vasoconstriction of the pulmonary capillaries, which in turn brings about a further rise in an already high pulmonary artery pressure.

In addition it must be mentioned that in such a disease as bronchial carcinoma, where the prognosis without surgery is indeed poor, the decision is made sometimes to go ahead with operation even though the respiratory capacity has been found to be low by lung function tests. Such instances are no doubt quite justifiable, although the mortality and morbidity from respiratory insufficiency is fairly high.

Finally in the assessment of the functional loss resulting from any surgical procedure (resection or thoracoplasty), it should be borne in mind that any factor complicating the procedure (such as haemothorax in a resection case) must inevitably produce a further loss of function in that individual case. This must be taken into account when the overall loss of function from the procedure in question is being assessed.

2. Particular Disease.

(a) Pulmonary tuberculosis. The main indications for lung function tests in this disease have been mentioned already, and include cases of bilateral disease and where there have been previous collapse measures, prior to embarking on any surgery. Other indications include cases that become easily dyspnoeic, and where there has been previous pleural disease. Many authors have demonstrated conclusively that pleural disease is a much more important cause of impaired respiratory function than parenchymal disease (Jacobaeus, 1938; Pinner, Leiner, and Zavod, 1945; Donald, 1952).

In the present series bronchospirometry and overall lung function tests were carried out in cases for bilateral surgery, before pneumonectomy in cases where the function of the remaining lung was in some doubt due to previous disease, and in patients in the older age groups (47 years and above) to help in deciding the operation most suitable to control the patient's disease and at the same time decrease his lung function as little as possible.

In addition a series of cases was done before and after: lobectomy, thoracoplasty, plombage, pneumonectomy, phrenic crush and pneumoperitoneum induction, and artificial pneumothorax induction. It is hoped to show from this study the loss of function from each procedure, bearing in mind that if any complication arises this will increase further the end functional loss from the procedure in question.

(b) Bronchial Carcinoma. Very little has been reported to date in the literature about lung function studies in the pre-operative assessment of cases of lung cancer for lung resection. Such studies have proved valuable in the present series, bronchospirometry being carried out where respiratory function was in any doubt. In all such cases the bronchus of the affected lung was blocked by means of forceps, as described by Jacobaeus and Bruce (1940) and Pump (1954). If any discomfort, tightness, or dyspnoea occurred during the procedure, resection of the entire lung was deemed hazardous, and in several cases a more conservative lobectomy was effected with satisfactory results. Bronchospirometry is not required in all cases of bronchial carcinoma submitted for operation - in fact it has been considered necessary only in a few of the cases operated on in Mearnskirk during the course of this study. Where it has proved very helpful is in the older age group (50 years and over), where there is any accompanying pulmonary emphysema, or where there is any clinical evidence of pulmonary insufficiency, manifested by cyanosis or undue dyspnoea. Such studies have helped to decide whether to operate or not in the borderline case, that is one that is bronchoscopically just within the limits of operative removal but where respiratory capacity is low. At all times the clinical, radiological, and fluoroscopic and bronchoscopic findings have been correlated with the lung function studies.

(c) Bronchiectasis. Bronchospirometry and other lung function tests can occupy an important place in the selection of suitable cases of bronchiectasis for resection surgery (Long, Norris, et al., 1950). Kay, Meade, and Hughes (1947) found these tests useful in determining which was the worse side in bilateral cases, the extent of functional lung tissue in borderline cases, and the pulmonary reserve of the uninvolved lung in dyspnoeic subjects.

In certain cases such studies may preclude surgery altogether - this is particularly so in those over 40 years of age, where a superadded bronchitis may be the main factor incapacitating the patient, with his bronchiectasis taking a secondary place only. Manifestly in such cases resection of any lung tissue, even if it is diseased and partially non-functioning as a result of bronchiectasis, is not only fraught with the risk of mortality or permanent disability from respiratory insufficiency, but cannot at this late stage produce any dramatic improvement in the patient's condition.

(d) Miscellaneous. Under this heading may be considered such varied conditions as giant bullae (tension air-cysts) with associated generalised pulmonary emphysema, bronchiogenic cysts, ganglioneuromata, and other intrathoracic lesions occurring in older persons. There were only three cases in this series which entered this category - one was a man of 56 years with a giant emphysematous bullous cyst occupying most of his right lung, and cardio-pulmonary function studies precluded major surgery (Case 151). (A detailed report of this case is made later in this chapter.) The second (Case 284) had likewise a bulla of the right upper lobe, and, as with Case 151 was treated by pleurodesis followed later by deflation of the bulla. The third (Case 265) was a younger patient with emphysema confined to the lingula and the diseased area was excised.

3. Phase of Disease.

This is of importance, for all practical purposes, only in tuberculous cases. Obviously it would be harmful to inflict any procedure involving intubation on a patient with acute exudative disease or with acute miliary tuberculosis (Gaensler, 1953). Such patients, in addition, are not considered nowadays at this phase of their disease as being suitable for any form of surgical or medical collapse measures, treatment at this phase consisting of adequate bed-rest along with appropriate drug therapy. The need for lung function tests hence does not arise here.

Of more moment and practical importance is the advisability or otherwise of performing bronchospirometry in patients awaiting surgery where the lesion is a "blocked" cavity. In many such cases the initial disease has been a tension cavity with concomitant tuberculous endobronchitis of the bronchus draining the cavity. At such a stage the treatment in most centres, including Mearnskirk Hospital, consists of chemotherapy plus a period of postural retention, with the object of "blocking" the cavity with sputum, relieving the tension present, and thus effecting cavity closure. Such closure usually takes between two and four months, but this needs to be consolidated by some more definitive measure such as collapse surgery to ensure permanent closure of the cavity. While awaiting such surgery the practice at Mearnskirk is to keep the patient confined to bed to prevent the possibility of the cavity re-opening. It is then at this stage that the question of carrying out lung function studies arises. Many of these patients have had previously widespread disease or medical collapse measures (such as artificial pneumothorax), and in these cases bronchospirometry should be carried out to help not only in determining fitness for surgery but also in selecting the most suitable type of operation. If the overall function is found to be only moderate, with an equal contribution from each lung, then the operation of choice is that which impairs respiratory function least of all.

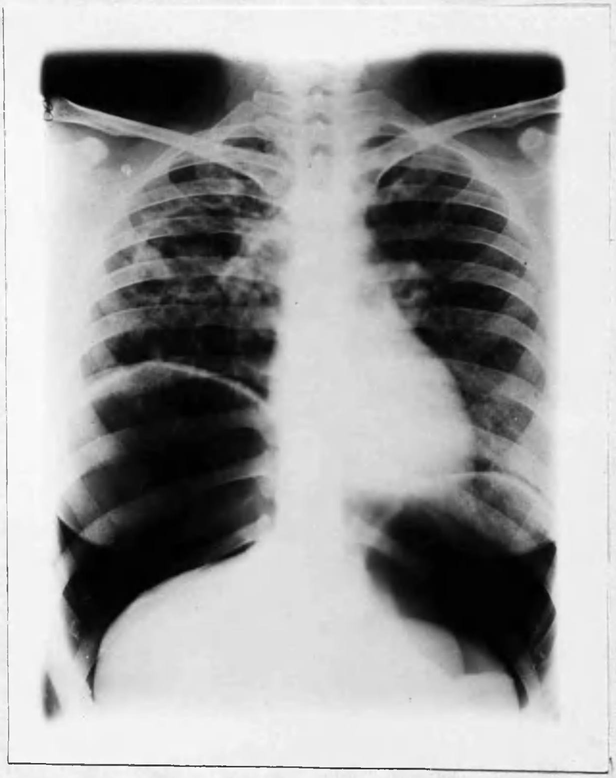
The possible consequence of undertaking bronchospirometry in such patients is naturally re-opening of the cavity, due simply to the mechanical effort of coughing, precipitated by spraying the throat, larynx, and trachea with local anaesthetic preparatory to intubation with the catheter. Jahn and Kaufman (1952) reported such a case. This unfortunate incident occurred in one case in the present series, but as this patient had been allowed up for three hours daily while awaiting surgery for a "blocked" cavity, bronchospirometry cannot be wholly blamed, if at all. Many other patients with "blocked" cavities have had lung function tests performed to judge their fitness for surgery, and no harmful results have ensued.

Thus the phase at which bronchospirometry is done in tuberculous patients is the same pathological phase at which most forms of surgery (collapse and resection) are contemplated, which is the non-exudative, more productive stage of the disease.

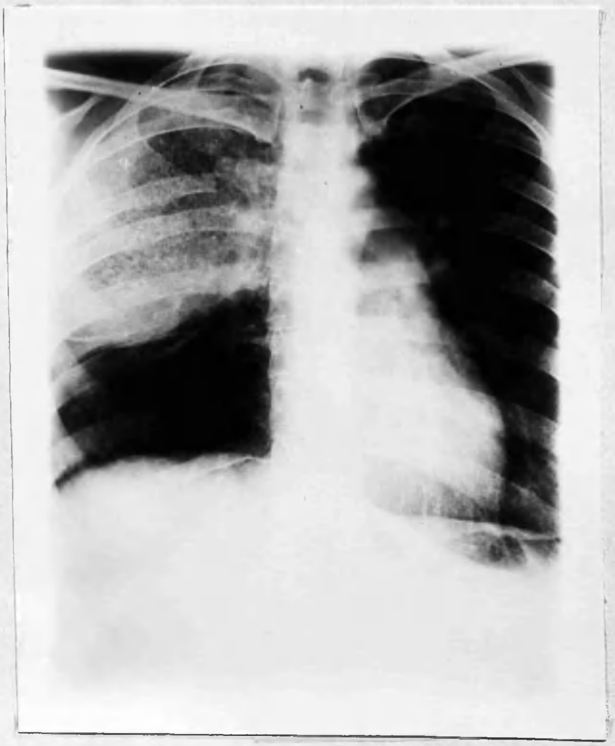
4. Site and Extent of Disease.

Where there has been extensive tuberculosis of one lung which has undergone marked regression with medical treatment but has left a residual cavity, it is important to ascertain the function of such a lung before deciding on the appropriate type of surgery. If the function is found to be markedly impaired, and the contralateral lung is otherwise healthy, then resection of the entire lung is the operation of choice.

Similarly in cavitated disease situated in the apical



CASE 123.
LARGE CAVITY APEX R.L.L.
UNCONTROLLED BY PHRENIC
+ PNEUMOPERITONEUM.



CASE 123.
POST-OPERATIVE.
LARGE RIGHT PLOMBE
EFFECTIVELY CONTROLLING
CAVITY.

segment of either lower lobe, with old disease in the ipsilateral upper lobe, bronchospirometry can play an important part in the choice of operation. Scadding (1955) advocated the use of artificial pneumothorax combined with chemotherapy for this type of disease. However, such treatment may fail to close the cavity, or the presence of indivisible adhesions may point to abandoning the pneumothorax. We have found such cases eventually require surgical treatment. Bronchospirometry may indicate pneumonectomy as the course to adopt where the lung in question shows poor function. But if it does contribute substantially to the patient's respiratory function, and particularly if the function of the remaining lung is somewhat impaired, then more conservative surgery (such as local resection of the cavitated area or a selective plombe) is deemed advisable.

Clinical Case Report. Case 123. This patient, a woman of 25 years, first contracted pulmonary tuberculosis in 1950. Since then she had had several courses of drug therapy with periods of bed-rest. In 1951 a right phrenicectomy was performed, and a pneumo-peritoneum was induced. This was maintained till September, 1955, when she was admitted to Mearnskirk Hospital for possible surgical treatment. Originally there had been a cavity in the apical segment of her right lower lobe with some scattered disease in the right upper lobe. The pneumo-peritoneum had effected temporary closure of the cavity, but on

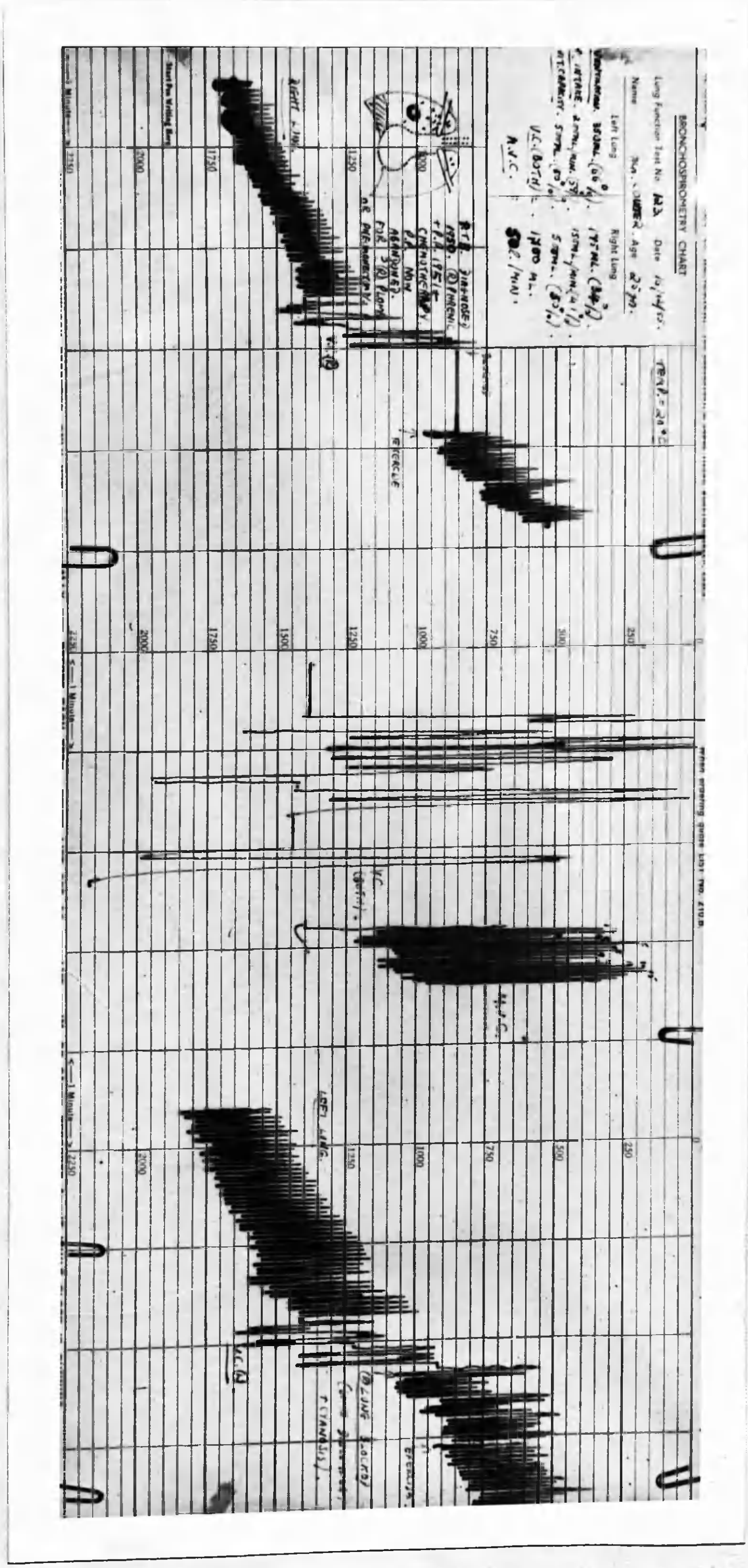
TABLE I.

Pre- & Post-Op.Figures for Case 123.

	Pre-Operative		Post-Operative	
	Right Lung	Left Lung	Right Lung	Left Lung
Tidal Air	175ml.(34%)	350ml.(66%)	200ml.(36%)	350ml.(64%)
O_2 Uptake/ Min.	150ml.(41%)	200ml.(59%)	100ml.(36%)	175ml.(64%)
Vit. Capacity.	500ml.(50%)	500ml.(50%)	600ml.(40%)	900ml.(60%)
Vit. Capacity (Both lungs)	1,700 ml.		1,750 ml.	
Max.Vent. Capacity.	50 litres/min.		50 litres/min.	

CASE 123.

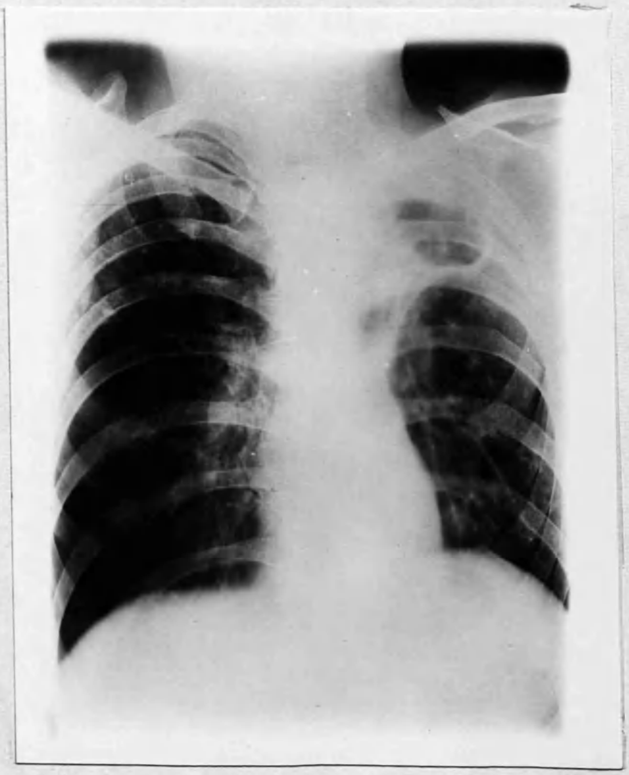
PRE-OP.CHART.
IMPAIRED
OVERALL FUNCTION.



her admission to Mearnskirk in 1955 the cavity had re-opened and was now of tension type. Bronchoscopy performed two months after admission showed no gross evidence of tuberculous endo-bronchitis and no bronchostenosis of the major bronchi. Lung function studies revealed some impairment of overall function (vital capacity = 1,700 ml., maximum ventilatory capacity = 50 litres per minute), with the right lung contributing more than one third of this function. (See Table I). In view of these findings, it was decided that conservative surgery would be best, and accordingly a right plombage operation was carried out in March, 1956. Her post-operative course was uneventful, and 11 weeks after her operation she was very well, and her chest X-ray showed a well-sited plombe with no visible evidence of the cavity in the apex of right lower lobe. Her sputum, almost negligible in amount, was negative for tubercle bacilli for the first time in many years.

Repeat bronchospirometry at this time showed minimal functional loss on the right from the plombe, and overall function was almost unchanged from the pre-operative value.

This case demonstrates not only the value of bronchospirometry in this type of case, but also the efficacy and function-conserving nature of a plombage operation when applied to patients with impaired respiratory function. The patient quoted above is now well, and her disease appears more than adequately controlled by an operation which has resulted in negligible functional loss.



CASE 202.

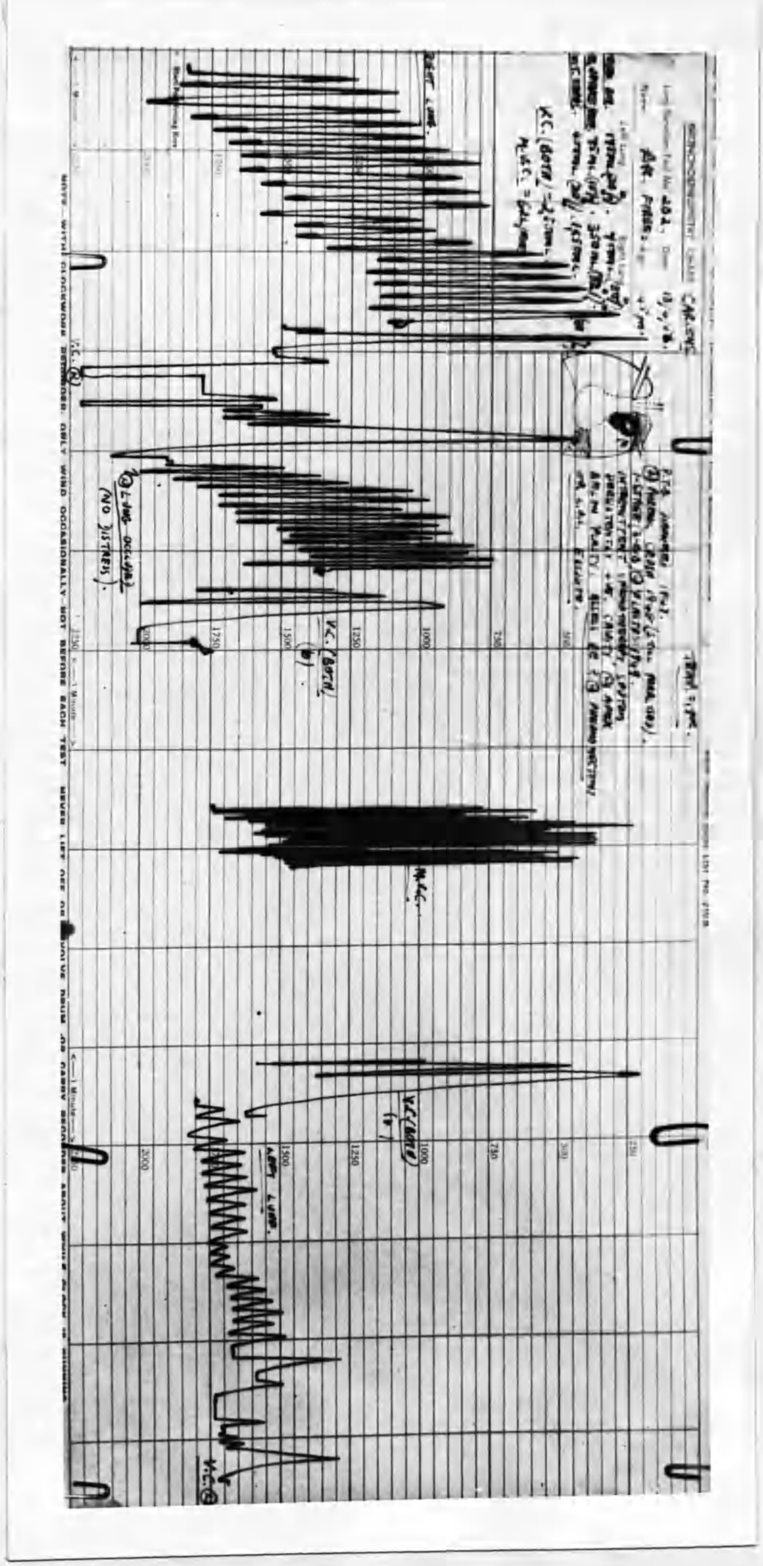
PRE-OP. SHOWING LARGE CAVITY L.U.L.
UNDER THORACOPLASTY.

5. <u>Previous Ipsilateral Disease or Collapse Measures.</u>

Again this is of special importance in considering tuberculous cases for surgery. A history of previous pleural disease is of particular significance, particularly if associated with an effusion. This clears by organization and ultimate pleurodesis of the pleural surfaces, and though radiological evidence of such may not be apparent, the functional impairment may be quite marked, particularly if the pleura is in addition grossly thickened (Jacobaeus, 1938; Pinner, Leiner, and Zavod, 1945; Donald, 1952). Previous collapse measures can likewise result in grossly impaired function, as the following case illustrates.

<u>Clinical Case Report.</u> <u>Case 202.</u> A male patient, aged 47 years, was first diagnosed as having pulmonary tuberculosis in 1947. In 1948 a left phrenic crush was performed because of a large cavity in the left apex, but as this did not succeed in cavity closure a three-rib left thoracoplasty was carried out a year later. He was first seen at Mearnskirk Hospital in March, 1956, when he was admitted for further surgery. The cavity in the left apex was still present, though the remainder of the left lung was free from any demonstrable disease. There was some healed disease in the right upper lobe. Fluoroscopy showed the left diaphragm to be permanently paralysed. The problem was to decide what function remained in the left lung, and whether it was desirable to try and conserve any part of it.

CASE 202.
PRE-OP. CHART, SHOWING
ALMOST FUNCTIONLESS
L.LUNG DUE TO EFFECT
OF PHRENIC CRUSH +
THORACOPLASTY.



Lung function studies were accordingly undertaken, and the results are shown in Table II and in Figure I.

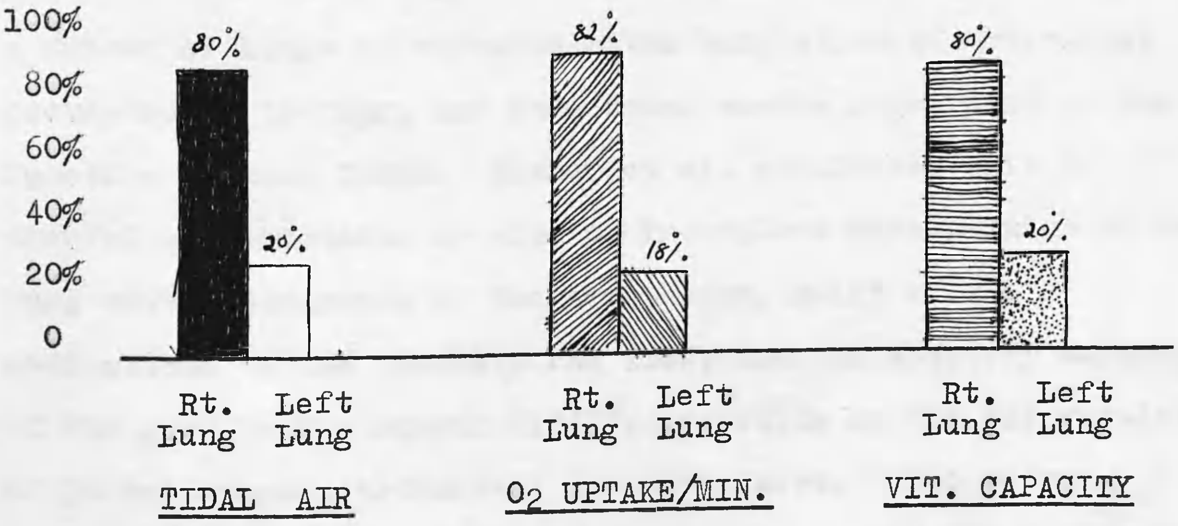
TABLE II.

Pre-Op. of Case 202.

Pre-Operative	Right Lung	Left Lung
Tidal Air	700 ml.(80%)	175 ml.(20%)
O_2 Uptake/min.	350 ml.(82%)	75 ml.(18%)
Vital Capacity.	1,650 ml.(80%)	400 ml.(20%)
Vital Capacity (both lungs)	2,500 ml.	
Max.Vent.Capac.	62 litres/min.	

FIGURE I.

Pre-Op.Representation of Differential Lung Function in Case 202.



From these results the left lung was manifestly contributing a minimal amount to the total function, due to the combined effects of a permanently paralysed diaphragm and a three-rib thoracoplasty. In such circumstances there seemed little point in contemplating merely resection of the left upper lobe containing the cavity, as this would leave a virtually functionless lower lobe. Furthermore the function of the right lung appeared more than adequate, and hence the decision was made to resect the entire lung.

6. Previous Contralateral Disease or Collapse Measures.

In cases with previous contralateral disease or collapse measures, be they surgical or medical, the need for lung function studies is almost imperative before embarking on any surgery to the other lung (Whitehead, Whitman, and Shacker, 1943; Gaensler, Patton, and Frank, 1953). Several authors (Pinner, Leiner, and Zavod, 1945; Vaccarezza, Lanari, and Soubrie, 1947) have studied a number of lungs re-expanded after completion of artificial pneumothorax therapy, and have found severe impairment of the function of such lungs. Pinner et al. attributed this to pleural obliteration, or else to incomplete re-expansion of the lung with contraction of the hemithorax, shift of the mediastinum to the pneumothorax side, and compensatory emphysema of the good lung. Birath (1947), reporting on the end results of 36 re-expanded artificial pneumothoraces, found severe impairment of overall lung function in 11 cases, due partly to compensatory emphysema and reduction in the amount of functioning lung parenchyma, but mostly as a result of marked pleural changes with complete pleural symphysis. Leiner (1944) recorded that the function of a pneumothorax lung still in being was impaired, but still contributed largely to respiration. He did not report the end functional result when the pneumothorax was allowed to re-expand. Gaensler and Streider (1950), in a series of cases subjected to pneumothorax therapy, thoracoplasty, lobectomy, phrenic crush, and extra-pleural pneumothorax,recorded the greatest reduction in function after artificial pneumothorax therapy. Mitchell (1951) stressed that to obtain good long-term results in pneumothorax cases such factors as effusion, empyema, and endobronchial disease should be avoided at all costs, as they all contributed to pleural symphysis and resultant poor function.

Croxatto and Sampietro (1951), in a pathological examination of 200 tuberculous lungs obtained at autopsy and 138 surgical specimens, found that when both the pleura and underlying lung parenchyma were involved in an inflammatory process (as in an artificial pneumothorax with effusion) pleural symphysis occurred, and the lamina elastica of the visceral pleura was destroyed. This resulted in a thickened pleura encasing an unexpandable lung with inevitable marked reduction of function.

In the present series there were 18 cases with previous pneumothorax therapy who were assessed for fitness as to surgery either for the other lung or the ipsilateral one. In only three of these cases was there any noticeable loss of function on the re-expanded pneumothorax side, but in no case was this of sufficient degree to preclude surgery to the other lung. The figures here, though admittedly small, are in marked contrast to those quoted above for re-expanded pneumothoraces.

The following case demonstrates the value once more of lung function studies in patients not only with previous contra-lateral disease and collapse measures but with ipsilateral collapse therapy in addition.

Clinical Case Report. Case 54. Following a diagnosis of pulmonary tuberculosis in 1947, this patient received no active treatment till the following year, when, following a haemoptysis due to a cavity in the right upper lobe, a right artificial pneumothorax was induced. This was maintained till 1951. In the year prior to this a left artificial pneumothorax had been induced on account of some disease in the left apex, but this pneumothorax was abandoned after a short period (less than one year), and a left phrenic crush with pneumoperitoneum was substituted. The latter was maintained till 1954. Supplementary to these measures she had several courses of anti-tuberculous drugs between 1950 and 1954.

She was first admitted to Mearnskirk in August, 1955, following a recent positive sputum due to a cavity situated in the apex of right lower lobe. She was at this time aged 27 years, but her general condition was considered only as moderate.

FIGURE II.

Pre-Op. Representation of Differential Lung Function in Case 54.

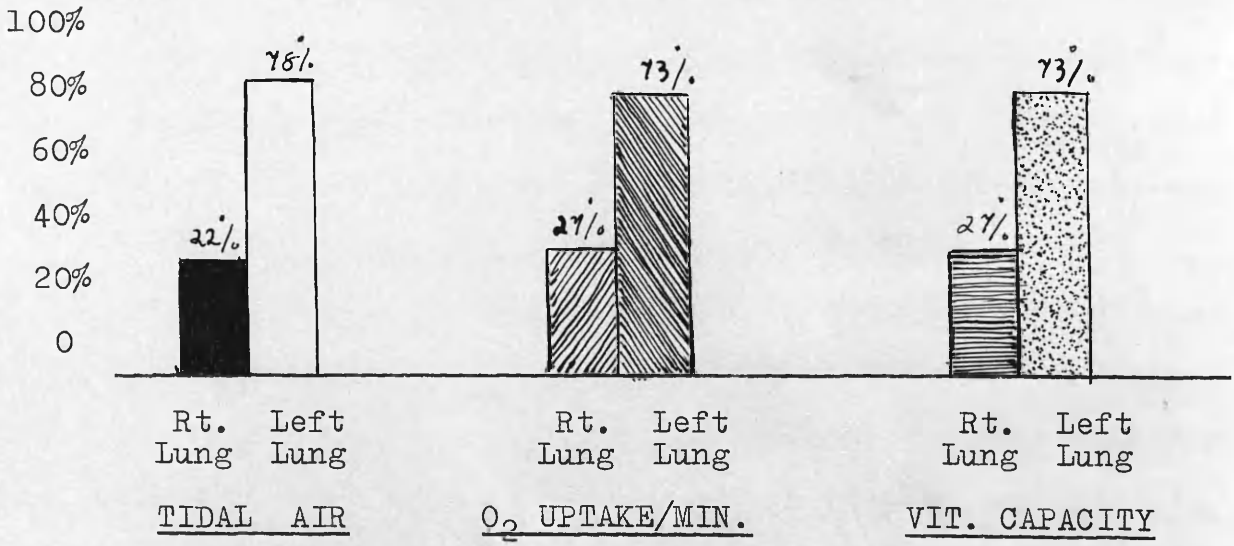
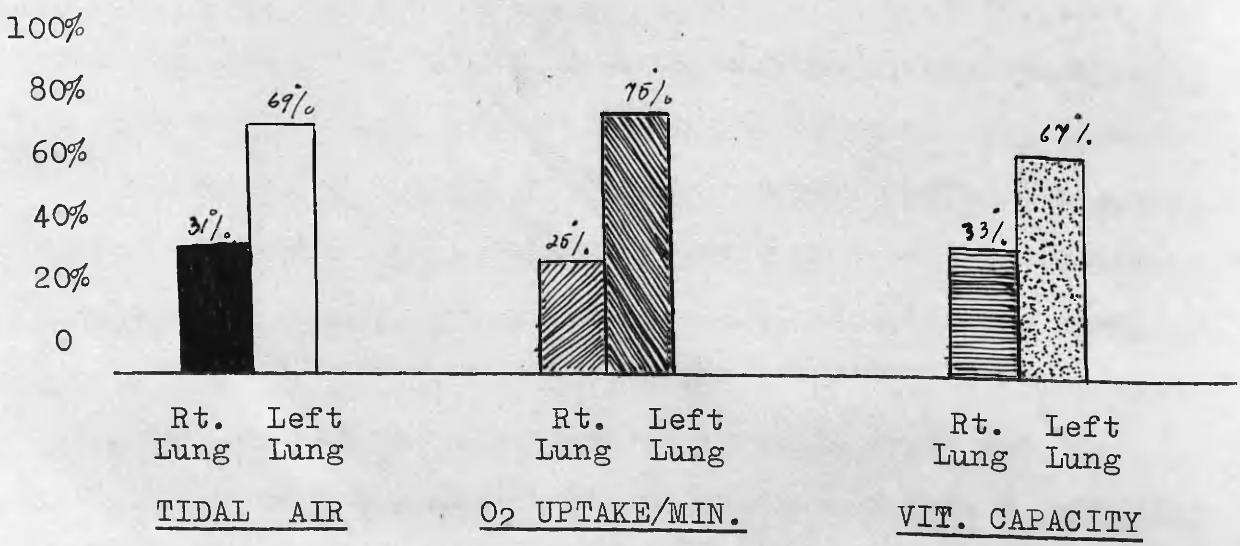


FIGURE III.

Post-Op. Representation of Differential Lung Function in Case 54.



In view of the multiple collapse measures that she had had over the years, lung function tests were performed to judge her fitness for surgery to the right lung.

From Figure II it will be easily seen that the right lung had quite marked reduction of function due to previous pneumothorax therapy, the relatively good function of the left lung being attributed to the left diaphragm having regained full function and to the fact that the pneumothorax on this side was of short duration and had no complicating factor such as effusion. The rather low vital capacity and maximum ventilatory capacity indicated impaired overall ventilatory function. The choice of operation of necessity had to be one that would cause minimal function loss, either an extra-pleural pneumothorax (Gaensler and Streider, 1950) or a plombage operation. As the former is not considered a suitable measure for cavities in the apex of lower lobe (Stevenson, 1952), the decision was to employ a polystan plombe situated posteriorly to compress the cavity. This was accomplished uneventfully in November, 1955.

The patient is now very well, her sputum is negative, and chest X-ray shows satisfactory control of the disease by the plombe. As shown in Table III and Figure III there has been no significant alteration in her lung function.

TABLE III

OVERALL FUNCTION PRE- & POST- OP. (CASE 54).

	Pre-Operative	Post-Operative
Vital Capacity (both lungs)	1,200 ml.	1,150 ml.
M.V.C.	57 litres/ min.	55 litres/ min.

It has been our experience that previous contralateral disease, where the disease has been purely parenchymal, does not reduce the function of that lung to any great extent. But if there has been pleural disease of the contralateral lung, particularly if this has brought about pleural thickening of any degree, or if there has been severe endobronchitis resulting ultimately in bronchostenosis of the major bronchus or bronchiectasis of the more distal bronchi, then there may be very severe reduction of function.

7. Bilateral Disease for Possible Bilateral Surgery.

This is the indication par excellence for performing lung function tests (Birath and Crafoord, 1951; Gaensler, 1952; Gaensler, Patton, and Frank, 1953). Its widest application is naturally in pulmonary tuberculosis, but Kay, Meade, and Hughes (1947) found it of inestimable value in assessing cases of bilateral bronchiectasis for surgery.

A female of 28 years, not included in the present series, was sent from another hospital in the area for bronchospirometry. She had suffered from bilateral bronchiectasis for many years, and had had excision of her left lower lobe on this account several years previously. She still had gross bronchiectasis of the right lower lobe, but her general condition was poor and she became easily dyspnoeic. Bronchospirometry was attempted twice unsuccessfully under local anaesthesia, and on the third occasion general anaesthesia was employed. The readings thus obtained were of poor quality and somewhat conflicting, but the vital capacity of both lungs was only 900 ml., with a maximum ventilatory capacity (M.V.C.) below 30 litres per minute. Such figures in combination with her poor exercise tolerance precluded any further surgery.

Such a case emphasises the need for careful judgement in cases for bilateral surgery, be they tuberculous or bronchiectasis, particularly where the respiratory capacity is at all in doubt. Lung function studies play a very important part in this type of case. To embark on major surgery of the lung in a borderline case without preliminary bronchospirometry is courting disaster, either in the form of death or permanent invalidism as a respiratory cripple.

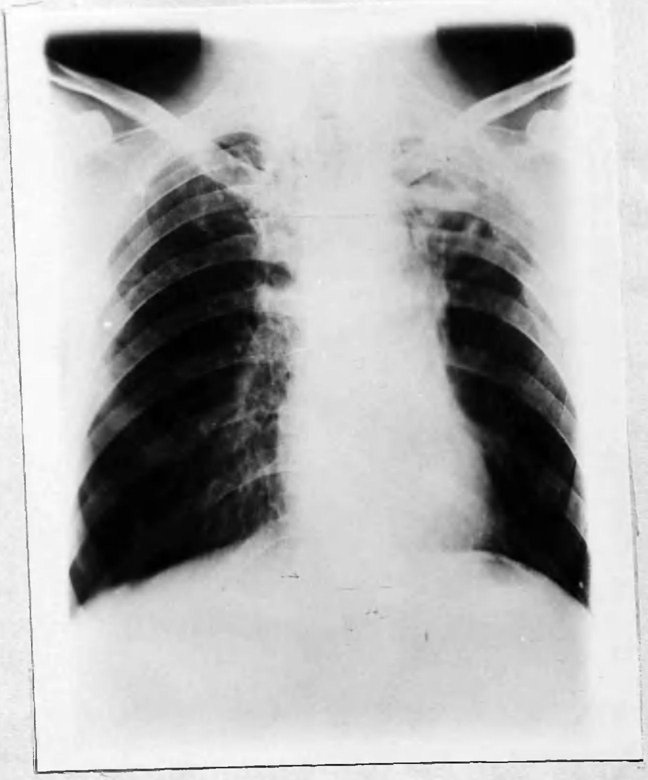
To underline the significance of lung function tests in cases for bilateral surgery and help in proving their indispensable value, the following case is quoted in full.

TABLE IV.

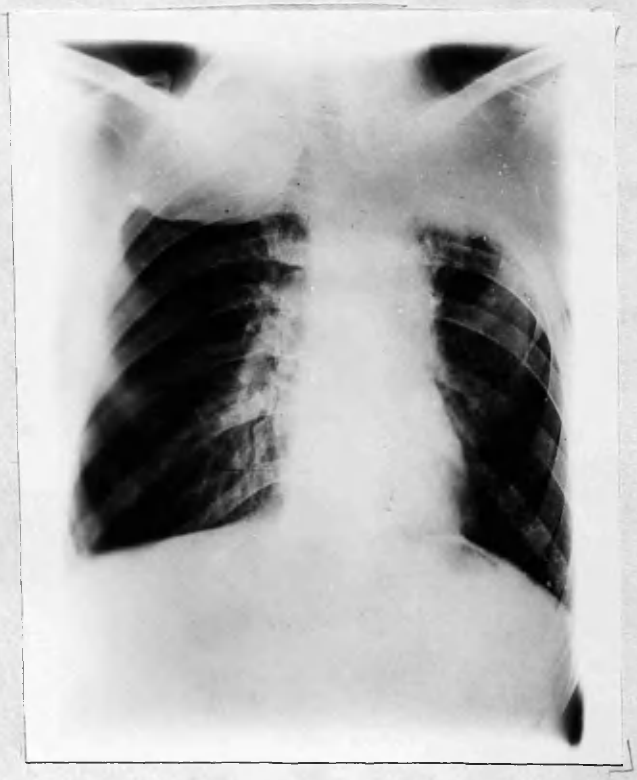
Case 6, Pre- & Post-Op. Figures.

	Pre-Operative		Post-Operative	
	Right Lung	Left Lung	Right Lung	Left Lung
Tidal Air	500ml.(63%)	300ml.(37%)	225ml.(65.5%)	125ml.(34.5%)
O_2 Uptake/ Min.	350ml.(87%)	50ml.(13%)	300ml.(80%)	75ml.(20%)
Vital Capacity	1450ml.(69%)	650ml.(31%)	1400ml.(80%)	350ml.(20%)
Vital Capacity (Both lungs)	3,600 ml.		1,950 ml.	
Max.Vent. Capacity	Not done		58 litres/min.	

(The pre-operative figures refer here to those obtained before either operation was performed; the post-operative figures refer to those after both operations were completed.)



CASE 6. BILATERAL
UPPER LOBE CAVITATED
DISEASE.



CASE 6. POST-OP.,
SHOWING RIGHT PLOMBAGE
AND LEFT 5-RIB THORA-
COPLASTY.

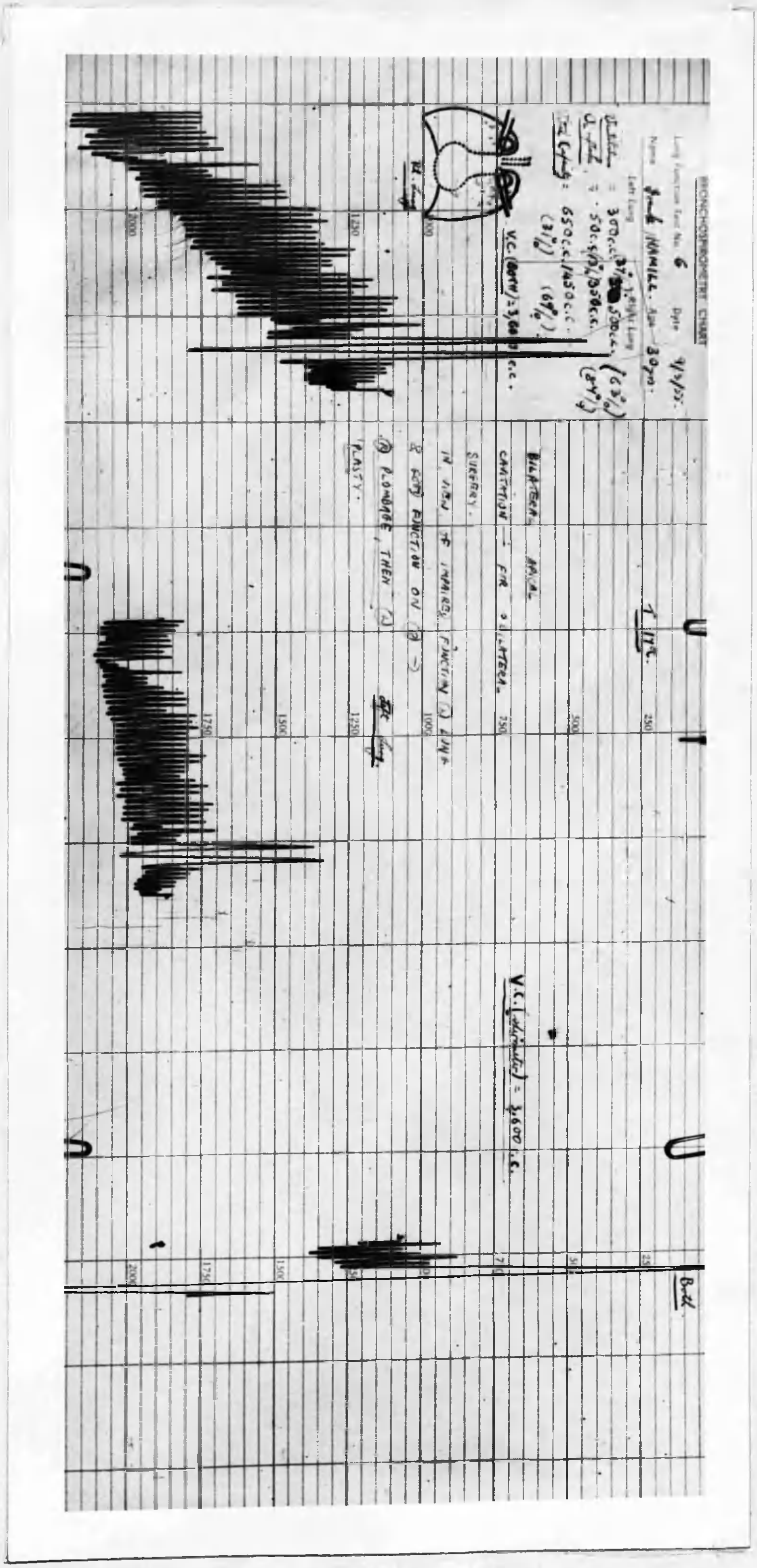
Clinical Case Report. Case 6.

On admission to Mearnskirk in December, 1954, this patient, a male aged 30 years, presented with bilateral apical cavitation, pulmonary tuberculosis having been diagnosed in 1951. His treatment prior to admission had consisted of drug therapy plus bed-rest, supplemented by a non-selective pneumoperitoneum for 18 months which was abandoned in May, 1954. His general condition was good, but as he had bilateral apical disease of equal severity and would obviously require bilateral surgery, lung function tests were carried out (Table IV). The left lung showed a definite reduction of function, particularly the oxygen uptake per minute (only 13 per cent. of the total). It was decided to perform a plombage operation on the right to conserve the function of the better lung, and, after a suitable interval, to effect control of the cavity at the left apex by a thoracoplasty.2

The plombage was accomplished uneventfully in May, 1955, and after three months' convalescence a left five-rib thoracoplasty (one-stage) was performed in August, 1955. He sustained a pleural tear during this operation with a complicating haemothorax and atelectasis of the left lung. This necessitated bronchoscopic suction on one occasion, the pleural tear sealing off and the haemothorax being absorbed spontaneously. At no time was the patient dyspnoeic or cyanosed in any manner despite these complicating factors. On his discharge from

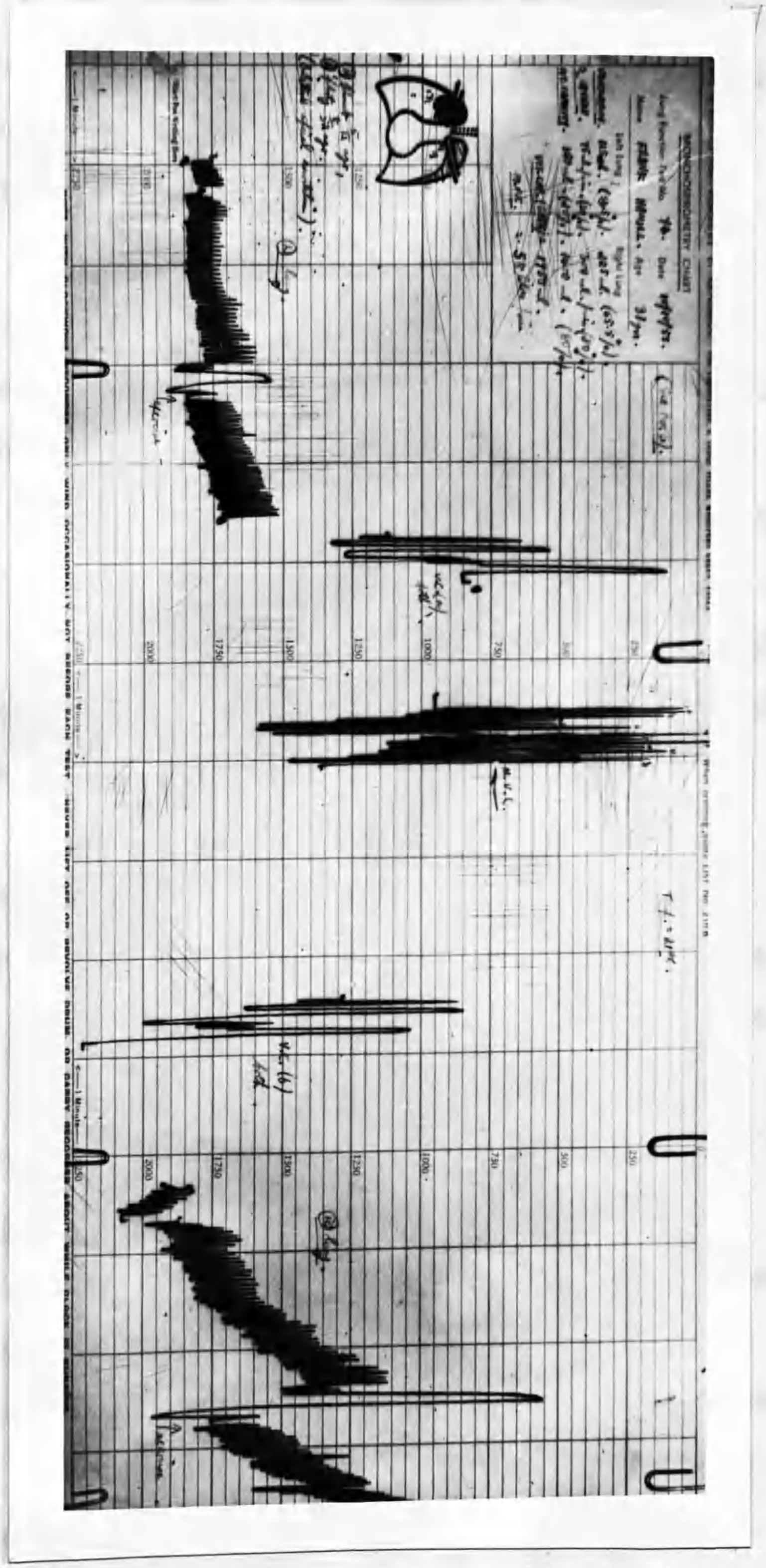
CASE 6.

PRE-OP. CHART.
IMPAIRED FUNCTION
LEFT LUNG.



CASE 6.

POST-OP. CHART (AFTER R.PLOMBE AND L.THORACO-PLASTY).



hospital in November, 1955, he was very well, the left lung had completely re-expanded, and the disease at both apices was more than adequately controlled by the collapse measures outlined.

Several interesting features emerge from this case. Firstly there appeared no very obvious cause for the relatively poor function of the left lung pre-operatively - there was no antecedent history of pleural effusion or collapse measures, nor had the disease in the lung at any time been extensive. Secondly there was minimal loss of function from the plombe, though the thoracoplasty culminated in definite reduction of total function. Lastly the most illuminating fact emerged that following the thoracoplasty, despite a complicating haemothorax with atelectasis of the left lung lasting for several days, at no point was the patient in any way distressed. This proved beyond any doubt the small contribution to total lung function made by the left lung, confirming the pre-operative results obtained by bronchospirometry.

8. <u>Age of Patients.</u>

The age of the patients in this series has varied from 16 years (a girl who was assessed for left pneumonectomy, having previously had a right artificial pneumothorax, Case 30) to 64 years. Many patients in their late 'teens have been subjected to bronchospirometry, in most cases with minimal discomfort. However, it is in this age group that the main difficulties associated with bronchospirometry are encountered - apprehension, difficulty in intubation due to a full set of teeth, a tight, unrelaxed jaw, and a narrow buccal cavity. Previous writers have made light of such difficulties, or have failed to mention them. But in our experience they do exist, and in the very odd case may prevent insertion of the catheter under local anaesthesia. Fortunately, the vast majority of patients who require bronchospirometry fall into the adult age group, where the factors of previous contralateral disease or collapse measures, concomitant pulmonary emphysema, and the possibility of bilateral surgery are more likely to arise. In this group difficulties are less likely to be met with, and bronchospirometry can be achieved comparatively easily, demanding from the person performing it merely a modicum of skill and experience in endoscopic work, perhaps a little more than for bronchoscopy.

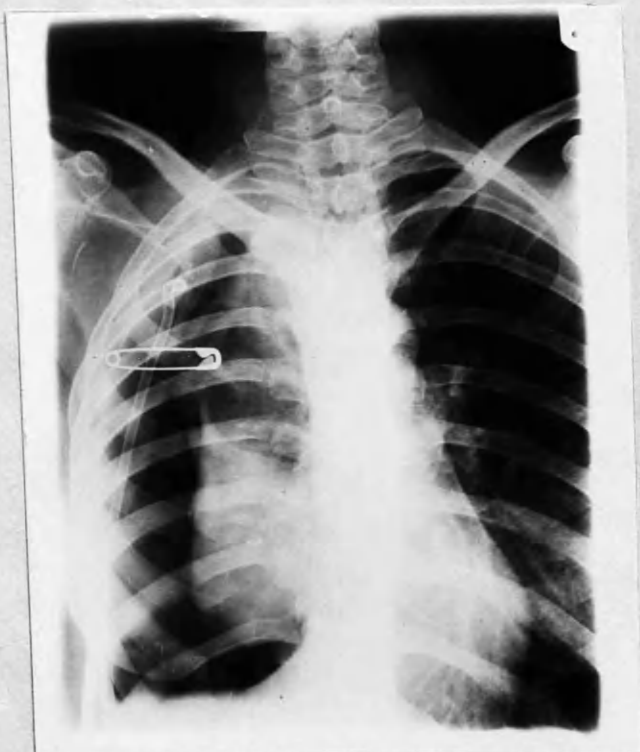
Lung function studies have proved of great value in the surgical assessment of tuberculous patients in their late forties, not only in deciding their fitness for operation, but additionally the type of operation best suited to meet both the adequate control of their disease and conservation of function. Such tests are likewise almost imperative in elderly patients with lung cancer, where clinically and bronchoscopically the tumour is deemed operable. Particularly is this so when it is remembered that age itself produces a gradual progressive decrease in lung function (Kaltreider, Fray, and Hyde, 1938), with advancing years.

9. General Condition.

The presence of any exertional dyspnoea, however slight, or cyanosis are two very potent indications for carrying out lung function studies, whenever the possibility of lung surgery is contemplated. In some cases the overall ventilatory capacity (as deduced from the vital capacity and maximum ventilatory capacity) in these dyspnoeic patients shows such reduction that surgery in any form is not feasible, and the need to go ahead with bronchospirometry is unnecessary.

Birath and Crafoord (1951), and Gaensler, Patton, and Frank (1953) pointed out how important these tests were before considering surgical intervention in dyspnoeic patients. Patients with tuberculous empyema (due to pneumothorax therapy, spontaneous rupture of a cavity with resultant pyopneumothorax, or to a pleural effusion becoming purulent) are often breathless on exertion. Overall function may be impaired in these cases, bronchospirometry often demonstrating little or no function from the empyema side. Surgical decortication of the lung is frequently the treatment of choice, in that it obliterates a dangerous, infected pleural space and also results in improvement in function of the underlying lung in most cases.

However, where there has been extensive parenchymal disease in the lung underlying an empyema and particularly where the

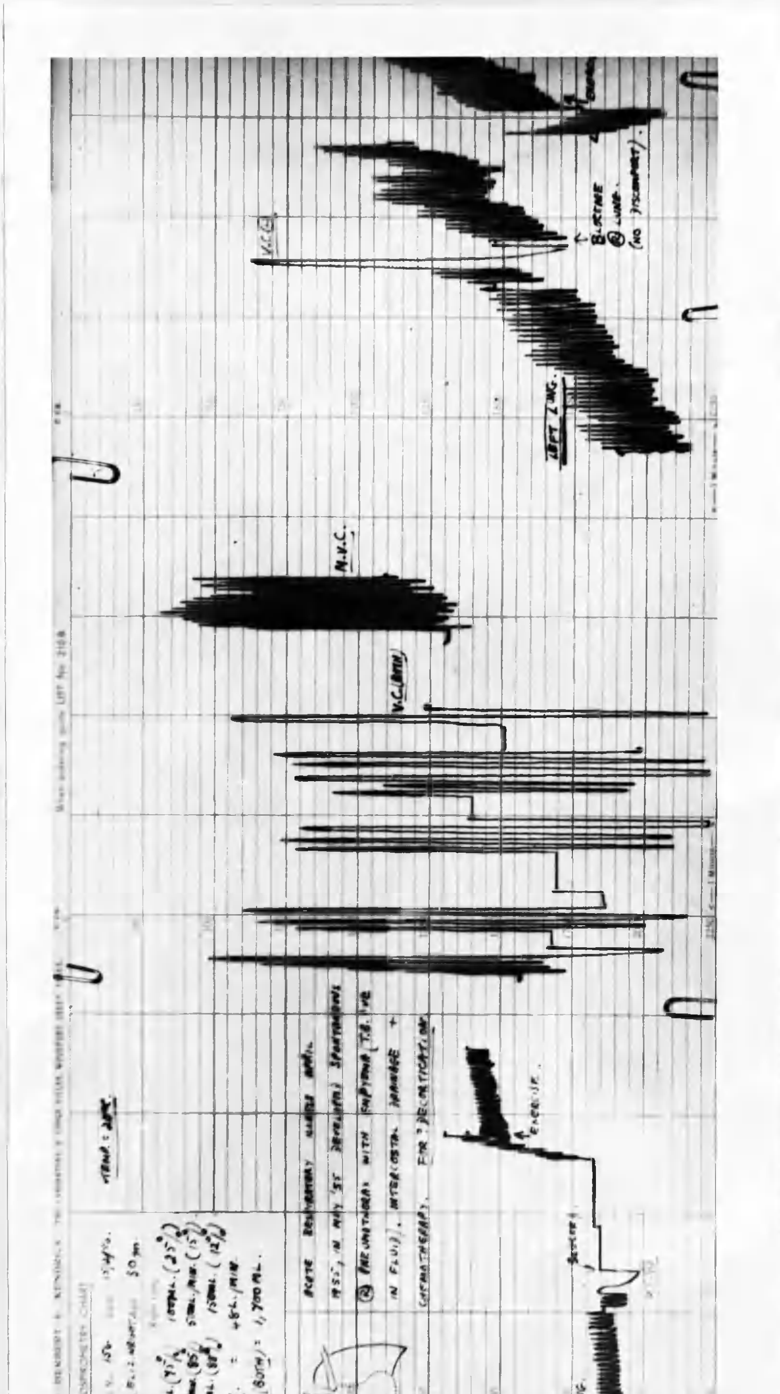


CASE 156.

RIGHT T.B. PYO-
PNEUMOTHORAX, SHOWING
DRAINAGE TUBE.

empyema is of long standing, little improvement in the function of such a lung can be expected from decortication (Gordon et al., 1949; Carrol et al., 1951; Falk et al., 1952; Patton et al., 1952). Certainly the best functional results follow decortication in cases of traumatic haemothorax (Wright, Yee, et al., 1949; Forsee et al., 1951). Savage and Fleming (1955) studied 43 cases of tuberculous empyema subjected to decortication, excluding cases with gross disease of the underlying lung and those with stenosis of a major bronchus. The duration of the empyema varied from less than one year to the longest at 20 years. All the cases were investigated intensively pre-operatively, and all had breathing exercises combined with courses of chemotherapy. At operation the thickened pleura with its empyema sac was removed, and any parenchymal disease that was present was dealt with either by resection or thoracoplasty. In all their cases full re-expansion of the lung was achieved, and in all but four there was a significant increase in lung function.

The policy in Mearnskirk Hospital for cases of tuberculous empyema is pneumonectomy with excision of the empyema sac in any case where there has been fairly extensive parenchymal disease of the involved lung. There was only one case of tuberculous empyema in this series, a woman of 30 years (Case 156) who had developed an empyema following rupture of a cavity one year previously. Drainage had been established by means of



CASE 156.

VIRTUALLY
FUNCTIONLESS
RIGHT LUNG.
(PRE.OP.CHART).

an intercostal tube, but only partial re-expansion of the underlying lung had occurred due to a persistent broncho-pleural fistula. Her general condition was poor, and overall lung function was markedly impaired with the empyema side contributing 15 per cent. of this. A pneumonectomy with removal of the empyema sac was achieved successfully, though only after a very lengthy and difficult operation. She survived the first two post-operative days, but then succumbed from a purulent and extremely virulent staphylococcus aureus bronchitis, despite bronchoscopic suction and appropriate drug therapy.

This case illustrates the precarious state of these patients with tuberculous empyema where the general condition is poor. The empyema side pre-operatively contributed very little to total lung function, and its removal should have in effect caused little disturbance to function. However, the gruelling nature of the operation and her poor general state resulted in a lowering of her resistance, so that when a complicating bronchitis supervened, her demise was fairly rapid.

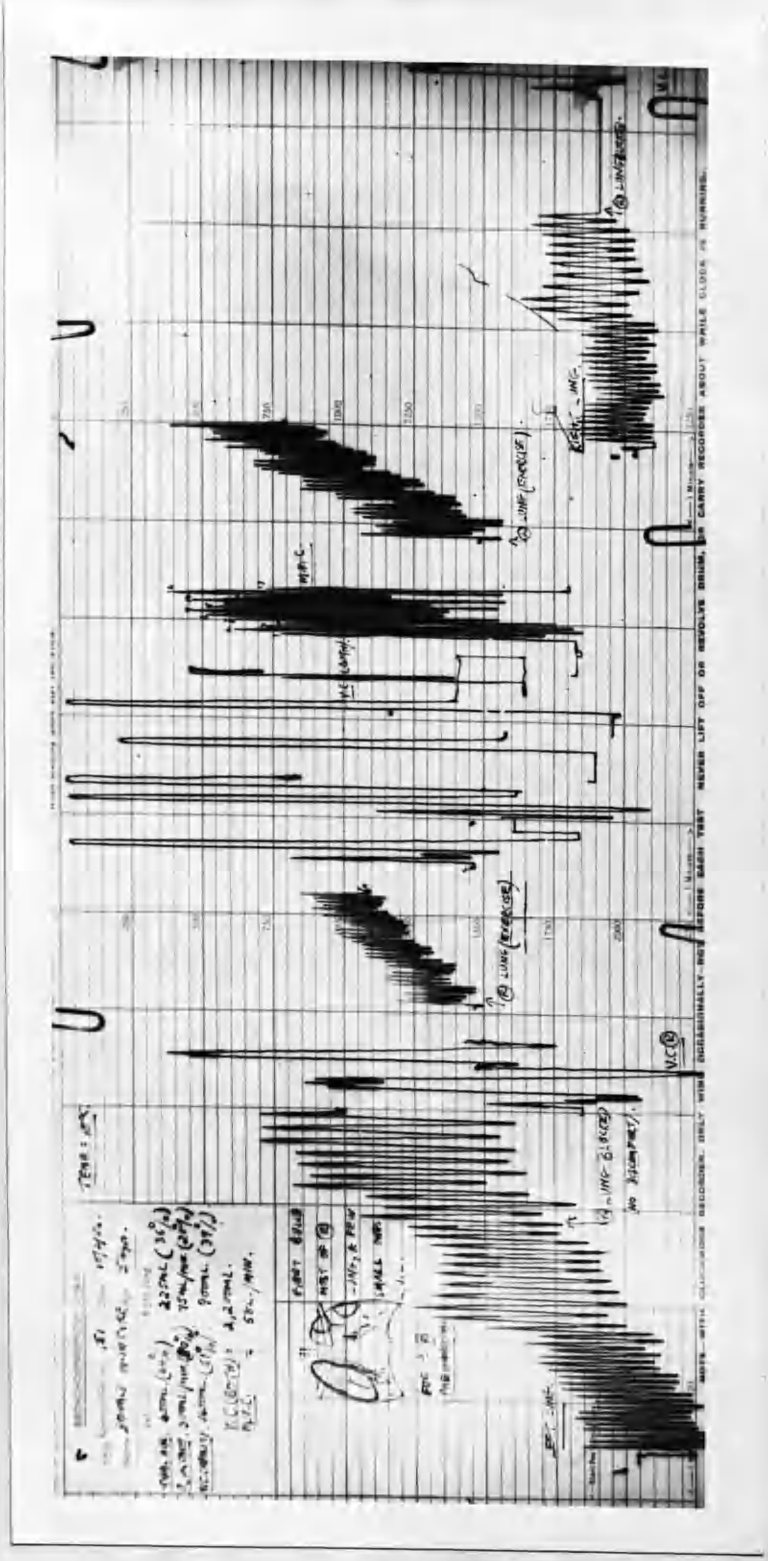
10. <u>Presence of Any Concomitant Cardio-Respiratory Disease.</u>

This group comprises a very interesting and important clinical problem. It includes tuberculous cases of long standing, where the productive phase of the disease has led ultimately to pulmonary fibrosis, but where a residual apical cavity persists and the question is to decide their fitness for surgery. The presence of pulmonary fibrosis is in most cases associated with some degree of emphysema, and this lead eventually to pulmonary insufficiency. This may be purely ventilatory (that is merely mechanical, affecting the bellows function of the lung, with dyspnoea as the predominant symptom), alveolo-respiratory (where the exchange of oxygen and carbon dioxide between the blood in the pulmonary capillaries and outside air is impaired, and hyperventilation and later cyanosis are present), or a combination of both (Baldwin, Cournand, and Richards, 1948). This imbalance in local alveolar ventilation-perfusion leads to anoxia with a tendency to carbon dioxide retention, while the anoxia in turn leads to constriction of the pulmonary arteriolar lung bed with consequent rise in the pulmonary artery pressure (West, Baldwin, et al., 1951; Harvey, Ferrer, et al., 1951). The eventual outcome of this pulmonary hypertension is enlargement of the pulmonary arteries and the right heart chambers (cor pulmonale, or cardio-respiratory insufficiency), with right heart failure as the penultimate ending to this vicious circle.

Obviously patients who have reached this stage are no longer candidates for any form of thoracic surgery. It is in the cases of early pulmonary insufficiency with perhaps slight dyspnoea on exertion as the only symptom (ventilatory insufficiency) that the decision whether to operate occasions no little difficulty. Total lung function studies will help, as will estimation of the arterial oxygen saturation in addition (Kaltreider and McCann, 1937; Harvey, Ferrer, et al., 1951; Bjork, 1953). (Unfortunately facilities do not exist at present in Mearnskirk for carrying out the last mentioned estimation, though we have managed to have it done in two cases at another hospital.).

In cases of giant bullous cysts associated with generalised pulmonary emphysema, and with dyspnoea and slight cyanosis as the presenting picture, it is invaluable to ascertain to what degree the giant cysts are responsible for these symptoms. If the breathlessness is due almost entirely to the mechanical effects of a space-occupying cyst under tension, then surgery will be beneficial in that it removes the compression effects exerted on surrounding structures by such a lesion. Contrarily, if the disablement is due mainly to generalised pulmonary emphysema, the effects of the bulla or cyst being of secondary moment, surgery can be of no avail, and in fact may even be disastrous.

Baldwin, Harden, et al. (1950) reported the results of such a study in 16 cases of large pulmonary air-containing cysts. They found that when there was no desaturation of the arterial oxygen content of the blood (indicating no disturbance of the alveolar ventilation perfusion), operation could be safely undertaken, and the end results were satisfactory. Even in



CASE 151.

GIANT BULLA RIGHT LUNG. IMPAIRED OVERALL FUNCTION.

cases of bilateral emphysema with a large bulla in one lung, provided bronchospirometry demonstrated that the lung containing the bulla had impaired function and provided the arterial oxygen saturation was normal, operation was justifiable if the symptoms warranted it. However, when arterial anoxia was present, indicating alveolo-respiratory insufficiency, surgery was contra-indicated. These authors maintained that the arterial anoxia in these cases was due not to the large bullous cyst (a relatively avascular structure), but to serious impairment of alveolo-respiratory function by the emphysematous lungs.

One case in this series fell into this category.

Clinical Case Report. Case 151. A male patient, aged 56 years, was admitted to Mearnskirk in January, 1956, as an emergency with acute dyspnoea and quite marked cyanosis, the presumptive diagnosis being a pneumonia occurring in an emphysematous subject. He was pyrexial and had marked clubbing of the fingers. Appropriate therapy was administered, consisting of tetracycline 1G. daily for six days with oxygen as needed. Chest X-ray on the day following admission showed a giant bullous cyst occupying more than half of the right lung with a pneumonic consolidation at the right base. The left lung showed generalised emphysema. Four days after admission his condition had improved considerably, the dyspnoea and cyanosis at rest had subsided, and his sputum was markedly reduced in amount. The consolidation at the right base had cleared completely within two weeks.

His previous history had been one of dyspnoea on exertion, progressive in character, with recurrent cough and spit, particularly each winter, over many years. Several days prior to admission his cough and spit had become very copious and his breathing very laboured, due to the onset of the pneumonia.

Bronchospirometry and lung function studies were carried out in February, 1956, to judge the advisability of surgical removal of the large bulla in the right lung. Overall function was fair only, with the right lung contributing between a quarter and a third of that function (Table V).

TABLE V.

Case 151 - large bulla of Rt. Lung.

Pre-Operative	Right Lung.		Left Lung.	
Tidal Air	225 ml.	(36 %).	400 ml.	(64%)
O_2 Uptake/min.	75 ml.	(20%)	300 ml.	(80%)
Vit. Capacity	900 ml.	(39%)	1,400 ml.	(61%)
Vit. Capacity (both lungs)	2,200 ml.			
Max. Vent. Cap.	58 litres/min.			

Cardiac catheterization was carried out at the Victoria Infirmary (Dr. Peel). This showed a resting pulmonary pressure of 22/8 millimetres of mercury, with a rise to 44/22 millimetres of mercury after exercise for two minutes. The arterial oxygen saturation at rest was 96.8 per cent. (femoral artery).

Operation was considered unwarranted in this case because of the information derived from the above two investigations. Firstly because the overall function was fair only, the right lung contributing nearly one third of that function. A right pneumonectomy, the only feasible undertaking, would thus reduce total lung function by one third, and would produce respiratory insufficiency of a degree sufficient to produce either early post-operative death or at the best a respiratory cripple. Secondly, although there was no arterial anoxia at rest, the pulmonary artery pressure was just within the upper limits of normality, and pulmonary hypertension was produced quite easily by very moderate exercise. His disability was due not to the presence of the giant bulla per se, but to generalised emphysema. However, subsequently he was reassessed, and judged fit to withstand a localised pleurodesis with suction of the bulla through an indwelling intercostal tube. (Chapter VII).

This case helps to elucidate some important factors concerned in the aetiology of pulmonary hypertension in pulmonary emphysema. Normally the pulmonary artery pressure remains unchanged at rest and on severe exercise, unless the exercise is of such magnitude or duration that the cardiac output is increased threefold, when a slight rise in pulmonary artery pressure may occur. This stability of pressure in the pulmonary circulation in normal subjects during all grades of activity implies that, during exercise, there occurs an expansion of the pulmonary vascular bed either by widening of existing blood channels or by the opening of new ones, or else a combination of the two. When there is advanced pulmonary emphysema the relationship between pulmonary blood flow and the capacity of the pulmonary vascular bed may be altered in several ways. The distensibility of the vascular bed may be reduced by anatomical lesions, or by the anoxic effect on pulmonary arteries and arterioles, or by both. In addition the polycythaemia resulting from the anoxia produces engorgement of the pulmonary vessels, which leads in turn to a further decrease in the distensibility of the lung vascular bed. If there is increased blood flow, as on exercise, through such a restricted bed, resistance is raised, and pulmonary hypertension eventuates (Harvey, Ferrer, et al., 1951).

The disease process, by producing thinning or rupture of alveolar septa and the development of blebs or bullae, reduces the number, calibre, and distensibility of the smaller vascular channels. At first, when there is no arterial oxygen desaturation at rest, pulmonary hypertension may occur only on exercise, but later when there is anoxia combined with greater restriction of the pulmonary vascular bed due to destruction of lung tissue and vascular sclerosis, pulmonary hypertension is present at rest, and a further rise occurs on exercise (Riley, Himmelstein, et al., 1948).

11. Investigational.

In addition to the indications already discussed for carrying out lung function tests, it was decided to undertake a study of a selected group of patients suffering from tuberculosis who were subjected to various medical and surgical collapse procedures and to resection surgery. The object of this was that by comparing the figures obtained before and after each measure was accomplished, the mean functional loss eventuating from each particular procedure could be estimated. It was hoped from this to be able to state which would be the most suitable measure for each particular patient, bearing in mind the situation and extent of the disease and the patient's respiratory capacity.

Two annotations in the British Medical Journal (1953 and 1955) urged the use of bronchospirometry as an investigational procedure, to help delineate the loss of function brought about by various types of operation. Gaensler and Streider (1950) compared extra-pleural pneumothorax with pneumonectomy, pneumothorax, lobectomy, thoracoplasty, and phrenic crush, and found the former to be the most selective and function-conserving of them all. This is the only large series of cases reported so far, comparing derangement of function from all these procedures. Several other writers have described the loss of function occurring from one single measure (Burnett, Long, et al., 1949; Dressler, Bronfin, et al., 1950; Powers and Himmelstein, 1951; Paul, Beattie, et al., 1951; and Lindahl,1954).

In a later chapter it is hoped to present the figures obtained in this series for the functional loss due to: thoracoplasty, pneumonectomy, lobectomy, segmentectomy, artificial pneumothorax, phrenic crush plus pneumoperitoneum, plombage operation, and extra-pleural apicolysis (similar to extra-pleural pneumothorax in technique, but as the space fills with blood clot no air refills are necessary). The numbers comprising pneumothorax and pneumoperitoneum are small in comparison with thoracoplasty and resection, but this merely reflects the present trend in the treatment of pulmonary tuberculosis. Pneumoperitoneum and phrenic crush are used only occasionally in Mearnskirk at present, being reserved for cases of recent lower lobe disease, or as a "cooling-off" process in acute disease that may require at a future date more definitive treatment in the form of resection surgery.

Pneumothorax therapy is still used by us, although the indications are very limited. Cases with a persistent small cavity after a reasonable course of chemotherapy with bed-rest, but with disease of too recent onset to contemplate surgery, are suitable candidates for induction of a pneumothorax. If the pneumothorax is unsatisfactory (indivisible adhesions at thoracoscopy, an open cavity persisting, or an area of atelectasis), the project is abandoned forthwith.

B. CONTRA-INDICATIONS.

1. General.

The only general contra-indications to the performance of bronchospirometry in this series have comprised the following:- acute exudative tuberculosis, pyrexia, and where overall lung function is so poor that surgery is precluded and the need to carry out bronchospirometry does not arise.

Several authors have mentioned dyspnoea as a contra-indication (Norris, Long, and Oppenheimer, 1948), but this has not hindered the performance of bronchospirometry in the present series. On the contrary, it has been considered a very definite indication for bronchospirometry.

2. Local.

Amongst the local contra-indications to bronchospirometry are included those outlined by Pinner, Leiner, and Zavod (1945) and by Gaensler and Watson (1952). Recent haemoptysis, tuberculous ulceration of the larynx, and severe bronchostenosis of one main bronchus are absolute contra-indications.

Gaensler and Watson (1952) included tracheal and bronchial deformity as a potent cause of poor results in bronchospirometry, because of difficulty in siting the tube. In this series several cases with tracheal deformity have been subjected to bronchospirometry, some quite successfully. Nevertheless, it is in this type of case that such obstacles as air shunting and poor readings are encountered most frequently.

The presence of copious, viscid sputum need not preclude successful tracings. Diligent attention to postural drainage beforehand, combined with suitable drug cover (a three-day course of tetracycline in most cases), will enable the tests to be accomplished satisfactorily. Similarly in those with a tendency to bronchospasm the use of an antispasmodic one hour before the intubation is carried out will ensure no difficulty on that account. In several severe cases we have had to administer 10 to 15 minims of 1:1,000 adrenaline subcutaneously during the actual procedure. In no manner can the co-existence of bronchitis be considered a cogent argument against broncho-spirometry - on the contrary it is very often in our experience a strong indication for studying lung function.

Manifestly no method of investigation, involving intubation, should be done while the patient has a severe coryza. When the upper respiratory tract has returned to its normal state, intubation can be undertaken then without the danger of precipitating an aspiration pneumonitis.

With these few limitations, bronchospirometry is a procedure entirely safe and with little attendant danger, and in the majority of patients it produces little in the way of discomfort, distress, or sequelae.

* * * * * * *

Summary:

The indications for bronchospirometry are outlined, and discussed in detail. Its importance in pulmonary tuberculosis, bronchial carcinoma, bronchiectasis, and various other conditions are dealt with. Where there has been previously extensive parenchymal or pleural disease or collapse measures confined to one or other lung (in some cases both lungs), the procedure gives valuable information concerning the function of the lung in question. Bronchospirometry along with other lung function tests are imperative before embarking on surgical treatment for one lung when there has been prior contralateral disease or collapse therapy. They also assist in assessing cases for bilateral surgery, be they tubercle or bronchiectasis.

In older patients, and in the presence of accompanying bronchitis and emphysema, lung function studies occupy a prominent position in judging suitability for operation, and the form of surgery most fitting to meet the individual's requirements.

Pulmonary hypertension is discussed in passing.

Illustrative cases of the various indications for bronchospirometry are presented, and the value of the procedure for estimating accurately the loss of function after any measure (medical or surgical) is stressed.

The contra-indications are few, comprising mainly recent haemoptysis, T.B. ulceration of the larynx, and severe

bronchostenosis or tracheal deformity.

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CHAPTER IV.

TECHNIQUE

A. PRELIMINARY OBSERVATIONS.

1. Lung Physiology.
2. The Lung Volume and Its Components.
3. Resistance Breathing.

B. ACTUAL TECHNIQUE OF BRONCHOSPIROMETRY.

1. Initial Assessment of Lung Function by Clinical and Radiological Appearances.
2. Preparatory Postural Drainage, Antibiotic cover, Antispasmodics.
3. Pre-medication Used.
4. Description of Apparatus Used.
5. Various types of Catheters Available.
6. Description of Method of Intubation (preliminary bronchography or bronchoscopy).
7. Technical Difficulties.
8. Number of Failures in Series.

C. DESCRIPTION OF READINGS OBTAINED AND THEIR VALUE AND APPLICATION CLINICALLY.

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TECHNIQUE

A. PRELIMINARY OBSERVATIONS.

1. Lung Physiology.

A sound, working knowledge of respiratory physiology in the normal subject is paramount before attempting to study and analyse abnormal lung function. The function of the lungs is to maintain normal and nearly constant tensions of oxygen and carbon dioxide in the arterial blood in all physiological conditions, without producing any undue sensation of ventilatory discomfort or adverse effect on the heart or any other organ (Donald, 1953). This constancy of the arterial blood gases in all degrees of activity and oxygen usage is maintained only by the efficient transfer of gases between the alveolar air and the blood passing through the alveolar capillaries.

Respiration has two essential components, namely ventilation and respiratory gase exchange (alveolo-respiratory function) (Baldwin et al., 1948). Ventilation was defined by these authors as the mass displacement of air between the outside atmosphere and the interior of the lungs. Normal ventilation depends on the integrity of the bony framework of the chest and of the respiratory muscles, the normal structure and elasticity of the pleura and mediastinal contents, patency of the air passages, and a normal respiratory stimulus transmitted from the respiratory centre. Herxheimer (1949), however, demonstrated that in the standing position at rest breathing was often purely diaphragmatic in type, while in the supine position the intercostal muscles took a more active part.

Alveolo-respiratory function, as the term implies, involves the exchange of oxygen and carbon dioxide between the blood in the pulmonary capillaries and the outside air. It is in effect a purely chemical function as opposed to ventilation, which is mainly mechanical.

During normal quiet respiration the quantity of air inspired or expired is equivalent to 350-500 ml. (tidal air). However, only a part of this volume takes part in actual gaseous exchange, 25 per cent. - 30 per cent. comprising what is known as dead-space air which does not contribute in any way to this process.

Alveolar air is the main functional component in the exchange of gases, because due to its position in the depths of the lungs, it is in constant contact with the respiratory epithelium. Interchange of gases between the alveolar air and pulmonary blood circulating in the capillaries in the walls of the alveoli occurs in both directions by simple diffusion. Functional residual air and alveolar air are approximately equal, the normal value for each being equivalent to 3,000 ml. Riley et al.(1946) described a method for calculating alveolar gas pressures simply by determining the partial pressures of carbon dioxide and oyxgen in inspired and expired air, and the pressure of these two gases in arterial blood. Roelsen (1938) obtained a fractional analysis of alveolar air by inducing the subject to breathe in hydrogen, while Birath in 1947 obtained simultaneous samples of alveolar air from each lung by means of bronchial catheterization.

Breathing is under the regulation of the respiratory centre, which, according to Wright (1953), consists of an inspiratory and expiratory centre situated in the medulla, and a pneumotaxic centre situated in the upper pons. The respiratory centre in turn is regulated reflexly by afferent vagal impulses from stretch receptors in the lungs, by afferents from chemoreceptors and vascular pressure-receptors, and by stimuli from higher levels of the brain. The inspiratory centre is extremely sensitive to changes in the chemical composition of the blood. Both the inspiratory and pneumotaxic centres form a mutually reacting closed circuit, which converts the steady discharge of the inspiratory centre into an alternating pattern of activity and rest. During inspiration the lungs become progressively stretched, and more impulses pass up the vagi till the discharge of the inspiratory centre is arrested, and expiration commences. Vagal impulses then cease, but an inhibiting after-discharge maintains the quiescence of the inspiratory centre, producing a pause between the end of expiration and the next inspiration.

Pitts (1942) divided the central respiratory system functionally into four subsidiary parts, - the respiratory centre-motor neurone, the vagal inhibitory, the brain-stem inhibitory, and other excitatory and inhibitory parts.

Ciliary Action. This plays a very prominent part in the defence mechanism of the respiratory tract against bacterial invasion, chemical action, and trauma. It exerts this protective activity by virtue of its dual function of locomotion and cleansing. Ciliated epithelium lines the greater part of the respiratory tract, including the nasal fossae, and for its proper function it requires a certain amount of moisture, a slightly alkaline medium, and the correct osmotic pressure (Negus, 1949). Any alteration in such requisites, such as the drying-up action of drugs like atropine or any trauma to the air passages, can lead to cessation of ciliary action. This in turn facilitates the ingress of foreign bodies, including pathogenic bacteria, into the lower respiratory tract and terminal bronchioles. There the invading organisms can set up a focus of inflammation having penetrated the protective barrier afforded by the cilia.

Arterial Oxygen Saturation. Because there is a continuous exchange of oxygen from the alveolar air to the blood circulating in the pulmonary capillaries and of carbon dioxide in the opposite direction, estimation of the oxygen and carbon dioxide contents of the arterial blood, along with their partial pressures, obviously can supply useful information regarding gaseous exchange in the lungs (alveolo-respiratory function). Arterial anoxia may in fact be the first significant sign of impaired respiratory function (Whitehead and Miller, 1940).

The arterial oxygen tension in normal young adults was found to be 97.1 millimetres of mercury by Comroe and Dripps in 1944, while the oxygen pressure of alveolar air obtained from end-expiratory samples was 97.4 millimetres of mercury. Lillienthal et al. (1946) found that the oxygen pressure gradient existing between the alveolar air and the peripheral artieral blood increased during exercise. A method for simultaneous determination of the blood flow through each lung was described by Rahn and Bahnson (1950). Making use of the Fick principle, they were able to estimate the blood flow through each lung, provided the arterial gas content of the lungs differed, from the gas content of the arterial blood, the respiratory quotient, and metabolic rates. The importance of arterial oxygen saturation estimations post-operatively in thoracic cases was stressed by Maier and Cournand (1943). They regarded 94-96 per cent. as the normal range of arterial oxygen saturation by the Van Slyke method, less than 90 per cent. indicating a degree of anoxia, and 85 per cent. or less pointing to severe anoxia. Their findings were based on a series of cases after pneumonectomy, lobectomy, and thoracoplasty. In most cases a degree of anoxia was present in the first week after operation, but if this persisted beyond that period some complicating factor such as atelectasis, pleural effusion, broncho-pleural fistula, or pneumonic consolidation was present.

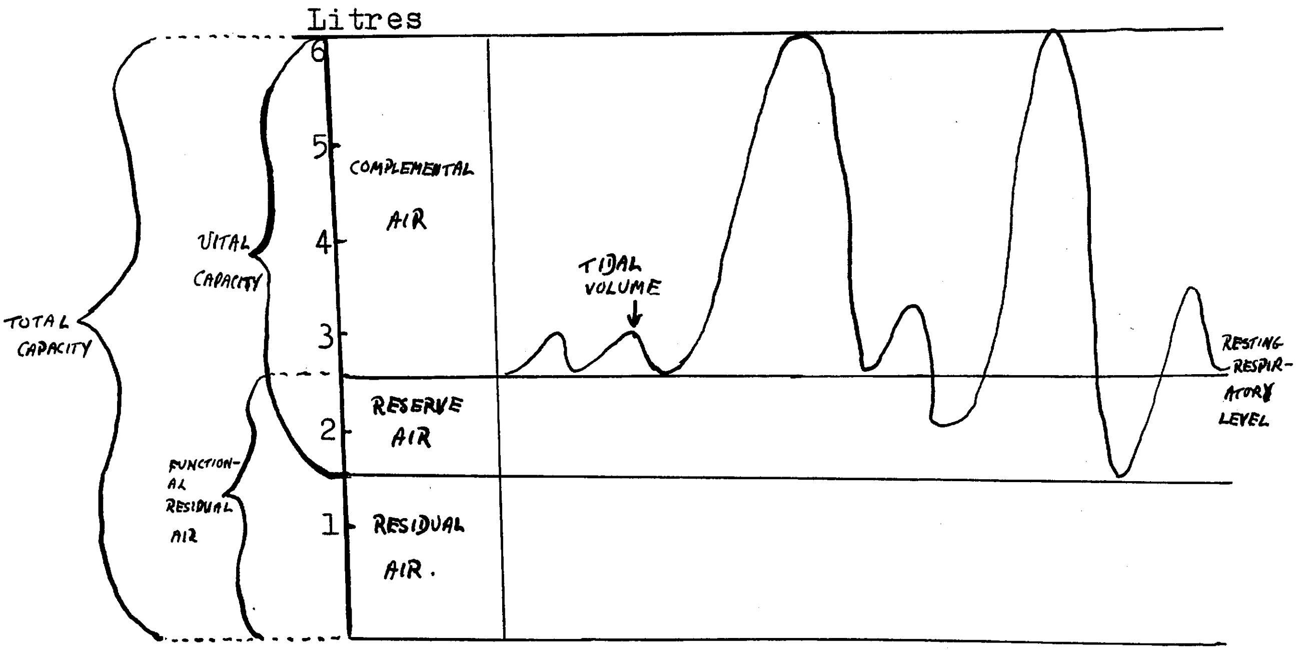
As mentioned already, the facilities for performing this very valuable estimation have not been available up to the present in Mearnskirk Hospital. A degree of anoxia may be present post-operatively, which in its early stages may not be obvious clinically with the customary signs of cyanosis and dyspnoea, and yet estimation of the arterial oxygen saturation would reveal the presence of anoxia. The performance of this test during the post-operative phase of cases with low respiratory reserve would be of very real assistance in the management of such patients.

Lastly, before completing this brief discussion of lung physiology, the pulmonary circulation must be mentioned. By means of cardiac catheterization, which was first introduced by Bloomfield et al. in 1946, the pulmonary artery pressure can be measured at rest and on exercise. The normal mean pressure in the pulmonary artery is around 15 millimetres of mercury, 30 millimetres being regarded as the upper limit of normal for the systolic pressure. In a healthy individual the pressure of the pulmonary artery remains the same at rest and on exercise, this constancy being attributable to opening up of new vascular channels and the widening of ones already existent. This latter property of expansion possessed by the pulmonary vascular bed, along with the low resistance in the pulmonary circulation, permits resection of areas of lung tissue, or their destruction by disease, without precipitating a rise in the pulmonary artery pressure in otherwise normal subjects (Donald, 1953). It is when there is generalised lung destruction, as in widespread

FIGURE IV.

LUNG VOLUME & ITS SUBDIVISIONS

(AFTER CHRISTIE, 1932)



emphysema from any cause, with consequent obliteration of considerable numbers of vascular channels and increase in the resistance in the pulmonary circulation, that pulmonary hypertension becomes manifest (Riley et al., 1948). The pulmonary hypertension is present at first only on exercise, but later in more advanced cases it is present at rest with a further rise on exercise. Cor pulmonale is the next step in this vicious circle, with right heart failure the penultimate stage before death.

2. The Lung Volume and its Components.

Christie in 1932 was perhaps the first to describe in full the subdivisions of lung volume and their measurements. No better method of presentation of the various components of lung volume exists than the original diagram formulated by Christie (Figure IV).

Tidal air is the quantity of air expired by a breath of average depth (350-500 ml.). Vital capacity is the amount of air than can be expired from the fullest inspiration to the fullest expiration. The functional residual capacity or air is the amount of air remaining in the lungs after a normal expiration (that is, the sum of the reserve air plus the residual air). Whitfield et al. (1950), examining a number of normal male and female subjects, found the mean total lung volume to be five-and-a-half to five-and-three-quarters litres in males, four-and-a-quarter litres in females. Vital capacity they ascertained to be seventy per cent. of the total lung volume. The same authors demonstrated that these measurements of lung volume were less in the recumbent position, and that they were correlated with age, height, weight, and chest expansion.

The functional residual air can be measured either by a closed-circuit method, whereby helium is introduced into the oxygen mixture and the dilation of the helium is estimated; or by an open-circuit method, in which the volume of nitrogen eliminated from the subject into a spirometer, when taking successive breaths of oxygen, is measured (Gibson and Hugh-Jones, 1949).

In the present series the subdivisions of lung volume have not been regarded as of such importance as the contribution which each lung separately makes to total pulmonary function. However, as an estimation of overall function, the vital capacity by itself can be grossly inaccurate and totally misleading, as pointed out by Warring in 1945. This is particularly so in generalised pulmonary emphysema, where a false high vital capacity may be recorded due to an increase in the residual air, representing largely dead-space air. The maximum ventilatory capacity (designated M.V.C.) has been found to be more reliable and informative. First described in 1933 by Hermannsen, it was known then as the maximum breathing capacity, the patient being instructed to breathe as quickly and as deeply as possible over the space of one minute. Owing to the wide diversity in rates of breathing that could occur with such a test, the maximum ventilatory capacity was introduced to give a more scientific approach and a more uniform result to the test. By definition the maximum ventilatory capacity is the maximum volume of air that can be ventilated by a patient in unit time, and in this series the practice has been to tell the patients to breathe as deeply as possible at a rate of 60 respirations per minute over a period of 30 seconds. Such a test portrays in a fairly precise manner the dynamic state of ventilatory function, and was regarded as a very informative test by Baldwin et al. (1948).

3. Resistance Breathing.

A brief reference to this subject has been made in Chapter II. The term as used here implies any abnormal reduction in the airway which results in resistance to breathing. This may occur, for example, in bronchospasm from any cause, where the reduction in the lumina of the air passages is due to an intrinsic mechanism arising in the bronchial wall itself, and where the resistance to breathing affects particularly the expiratory phase. During bronchoscopy, bronchospirometry, or any procedure that involves the insertion of a tube down the main airway, resistance breathing is present in varying degree owing to a reduction in the diameter of the airway by the tube. This was of considerable importance with the early flexible double-lumen catheters devised for bronchospirometry by Gebauer and Zavod.

In 1949 Cain and Otis reported their findings on the physiological effects resulting from resistance to breathing. There was an alteration in the respiratory patterns, in that the total duration of each phase of respiration was lengthened, the maximum rate of flow decreased as did the time required to reach the maximum rate of flow, there was a decrease in the mean rate of flow, and the peak inspiratory and expiratory pressures were increased. Resistance breathing brought about a reduction in total ventilation, and caused a rise in the partial pressure of alveolar carbon dioxide and a decrease in the corresponding alveolar oxygen value.

The problem of air reistance in relation to bronchospirometry was studied by Gaensler et al. (1952). They observed the resistances to air flow for both lumina of the Gebauer, Zavod, Norris, and Carlens catheters at volumetric flow rates varying from five to forty litres per minute, and concluded that the resistances were least with the Carlens tube. This was in great part due to a wider internal diameter of each lumen in the Carlens catheter. In addition, with this tube the sum of the vital capacity of each lung obtained during bronchospirometry corresponded to 88 per cent. of the overall vital capacity of both lungs estimated by ordinary spirometry in the upright position. With none of the other catheters studied was such a correspondingly high percentage recorded, confirming again that resistance to air flow was at a minimum with the Carlens catheter.

However, despite air resistance being reduced to a minimum during bronchospirometry with the Carlens tube, it is still a factor which must be taken into account in assessing the results of such an examination. It is one of the reasons why the present author prefers the patient breathing pure oxygen during the procedure, even although Gaensler and Cugell (1952) pointed out that this may result in greater participation in oxygen uptake by the diseased lung than would occur were the patient breathing ordinary room, or atmospheric, air. A patient with diminished respiratory capacity, with perhaps copious secretions and a tendency to bronchospasm, might experience some undue discomfort and distress during bronchospirometry in these circumstances, where in addition to all these factors and that of air resistance is superimposed that of breathing a gas mixture with a low oxygen content. In all patients in this series, therefore, pure oxygen was used throughout, and it is this author's contention that this in no way interferes with or invalidates the results obtained.

B. ACTUAL TECHNIQUE OF BRONCHOSPIROMETRY.

1. Initial Assessment of Lung Function by Clinical and Radiological Appearances.

The earliest writers on this subject have mentioned the information which may be acquired regarding lung function from a careful clinical examination of the patient. This is most obvious, for example, in a case of pleural effusion, where the absence of any movement on the affected side signifies little or no function in the underlying lung. Or again in generalised pulmonary emphysema expansion of the chest wall and its integuments becomes progessively impaired, leading ultimately to an unexpandable chest fixed in the position of full inspiration. Such voluminous, ephysematous lungs manifestly require the maximum capacity available within the thorax, and this is achieved at the loss of normal expansion of the chest wall. Such estimates of lung function are necessarily crude and often inaccurate, as a patient may have good expansion of the chest on both sides and still be unsuitable for major lung surgery.

Radiology including fluoroscopy can help in the assessment of pulmonary function. Bjorkman et al. (1955) advocated using both procedures to observe the mobility of the diaphragm, to detect the presence of pleural thickening particularly at the costo-phrenic sulci, to see whether there were any spinal deformities, and to indicate the possible occurrence of broncho-stenosis or bronchiectasis. Any of these abnormalities can produce severe functional impairment. Warring (1949) considered fluoroscopy of immense value in detecting any mediastinal or cardiac displacement, and also in demonstrating "air trapping" in a lobe or lung, indicative of obstructive emphysema. Films taken on inspiration and on expiration, combined with careful screening of the patient, can give an approximate estimate of the amount of expansion of which each lung is capable, and in this way help in judging crudely respiratory function (Cohen and Goffen, 1951). Bronchography can act as a useful adjunct in establishing the presence of any bronchiectasis or broncho-stenosis, in addition to which it may depict emphysema of a lobe or segment of lung, where the draining bronchi are seen to be abnormally splayed.

Vaccarezza et al. (1947), however, mentioned discrepancies between their findings derived from clinical and radiological examination and those arrived at by bronchospirometry. In this present series the radiological and bronchospirometric readings in the majority of cases have been very much in accord. So much is this so that radiological appearances are taken into account in estimating pulmonary function in every case considered for operation. By means of X-rays a rough guide as to reduction of function in one or both lungs can be obtained, although only by bronchospirometry and overall lung function tests can a more accurate appraisal of respiratory capacity be obtained, and the exact contribution by each lung be noted.

A very refined form of radiological technique for studying the function of the lung remaining after pneumonectomy is that of angiocardiography, as described in 1948 by Neuhof and Nabatoff. They found this method of value in elucidating the presence of either any gross emphysema of the remaining lung, or any marked displacement of the mediastrium and great vessels, simply by noting the size and distribution of the vascular pattern in the lung as portrayed by the angiocardiograms.

2. Preparatory Postural Drainage, Antibiotic Cover, and Antispasmodics.

In cases with copious sputum the use of postural drainage for several days before carrying out bronchospirometry can mean all the difference between obtaining satisfactory readings and not. Gebauer (1939) was the first author to emphasise how important it was as a preparatory measure. It is quite easy to envisage how thick, viscid sputum or plentiful secretions can lead to partial blockage of one or both lumina of the catheter, this in turn producing inaccurate and often misleading results, quite apart from the alarm and distress occasioned to the patient.

The method of postural drainage used in these cases is exactly identical with that used for bronchiectasis. The patient is placed on the Nelson bed, and tipped so that the part of the lobe or lung to be drained is uppermost, a physiotherapist or trained nurse being in attendance. Pursued diligently for 20 minutes each morning for three or four days before bronchospirometry, the bronchial tree can be made reasonably dry by this means, and the examination conducted with the minimum discomfort to the patient and with the certainty of obtaining satisfactory readings.

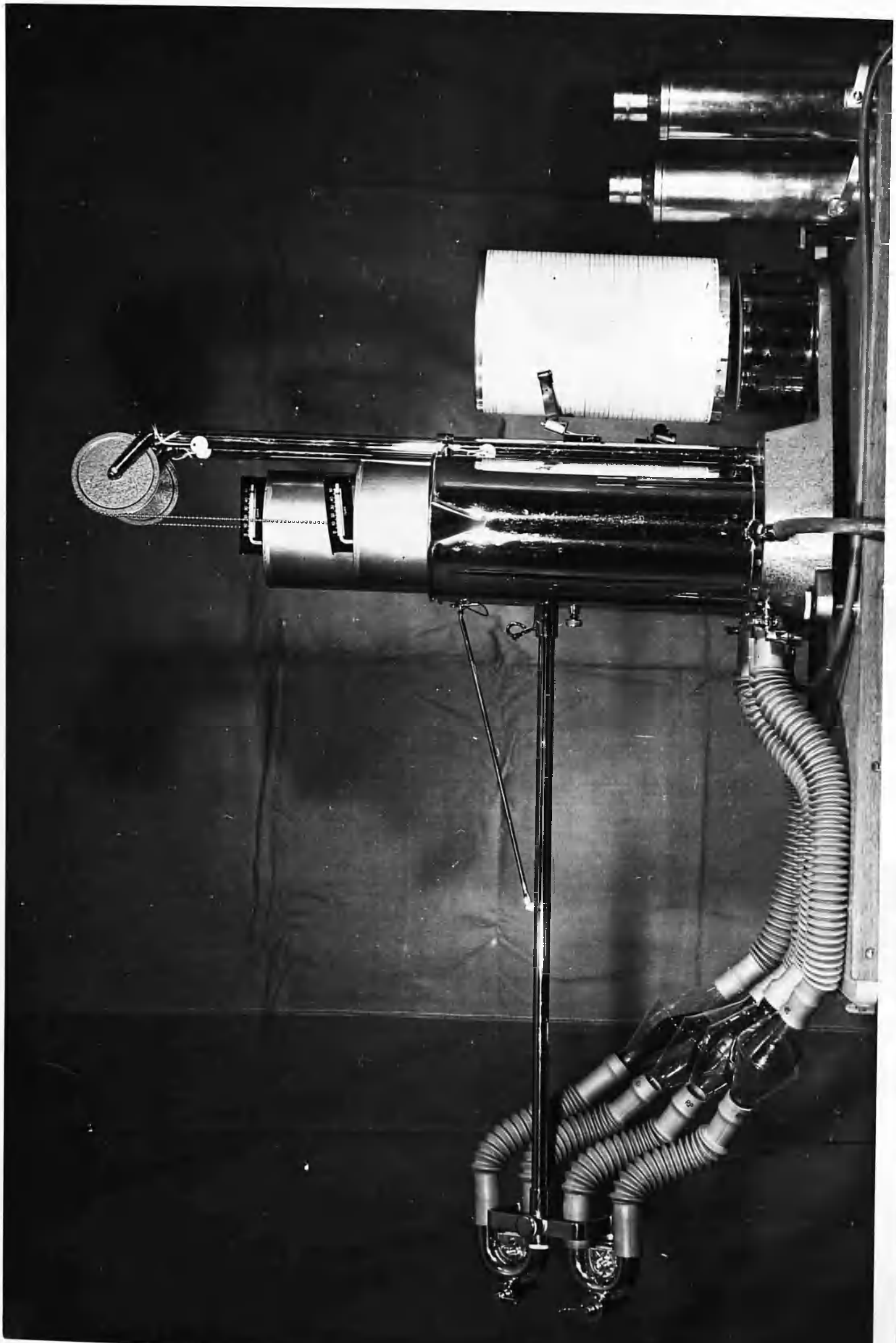
In addition to postural drainage in cases with very copious sputum, whether this be due to excavated tuberculosis, true bronchiectasis, or bronchostenosis with retained secretions, it is often advantageous to administer antibiotic cover for bronchospirometry. Tuberculous patients are usually having specific anti-tuberculous drugs, such as a combination of streptomycin with para-amino-salicylic acid (P.A.S.), or ioniazed with P.A.S.; but where there are pyogenic organisms present in the sputum, too, and in non-tuberculous cases, the antibiotic of choice is tetracycline because of its wide spectrum. The present author, however, prefers reserving such therapy for the very occasional case that develops a bronchitis or respiratory infection following bronchospirometry. Complete bacteriological investigation of the sputum with antibiotic-sensitivity tests in such a case ensures the administration of the most effective therapeutic drug. By this means the giving of expensive drugs indiscriminately to every patient with productive cough underoing bronchospirometry is avoided, and the unpleasant side effects that may occur rarely with these drugs (such as diarrhoea and vomiting, and even a staphylococcus aureus enteritis with oxytetracycline) are reduced to a minimum.

Bronchospirometry can be accomplished successfully in patients with a tendency to bronchitis or bronchospasm by giving an antispasmodic 30 minutes before the examination. Ephedrine in the dosage of one grain has been found very effective in this series. Asthmatic subjects are prepared in the same manner, an "Agla" spray containing neo-epinine being used in addition just before the actual insertion of the catheter. Very infrequently has it been necessary to supplement these measures with 1 : 1,000 adrenaline given subcutaneously if bronchospasm recurs during the procedure.

3. Pre-Medication Used.

Initially the premedication adopted in otherwise healthy young subjects in this series consisted of one-and-a-half grains of nembutal one hour beforehand, followed by one-third of a grain of omnopon and 1/150th of a grain of scopolamine 30 minutes later. However, experience with this moderately heavy basal sedation led to the introduction of a modified pre-medication shortly afterwards. The effect of scopolamine in many cases was to potentiate the action of omnopon, resulting in quite marked respiratory depression and an extremely somnolent patient. A true assessment of the patient's respiratory capacity manifestly could not be effected in such circumstances, and the danger of secretions accumulating and not being expectorated effectively was increased manifoldly. Accordingly, the present regime used in all cases consists of nembutal given at the same time and in the same dosage as previously, but in place of omnopon and scopolamine, omnopon grain one-sixth with atropine grain 1/100 is substituted. Very little in the way of respiratory depression occurs with this scheme, and the patient is sufficiently drowsy for the keen edge to be taken off his

PHOTOGRAPH OF APPARATUS
KENDRICK TWINSPIROMETER, KYMOGRAPH, AND TWO INLET AND OUTLET VALVE



apprehension. The examination can be conducted expeditiously, and with little danger of secretions being retained after the investigation is completed.

4. Description of Apparatus Used.

The apparatus used comprises two Benedict-Roth type of spirometer systems (Kendrick twinspirometer), each equipped with an inlet and outlet one-way valve and a canister containing soda lime for carbon dioxide absorption. There is a common recording kymograph for the two spirometers. An interconnecting tube conveys oxygen from a nearby oxygen cylinder on a small mobile stand to each spirometer system as required. Each spirometer consists of an inner chamber containing the canister for carbon dioxide absorption and an outer container which fits over the chamber. The space between the container and the wall of the spirometer is filled with water up to the spout when the apparatus is being assembled for use, and then oxygen is conveyed to each spirometer till the outer container is almost completely filled with oxygen. The recording pen of each system is filled with ink, a bronchospirometry chart placed on the kymograph, and the apparatus is ready for use. In this series red ink is used for the left side of the circuit, corresponding to the left lung, and black ink for the right. This makes comparison of the two sides easier at a quick glance, before actually calculating the exact percentage contributions of each lung.

Such a circuit as described is a closed one, the patient breathing pure oxygen during the entire period he is connected to the apparatus, the carbon dioxide in the expired air being absorbed in the soda-lime canister. As the oxygen in each spirometer system is used, the level of the recording-pen rises on the chart in relation to the quantity of oxygen used. The quantity of oxygen in millilitres used by each lung over the period of a minute can be recorded on the revolving kymograph.

In addition to the equipment discussed already, there are various lengths of rubber or polythene connecting pieces by which the twinspirometer system is attached to the catheter, once this has been introduced down the trachea and is fixed in position. For measuring the combined vital capacity of both lungs externally, a single rubber tube with a Y-connection to both spirometers is used. With a nose clip in place, the patient breathes through this tube held in his mouth. The reason for using both spirometers for measuring the external vital capacity of both lungs is that in the apparatus used in this series the capacity of each spirometer is only 2,250 ml. The kymograph itself is driven by a clockwork motor, and although several types of kymographs are available with a range of speed varying from 40 to 800 millimetres per minute, the one used in this series has only one speed.

The canisters containing the soda-lime require changing every 40 to 50 examinations, each examination lasting approximately seven to ten minutes. Sterilization of the various components of the apparatus presented some difficulties at the commencement.

Boiling for five minutes is quite adequate for the rubber and metallic parts, not so for the catheters, as boiling is apt to lead to distortion of the tube and the rubber balloons becoming perished. The catheters hence after use are washed carefully with ordinary soap and water, dried thoroughly, and then placed in a formalin-vapour container for 36 to 48 hours. This method of sterilization was proven to be very effective and quite reliable by Dr. Bruce, Consultant Bacteriologist to Mearnskirk Hospital by the following procedure. After the catheters had been washed and dried, swabs were taken from them before putting them in the formalin-vapour sterilizer, and a second series of swabs was taken from the catheters on their withdrawal from the sterilizer after a period of 36 hours. Although there was an occasional colony of bacteria grown from the swabs taken prior to immersion of the catheters in the sterilizer, in no instance did any organisms grow on culture from swabs taken from the catheters after 36 hours sojourn in the formalin-vapour container. As an additional test of the efficacy of this method of sterilization, a colony of bacteria plated in a tube was placed in the formalin-vapour container for 36 hours, and on removal from the container no organisms could be isolated from the tube either on direct examination or on culture.

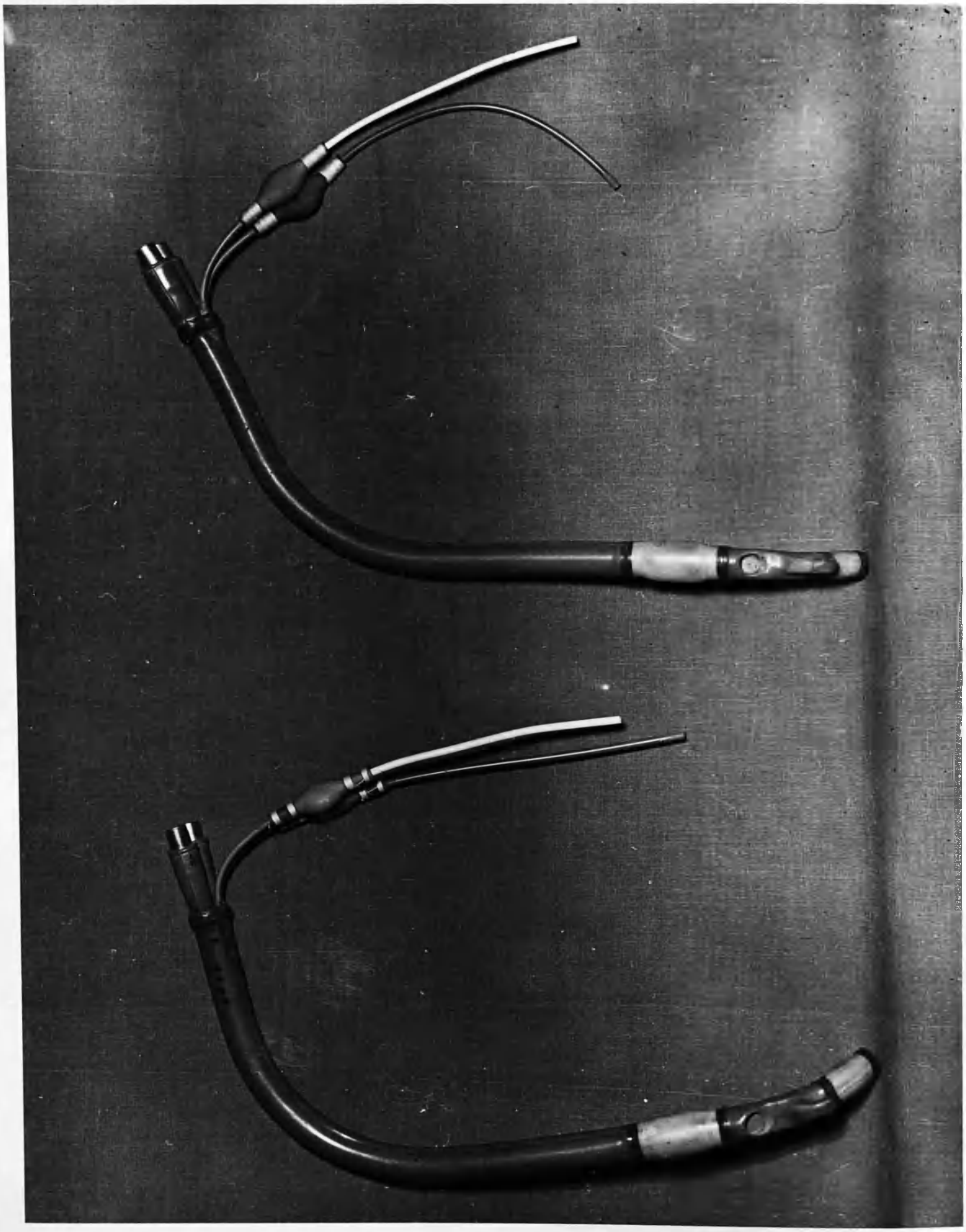
5. Various Types of Catheters Available.

The types of tubes available for bronchospirometry have all been referred to in Chapter II. The two types used in the present series (namely the Carlens and Marsh tubes) are described in full below, a brief reference being given to the others in passing.

The first tube used for bronchospirometry in man was that devised by Bjorkman (1934), this consisting of a double-lumen metal bronchoscope designed specifically for the analysis of differential lung function. The main defect of this tube was quite obviously its rigidity, which made the examination rather unpleasant for the patient.

Gebauer (1939) and Zavod (1940) introduced flexible double-lumen catheters, but in these tubes air resistance was especially prominent, resulting in somewhat inaccurate readings. The necessity for introducing either of these catheters under fluoroscopic control, the difficulty encountered in placing the tube in the left main bronchus when the trachea was distorted in any way, and the ease with which the narrow lumina of these catheters could be obstructed by sputum, all contributed to a search for a better type of tube.

In 1948 Norris et al. attempted to overcome the hindrances associated with "stenosis breathing" through narrow channels by using an endobronchial catheter with a single, wide lumen and a distal inflatable cuff. This tube was placed in position in the left main bronchus under fluoroscopic guidance, its lumen providing an airway to the left lung and that alone. Air-exchange to the right lung was maintained through the larynx,



Carlens Catheter, Male on left, Female on right.

outside and around the catheter. The oral part of the catheter was brought out through a Connell mask and through a rubber diaphragm in one arm of a Heindenbrinck Y-connector.

Carlens (1949) devised a catheter which did not require X-ray screening for its insertion, and in which there was minimal air resistance or "stenosis breathing", This is the one used widely in most respiratory function centres now, and was used for half of the number of examinations in the present series. The catheter is flexible, has a double-lumen, and is made of rubber with the same consistency as an ordinary rubber urethral catheter. There is a small hook at the distal end, which is automatically engaged by the carina when the tube is being inserted down the trachea into the left main bronchus, and this hook anchors the tube on the carina. There are two inflatable cuffs, one situated at the tip proximal to the opening for the left main bronchus, the other proximal to the opening for the right main bronchus and lying low down in the trachea when the tube is in position. When inflated these balloons ensure that no air can escape up the trachea outside the catheter, nor can any be shunted from the left to the right main bronchus. The catheter tip is curved to the left, ensuring that it enters without fail the left main bronchus, and thus obviates the need to screen the patient during intubation. However, fluoroscopy still remains an important supplement in the estimation of lung function. One additional feature is that there are two small external balloons, fitted on to the rubber capillaries, which are used for inflation of the cuffs on the catheter. The purpose of these external balloons is to act as controls in judging the pressure required to distend the cuffs to the optimum level and also to detect any air leaks.

The Carlens tube is supplied in two sizes, one for male patients, the other for female. The tubes are equal in length and similar in every way, except that the female one has a smaller diameter (each channel in the latter having a diameter of six millimetres, that of the male being eight millimetres, which is identical with the diameter of the single-lumen tube of Norris and his associates). Introduced with adequate skill and with suitable topical anaesthesia, the insertion of the Carlens catheter causes minimal discomfort to the patient, and as air resistance is almost negligible with it, the tube can be used in dyspnoeic patients without causing any untoward events. Because of its flexibility and of its being made of rubber, the catheter may be left in position for up to 20 minutes, if need be, to complete the examination. This allows readings to be taken both at rest and on exercise (Bjorkman and Carlens, 1951; Inada et al., 1954), and also with one bronchus occluded (Jacobaeus and Bruce, 1940), without unduly disturbing the patient.

Marsh in 1953 modified the Carlens tube in several ways, claiming several advantages for his new tube. The over-all measurements are precisely the same, but the tube is made of latex material in preference to rubber, as the latex is more malleable. A wiral spiral is incorporated in the whole length of the tube, the tube itself being easily visible on screening due to the presence of radiopaque material at the level of the two cuffs and at the tip.

In the present series the Marsh tube has been used in over 150 examinations, as has the Carlens, and it has been the author's experience that the Carlens variety is superior in every respect to its counterpart. It is much more durable, and does not lose its shape as the Marsh one does with continued use. Fluoroscopic control is necessary for insertion of the Marsh catheter, and even so it is sometimes difficult to ascertain which bronchus the tip has entered. When the hook near the tip of the Carlens catheter engages the carina, the tube is thereby fixed in position; with the Marsh variety the hook on occasion may fail to engage the carina, and the tip may descend farther down the bronchus than intended, which may produce false readings. For these reasons the Marsh tube is no longer used in Mearnskirk, the Carlens one being employed now for every bronchospirometric examination.

6. <u>Description of Method of Intubation.</u>

It is the habit of several investigators to carry out preliminary bronchography or bronchoscopy or both prior to embarking on bronchospirometry on their patients (Gebauer, 1939; Donald, 1952; Gaensler et al., 1953). Their main object in so doing is to exclude gross bronchostenosis, tuberculous endobronchitis, and any marked distortion or deformity of the trachea, any of which can vitiate the value to be derived from bronchospirometry. However, it is the present author's contention that careful study of the patients' X-rays reveals any deformity of the trachea, and the presence of significant endobronchitis can be detected by the presence of a "tension cavity" radiologically, or clinically by a persistent, irritable cough associated with a localised "wheeze". Such manifestations usually preclude the performance of bronchospirometry until appropriate drug therapy has effected healing of the endobroncitis. Bronchoscopy is accordingly not carried out routinely before bronchospirometry in this unit; but in all cases of bronchial carcinoma bronchoscopy manifestly must be done for the dual purpose of confirming the diagnosis and of determining whether the tumour is operable or not.

A special room has been set aside in the hospital for performing bronchospirometric examination. There is a small fluoroscopic unit conveniently situated in an adjacent room, and although the Carlens catheter dispenses with the necessity for screening the patient during insertion of the catheter, it is very useful to be able to screen the patient before inserting the catheter. From such screening, information regarding diaphragmatic excursion on both sides, the amount of expansion of both lungs, and the presence of any scoliosis of the spine can be derived. Considering how long it takes to prepare the apparatus for use, it is more convenient to carry out broncho-spirometry on three patients at each session.

Once the circuit is set up and ready, the patient, suitably premedicated, is brought in from an adjoining room. The pre-medication as stated above is not heavy, sufficing to remove the patient's apprehension but not his ability to co-operate fully during the entire procedure. With the patient seated, the preparation of his mouth, throat, larynx, and trachea is commenced. For this purpose a solution of one per cent. amethocaine is used, this being the standard preparation used both for bronchoscopy and bronchography in addition to bronchospirometry in Mearnskirk. A two per cent. solution of the same topical anaesthetic is more liable to produce unwanted side-effects, such as sickness and syncope, in susceptible patients. With the half-strength preparation only twice have toxic symptoms been encountered in over 1,000 instances of its use. Xylocaine, the most recent local anaesthetic available, is reputed to possess little or nothing in the way of side-effects, and to produce its desired effect in a very short time. However much the advocates of xylocaine stress its value in bronchoscopy and bronchography, its action is too brief for the preparation of a case for bronchospirometry, where the examination may last up to 20 minutes.

The patient's mouth, tongue, tonsillar fossae, posterior pharyngeal wall, epiglottis, and larynx are sprayed in that sequence with a fine jet of the local anaesthetic till they are adequately anaesthetized. Next the trachea, carina, and major bronchi are prepared by instillation of the amethocaine over the back of the fauces, the tongue being held forward to prevent the patient swallowing, and the patient being inclined to the left while this is being done. This ensures proper anaesthetization of the carina and the commencement of the left main bronchus into which the tip of the catheter is to be introduced.

A metal stylet is then inserted into the bronchial lumen of the catheter to aid its passage through the cords. Carlens (1949) guided the catheter through the vocal cords by means of a laryngoscopic mirror, but the present author prefers to employ a Magill laryngoscope. The patient is placed comfortably on a couch in the supine position, with his neck fully extended (as for bronchoscopy) and his mouth wide open. His tongue being gently pulled forward, the blade of the laryngoscope, suitably lubricated with "KY jelly", is passed into the patient's mouth, over the back of the throat, under the epiglottis, and then gently levered upwards till a clear view of the cords is seen. The catheter, also lubricated with jelly, with the tip pointing uppermost, is next eased along the blade of the larynoscope, and passes through the larynx and cords. At this point the laryngoscope is withdrawn, and the stylet removed from the lumen of the catheter. The tube is turned 90 degrees in an anticlockwise direction so that the tip points to the left, and then the tube is gently pushed down the trachea till the hook engages in the carina. This stage is easily detectable, because further descent of the tube is prevented once the hook is fixed. The tip of the catheter now lies in the commencement of the left main bronchus.

With adequate local anaesthesia intubation can be accomplished with very little discomfort to the patient, although occasionally either passage of the tube through the cords or engagement of the hook by the carina may induce a spasm of coughing for a short period. Once the tube is in position, the cuffs are inflated by means of a syringe attached to the capillary air leads, the small external balloons on the leads acting as controls to the amount of air required to distend the cuffs to the correct degree. The capillary air leads are clamped by forceps when this point is reached.

Finally the breathing channels of the catheter are connected to the twinspirometer, the patient is allowed to settle for a minute or two, and then the kymograph is set in motion, and the tracing recorded.

7. <u>Technical Difficulties.</u>

The more experienced the operator is in intubation generally, the less likely is he to encounter the difficulties now to be mentioned during bronchospirometry. The technique certainly requires a little more adeptness than for bronchoscopy, but this can be achieved quite quickly, particularly if the operator displays patience and gains the full confidence and co-operation of the patient.

One of the main stumbling-blocks is presented in young individuals with a complete set of teeth and a very tight jaw, particularly if in addition the mouth is proportionately small in size. Sometimes reassuring the patient and proceeding very slowly and gently enables a successful outcome to be attained in these cases, but in some it is simply impossible to carry out the examination on this account. That has been the experience in this series, although surprisingly enough previous reports have failed to record this triad as being a cogent reason for non-success in bronchospirometry.

Another barrier to success may be met with in females of small or slight build who possess a very small larynx. This difficulty has occurred 12 times in the present series; on each occasion the tip of the catheter seemed to have passed through the cords, but farther downward progress was arrested by the cords gripping the catheter just proximal to the tip. To apply force in these cases in an attempt to force the catheter through may damage the cords, and the wisest policy in such instances is to withdraw the catheter, and abandon the procedure altogether. A point of interest is that the 12 cases mentioned all occurred while using the Marsh tube, and since switching over to the Carlens this difficulty has not been encountered. Steele in 1943 mentioned that inability to gain adequate exposure of the larynx might prevent passage of the tube, but this has not been met with in the present series.

When there are copious secretions, one or both channels of the catheter may become blocked, contributing to either poor or completely fallacious readings. However, careful preparation beforehand (with particular reference to postural drainage as already described) will overcome this difficulty.

Tracheal distortion or deformity of any marked degree may present quite a difficult problem during bronchospirometry. Some authors go so far as to stipulate that it contra-indicates the examination altogether (Steele, 1943; Donald, 1952). However, it is very often these cases with tracheal distortion who are the ones par excellence that require lung function studies in judging fitness for operation. It has been the experience of the present author that with patience successful readings can be achieved in such individuals. Similarly cases presenting with stenosis of the left main bronchus, or with tumour tissue protruding from the left upper lobe orifice and growing into the main bronchus with almost complete atelectasis of the lung distally, do not necessarily preclude successful and useful bronchospirometric readings.

Faulty positioning of the catheter tip or insufficient distension of the cuffs on the tube can produce shunting of air from one lung to the other. This can be recognised quite readily when one side appears to take up oxygen very rapidly and steeply with a corresponding fall in the level of the cylinder, while the opposite side appears to give out oxygen with a rise in the level of the cylinder. Righting the position of the catheter, or inflating the cuffs more fully, soon overcomes this difficulty.

Bronchospirometry can be carried out successfully in patients subject to bronchospasm and asthmatic attacks, provided suitable preparation is carried out beforehand, as discussed already. However, even with the most careful preparation, a true asthmatic attack may occur during the examination. This will be dealt with more fully in the chapter devoted to complications.

8. Number of Failures in this Series.

Out of a total of 316 examinations there were altogether 34 failures. Although this may appear an unduly high failure rate, the causes of such non-success must be tabulated and discussed. (See Table VI).

Causes of Failure (Table VI).

Tight Jaw with full set of teeth.	Narrow Larynx.	Bronchitis.	Apprehension.	Tracheal Distortion.	Total.
16	12	1	2	3	34

Most of the failures in this series were due to a tight, unrelaxed jaw with a full set of teeth (16 cases). This difficulty has been alluded to previously. A narrow larynx with tight vocal cords accounted for 12 failures, all of whom were in females. The single case included under bronchitis was unsuccessful on account of uncontrollable cough and frothy sputum during the procedure. After appropriate drug therapy combined with more intensive preparation, in the way of postural drainage and antispasmodics, bronchospirometry was accomplished successfully on the second attempt. Apprehension prevented the investigation being carried out in two patients, the first being a girl of 19 years in whom bronchospirometry was not absolutely necessary in helping to decide her operative therapy, the other was a male patient in whom bronchospirometry was repeated at a later date without any hindrance whatever. Tracheal distortion made it impossible to obtain any informative readings of any description in three cases in the present series, despite frequent manipulation and change in position of the catheter. Several authors, as mentioned previously, consider tracheal distortion as an absolute contra-indication to bronchospirometry (Steele, 1943; Donald, 1952), but many cases with this deformity have been done successfully in the present series.

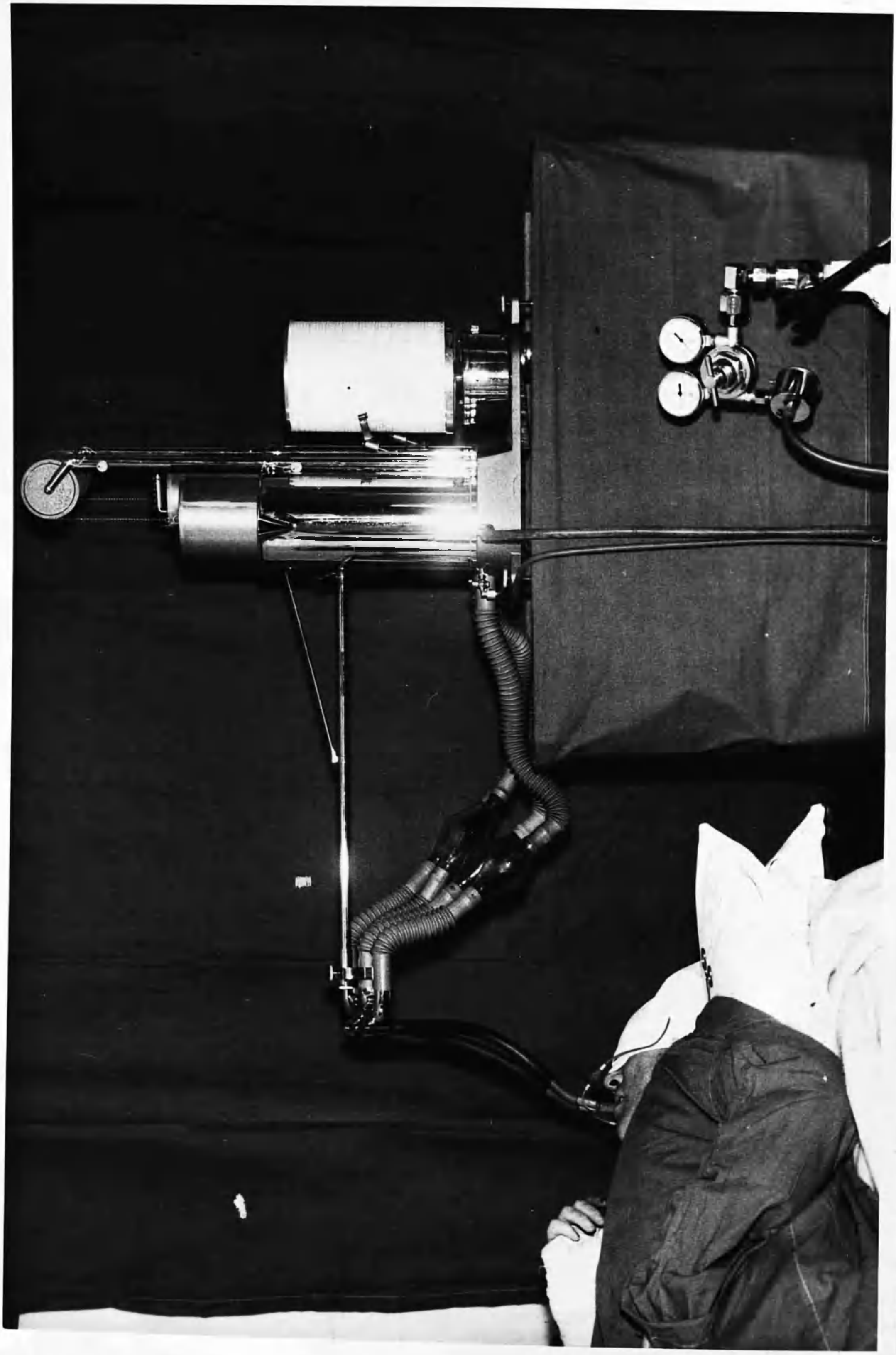
Most of the failures due to a tight jaw and a full set of teeth occurred early in the series, as did those due to a narrow larynx. Manifestly inexperience in the technique of intubation accounted largely for these 28 cases. Another factor, in addition, was that in these cases Marsh's catheter was used, and in no case since using the Carlens' one have these difficulties arisen. With the Marsh catheter the method of sterilization employed previously was boiling for three minutes, and this ultimately resulted in the tube losing its shape and becoming far too pliable owing tothe latex material wearing thin. The method of sterilizing the Carlens' one, as mentioned previously, consists of 36 hours' immersion in a formalin-vapour container, and the tube retains its normal shape and resilience indefinitely. This has virtually counter-acted this difficulty.

Finally before leaving the discussion on the number of failures, it must be admitted that there were four patients who refused bronchospirometry after operation. Three were males, one female, and they had had bronchospirometry carried out pre-operatively. All were of rather nervous disposition, and were done early in the series when the technique of intubation was being mastered. It is small wonder they did not relish having the examination repeated after operation. However, there have been no other refusals for repeat bronchospirometry, possibly due to the examination now being carried out far more expeditiously, and with little or no disturbance to the patient.

C. DESCRIPTION OF READINGS OBTAINED AND THEIR VALUE AND APPLICATION CLINICALLY.

The readings obtained during bronchospirometry comprise the tidal air or ventilation, oxygen uptake (measured over a period of one minute), and the vital capacity of each lung. These are

Photograph showing the patient connected to the apparatus.



recorded simultaneously on the kymograph by the two pens attached to the twinspirometer circuit.

The catheter having been properly sited, with the hook engaged in the carina, the external (control) balloons are inflated to the level necessary to distend the cuffs sufficiently. Several minutes are allowed to pass after this before any readings are taken, to let the patient's respiration return to its normal level. Then, with the patient breathing quietly and evenly, the kymograph is switched on, and the breathing channels of the catheter are connected to the twinspirometer. Each upward stroke of the pen records the inspiratory phase of respiration, the downward stroke the expiratory phase.

The bronchospirometric chart is divided by vertical lines into minute intervals, the distance between each vertical line being traversed by the pen in one minute exactly when the kymograph is set in motion. Horizontal lines, in turn, mark off each 250 millilitres of volume, with further subdivisions into 50 millilitres. The chart used in this series measures a total of 2,250 millilitres capacity.

As the drum revolves slowly and respiration is recorded on the tracing, over the space of one minute the reading climbs upwards, indicating consumption of oxygen by the lung on that side (as for a simple basal metabolic estimation). The volume of oxygen uptake per minute can be calculated easily from the tracing. After two minutes' recording of quiet respiration, the patient is instructed to take a maximal inspiration, followed by a maximal expiration. This represents the vital capacity of each lung. These readings for tidal air, oxygen uptake, and vital capacity are expressed as percentages of the total. Normally the right lung contributes 53-54 per cent. of total pulmonary function, the left 46-47 per cent. (Frenckner and Bjorkman, 1936; Gebauer, 1939). This has been attributed, rightly enough, to the fact that anatomically and physiologically the right lung has a greater volume than the left.

When satisfactory readings have been obtained in as near basal conditions as can be envisaged during bronchospirometry, in cases for proposed pneumonectomy the breathing channel from the lung to be resected is clamped off simply by means of a pair of forceps (after the manner proposed by Jacobaeus and Bruce in 1940). The patient is duly instructed to signify by raising his right hand if he experiences any discomfort or tightness in his chest during the manoeuvre, a watchful eye in the meantime being kept on the patient's colour and respiration. Any objective data, such as cyanosis or tachypnoea, are noted, and if the patient indicates that he is becoming definitely distressed, the forceps are removed from the channel, and the patient is allowed to breathe pure oxygen from the twinspirometer for a short period. The occurrence of cyanosis or dyspnoea on blockage of one bronchus during bronchospirometry would tend to vitiate pneumonectomy, and in tuberculous subjects more conservative collapse surgery would appear preferable. Conversely, if the patient breathes quite undisturbed over the space of one to two minutes with one bronchus occluded, it would seem feasible to consider justifiably the question of pneumonectomy.

However, it must be remembered that although ventilation of one lung is suspended when its bronchus is blocked, circulation of pulmonary artery blood through the lung continues. Experience has demonstrated that the findings at bronchospirometry correspond fairly closely with both the operative and post-operative conditions and courses in these patients - that is, where no disturbance occurs on occlusion of one bronchus during bronchospirometry, pneumonectomy is accomplished successfully and the post-operative course is uneventful, barring any complications.

Bronchospirometry gives a percentage value only for the function of each lung, not an absolute value, and thus overall lung function must be estimated concordantly with bronchospirometry. In some cases of bilateral disease the percentage values of each lung may remain unchanged, but total ventilatory capacity (as expressed by the combined vital capacity and the maximum ventilatory capacity) may show a substantial reduction. Conversely, one lung may contribute as much as 90 per cent. of total lung function, the contralateral one only 10 per cent. or even a smaller amount. This may occur in a lung with extensive tuberculosis, particularly if there is additionally gross bronchostenosis. Such a lung is usually encased in a layer of pleura as much as one to two inches in thickness. Between these extremes, there are innumerable variations, depending on the effects of parenchysmal disease, pleural complications (whether the effusion arises spontaneously or as a complication of pneumothorax therapy), bronchial disease (particularly if there is marked bronchostenosis), and pulmonary arterial obstruction (Gaensler et al., 1953). These authors showed that parenchymal disease had to be very extensive before it produced any marked impairment of function, but when it did so ventilation and oxygen uptake were affected equally. Pleural disease could produce very marked reduction in function, more so in relation to the oxygen consumption. They showed that with bronchial disease the effect of function depended largely on the cause and severity of the bronchial obstruction. With almost total bronchial occlusion by, for example, a tumour, the affected lung might not record any ventilation or oxygen uptake on quiet respiration, but on forced inspiration (as for a vital capacity reading) some air might be drawn past the obstruction, and expelled on forced expiration.

When the pulmonary artery of one lung is absent (as a rare congenital anomaly) or else has been ligated during operation, little or no oxygen uptake takes place on the affected side, although ventilation may still occur.

Bjorkman and Carlens (1951) described an exercise test which they performed during bronchospirometry, and the present author utilizes this test in patients whose respiratory capacity is at all suspect. It is done after the readings described above have been obtained, and for this purpose a bicycle ergometer is required. The patient pedals on the ergometer for 90 seconds, then the breathing channels of the catheter are re-connected to the twinspirometer circuit while the patient continues to pedal, and a reading is taken of the oxygen consumption by each lung during exercise. Bjorkman and Carlens expected to find that in a lung extensively involved by tuberculosis, cancer, or bronchiectasis, with minimal oxygen uptake at rest, there would be little or no increase in the oxygen uptake on exercise; while the better-functioning lung would augment its uptake very substantially. However, contrary to their expectations, their results showed quite clearly that the percentage of oxygen consumption by each lung remained the same both at rest and on exercise, which meant that the blood flow to the lung with the poorer function increased with exercise proportionate to the augmentation of the circulation in the healthy lung. Even when the oxygen consumption was enhanced by moderately severe exercise to the extent of 555 per cent. of the value at rest, the relative percentages of both lungs remained the same.

Since both the inferior and the healthy lungs augment their uptake of oxygen on exercise relative to the resting values, it might appear pointless to make the patient exert himself on the ergometer during bronchospirometry. However, in this series the test has proved of value in estimating the exercise tolerance in those with low respiratory reserve. If cyanosis or marked dyspnoea become manifest during the course of the test, the exercise is stopped. Such cases, particularly in combination with a low overall respiratory function, are regarded as poor risks for major thoracic surgery.

An interesting bronchospirometric study, though not of any great practical importance, was made by Rothstein and Landis (1950). Readings were taken from 11 patients in the supine position, and then separately in both lateral decubitus positions. Oxygen consumption was increased by as much as 34 per cent. in the left lateral decubitus position, as opposed to the supine one. This they attributed to the under lung in each instance absorbing more oxygen, probably due to the blood flow to this lung being augmented simply from a mechanical, gravitational effect. A slight rise was found in the value for the total tidal air in the decubitus position, though the vital capacity, strangely enough, showed no alteration with any change in position.

On completion of the exercise test in cases where this is indicated in the present series, the balloons on the catheter are deflated, and the catheter itself is then withdrawn. The patient is made to sit up, and cough up any sputum or secretions that have accumulated. Then external spirometry, comprising the combined vital capacity of both lungs together with the maximum ventilatory capacity (M.V.C.), is carried out. For this purpose the patient's nose is occluded by a simple nasal clip, and he breathes through a tube, held in his mouth, which is connected to both spirometers by means of the Y-tube already mentioned. He is instructed to breathe quietly at first through the tube until he becomes accustomed to it, and then with the kymograph set in motion he takes a maximum inspiration followed by a maximal expiration. This is repeated three times, the highest reading being taken as the vital capacity.

The fallacies attached to the vital capacity as an index of ventilatory function have already been alluded to in the opening section of this chapter, and several authors have been most emphatic about its very limited value (Baldwin et al., 1949; Berke et al., 1952; Bjork, 1953). As Maier (1949) pointed out, the vital capacity is the amount of air which can be displaced by both lungs during a single maximal ventilatory effort, and it neither takes cognizance of the time factor, nor does it supply any information concerning the patient's ability to transport oxygen from the alveoli to the blood in the pulmonary capillaries. A patient with fairly advanced pulmonary emphysema, and who becomes dyspnoeic on the slightest exertion, may still manage to muster a vital capacity of 3,000 millilitres or above.

A much more reliable and accurate portrayal of ventilatory function is given by the maximum ventilatory capacity (M.V.C.). As stated earlier, it is the practice of the present author to tell the patient to breathe as deeply as possible at a rate of 60 breaths per minute over a period of 30 seconds, and the summation of these 30 maximal breaths multiplied by two represents the M.V.C. It is expressed in litres per minute at a respiratory rate of sixty.

Various disadvantages and potential hazards have been attributed to the M.V.C., such as the difficulty in performing the test in an ill, toxic patient, and the danger of aspiration of sputum or secretions in tuberculous patients, and thus precipitating spread of the disease. Such criticisms of the test may indeed be valid, and for this reason various modifications have been suggested, and will be discussed in a later chapter. Suffice to relate at this point that in no case in this series has any untoward incident followed the test carried out as described above. Certainly it has not been done in patients who were ill or toxic, for such cases do not fall into the category suitable for surgery or medical collapse measures; and hence for the purpose of this investigation lung function studies were not required in this group of patients.

Donald (1953) predicted the M.V.C. according to age and body size, stressing that it decreased with age, and became markedly reduced in emphysema (while the vital capacity might remain normal). Bjork (1953) gave the normal values for males as 127 plus or minus 7.5 litres per minute, for femals as 102 plus or minus 4.9 litres per minute. Motley (1955) stated that an M.V.C. of less than 40 litres per minute indicated a significant degree of emphysema, as in this pathological process there is gradual loss of lung elasticity with resultant progressive impairment of the bellows action of the lungs.

D'Silva and Mendel (1950), using a Knipping type of spirometer with a six-litre bell, estimated values for the M.V.C. at rates of 30, 40, and 50 respirations per minute, and found standard values for the M.V.C. at each of these rates. The respiratory rate of 60 per minute was selected for the present series as it appeared to give the most reliable figures for the test.

Maier it was who, in 1949, showed that the pulmonary circulation and ventilation of one lung were closely correlated, the oxygen uptake by that lung representing the circulation. The results in the present series are in complete concord with those of Maier; namely that tidal air, oxygen uptake, and vital capacity are very closely related. When there is a marked reduction in either tidal air or oxygen uptake, then the other is correspondingly decreased to an almost equal amount. This is in accordance with what one would surmise to be the case, as in the following example. When a lung or a lobe becomes gradually atelectatic, there is a progressive diminution in the pulmonary blood flow through the collapsed alveoli. until ultimately when complete atelectasis is established with absence of any aeration or ventilation of the lung or lobe involved, there is complete cessation of pulmonary circulation through the part, too.

The study of the circulation through an atelectatic lung in dogs was undertaken by Bjork and Salen (1950) and in men by Bjork (1953). From their findings they concluded that atelectasis produced acutely (effected in human patients simply by blocking one lumen of the intubation catheter during operation) resulted in little or no reduction in pulmonary blood flow. This they deduced from the fact that a pronounced degree of arterial oxygen desaturation occurred following clamping of the lumen, signifying that blood must still be circulating through non-aerated lung tissue. However, the same author (Bjork) demonstrated if a lung or lobe remained collapsed for one month or over, the pulmonary circulation came into complete abeyance for all practical purposes. Gilroy et al. (1951), basing their observations like Bjork on information derived from arterial oxygen saturation levels, came to identical conclusions regarding the blood flow traversing an atelectatic lung or lobe. Bjork showed additionately that when an atelectatic lobe re-expanded completely, provided the collapse was not of too long an interval, then circulation might be re-established to the previous level in full.

Nevertheless, there are two important conditions when the oxygen uptake and ventilation of a lung may fail to be in agreement. Firstly, when one branch of the main pulmonary artery is absent (congenital, as reported by Madoff et al., 1952) or has been ligated surgically (Roh et al., 1949). In these cases normal ventilation can take place in the affected lung, but little or no oxygen uptake occurs due to the absence of a pulmonary circulation in that lung. Eventually the bronchial arteries may open up anastomotic channels with the pulmonary capillary bed on the side concerned, and thus bring about participation by that lung in gaseous exchange, including oxygen uptake, to a minimal degree.

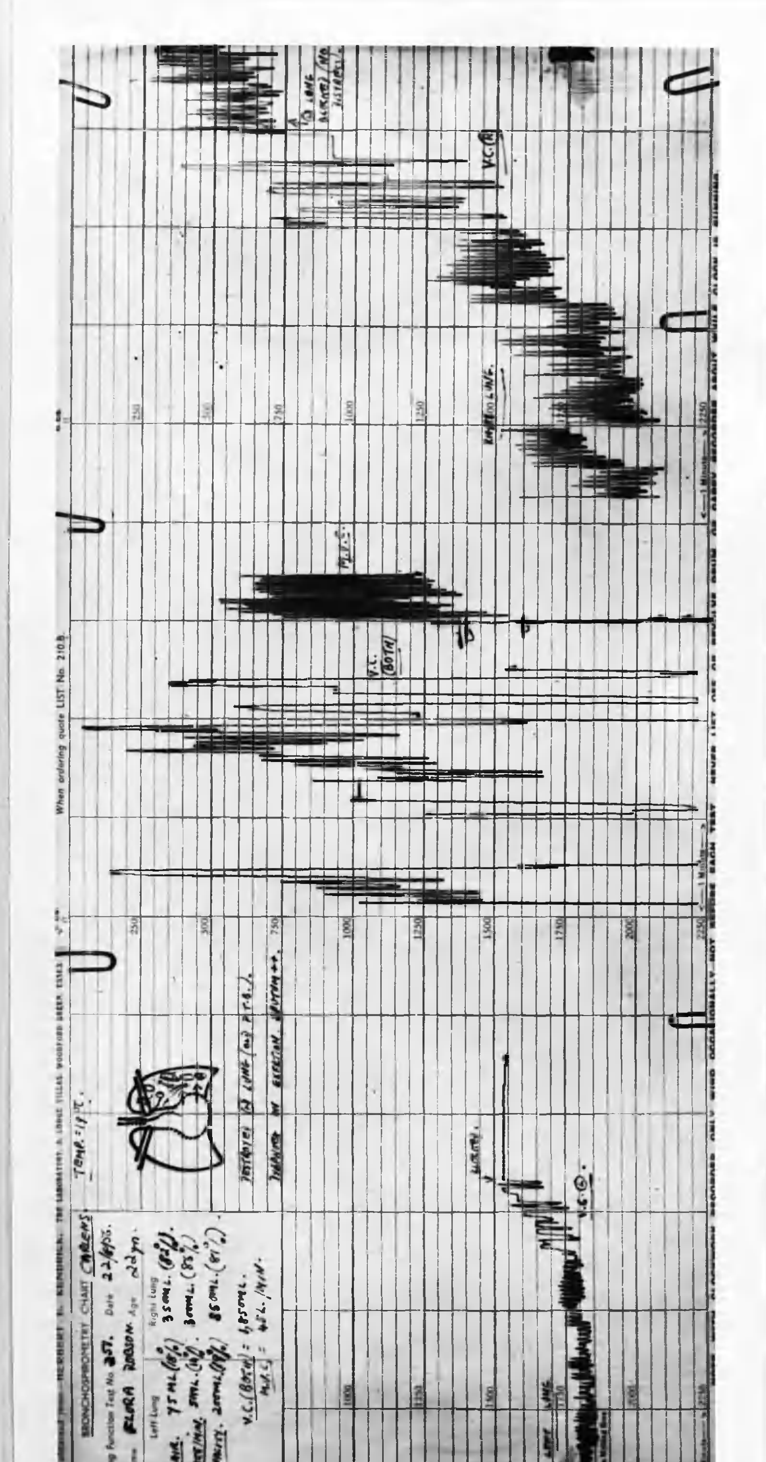
Secondly, in generalised pulmonary emohysema there may occur a marked discrepancy between ventilation and oxygen consumption in each lung individually. In the early stages of emphysema, whether it be due to tuberculosis, chronic bronchitis, pneumoconiosis, or sarcoidosis, there is widening of the alveolar spaces with stretching of the alveolar septa. With the passage of time many of the walls of the septa rupture, creating wider air spaces. With the stretching and consequent thinning of the alveolar walls, the pulmonary capillary bed in these walls becomes narrowed, with a reduction in the amount of blood circulating through the bed. Such changes taking place throughout the entire parenchyma of both lungs lead to a marked decrease in the total pulmonary capillary bed. Aeration of these widened alveolar air spaces still occurs normally, but there is lessened gaseous exchange due to the reduced capillary bed and circulation.

To retierate, bronchospirometry by itself measures only the percentage of function contributed by each lung, and apart from the vital capacity reading does not convey any absolute values. To illistruate this, one my cite the case of emphysema mentioned above, in which each lung may contribute 50 per cent. of total function with regard to ventilation, oxygen consumption, and vital capacity. Such percentage values do not, however, convey any impression of overall function, and measurement of the external combined vital capacity and the maximum ventilatory capacity must be performed for an estimate of total respiratory capacity, which in the case of moderate to severe emphysema alluded to would show a definite impairment.

In summary, then, it must be stated that bronchospirometry by itself is only one of the components necessary for the complete evaluation of respiratory function. Bronchospirometry (or internal spirometry) along with external spirometry can present together a very comprehensive picture of the ventilatory aspect of lung function, and have proved of inestimable value in the cases comprising the present series. Exercising the patient on a bicycle ergometer during internal spirometry, and noting the increase in oxygen uptake by both lungs, and the patient's response to exercise in the way of dyspnoea or cyanosis, proved a useful supplement in estimating the respiratory reserve.

Measurement of the arterial oxygen saturation at rest and on exercise, as advocated by Comroe (1951), is a useful test of alveolo-respiratory function (gaseous exchange in the lungs). For reasons already explained, it has been possible in only two cases in this series to carry out this examination, in combination with cardiac catheterization. One of these cases (Case 151) has been reported in full in the previous chapter. The other case (Case 251) was a female of 22 years with a destroyed tuberculous lung dating from childhood, and she was judged to be in the dubious category for major surgery, in the light of the bronchospirometry and external spirometry findings. Cardiac catheterization revealed a pulmonary artery pressure of 18/5 millimetres of mercury at rest, with a rise to 40/10 (mean 20) on exercise. These figures were considered within the realms of normality, arterial oxygen saturation being likewise near normal.

Operation was considered a justifiable undertaking in view of the poor prognosis without it, and accordingly removal of the offending lung was carried out. From a respiratory point of view, there was not the slightest occasion for alarm at any point in the post-operative period, but unfortunately she developed later recurrent and persistent vomiting due to renal failure with uraemia. She was treated with the usual measures for this, but developed uraemic convulsions necessitating the administration of magnesium sulphate enemata combined with heavy sedation. The convulsions were arrested fortunately very soon on this regime, and though intravenous drip therapy had to be continued for several weeks thereafter, the blood urea gradually fell to normal. This was associated with improvement in her clinical condition, and ultimately she made a complete recovery, and is now very well indeed.



CASE 251.

PRE-OP. CHART.
ALMOST FUNCTIONLESS
LEFT LUNG.

Obviously there must have been some antecedent renal disease, though the fact was not recognised before operation. Had it been, operation might possibly have been deferred. The important point, however, is that pre-operative lung function studies, including internal and external spirometry, arterial oxygen saturation, and pulmonary artery pressure at rest and on exercise, indicated that operation was feasible. That there was no concern at any time post-operatively from a respiratory point of view confirmed the pre-operative findings, and demonstrated their value.

There is no single test by which all aspects of respiratory function can be evaluated, but lung function tests can provide very helpful data with regard to assessment for operation, and the nature of the operation that is best suited to the patient's capacity.

* * * * * * *

Summary:

A brief resume of the relevant physiological aspects of lung function are presented. Respiration comprises essentially two basic components, ventilation (a mechanical function) and alveolo-respiratory function (concerned with gaseous exchange, a chemical action).

The lung volume and its components, as described first by Christie in 1932, are dealt with, and the importance of resistance breathing in relation to bronchospirometry is emphasized. This

is almost negligible with the Carlens catheter.

Clinical and radiological examination help in assessing lung function, though in rather a crude manner. Preliminary postural drainage in cases with copious secretions or purulent sputum ensures satisfactory bronchospirometric readings, while the value of light premedication is underlined. A full description of the apparatus used and of the various types of bronchial catheters available is presented. Experience shows the Carlens tube to be superior in every way to all the others. The method of intubation and the technical difficulties likely to be encountered are discussed. The number of failures and causes thereof are enumerated.

The readings obtained are described, and their clinical application indicated. Blockage of the bronchus on the side for proposed pneumonectomy forms an additional test of respiratory capacity, and the exercise test helps to elucidate respiratory reserve. The M.V.C. is regarded as a more accurate measurement of ventilatory capacity than the combined vital capacity.

Finally, two tests (arterial oxygen saturation at rest and on exercise, and pulmonary artery pressure likewise as measured by cardiac catheterization) are described which are very valuable in cases doubtful for major chest surgery.

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CHAPTER V.

COMPLICATIONS.

I. INTRODUCTORY.

II. FATALITY.

III. COMPLICATIONS IN PRESENT SERIES.

A. Occurring during performance of bronchospirometry.

1. Reactions to local anaesthetic.
2. Trauma to vocal cords.
3. Tetany.
4. Damage to teeth and gums.
5. Bronchospasm.
6. Anoxaemia and dyspnoea.

B. Occurring after completion of bronchospirometry.

1. Haemoptysis.
2. Bronchitis.
3. Re-opening of tension cavity.
4. Atelectasis of lung, lobe, or segment.
5. Spread of disease.

* * * * * * *

COMPLICATIONS.

I. Introductory.

In general the complications which may develop after bronchospirometry are very few in number, provided adequate attention is directed to preparation beforehand, and awareness of the indications and contra-indications listed in a previous chapter is borne in mind. It is quite manifest that complications are more likely to be encountered in patients with widespread disease, and in the presence of abundant secretions.

Before describing in detail those which occurred in the present series, the complications recorded by previous writers on the subject will be dealt with briefly. Pinner et al.,(1954) carried out 380 examinations with 270 satisfactory results. The undesirable effects encountered by these authors included bronchospasm, non-specific pulmonary infiltration, and a single case of alkalaemic tetany. The occurrence of the latter was occasioned by the patient hyperventilating during the entire endoscopic procedure, thus washing out large quantities of carbon dioxide from the body, which in turn brought about an alkaemia and a reduction in ionised calcium with resultant tetany. No instance of spread attributable to bronchospirometry was found by these authors.

Gaensler and Watson (1952) reported their results in a large series of 1,000 examinations, carried out over the course of four years. Very rarely did reactions (in the way of confusion, asthma, syncope) occur due to the local anaesthetic used (2 per cent. tetracaine in their cases). Local trauma to the vocal cords and to the trachea was met with on relatively few occasions, in no case being of major significance. However, nine cases out of their 1,000 developed spread of disease following bronchospirometry. Analysing these nine instances carefully, the authors concluded that in all but one the premedication was quite substantial and a long-acting local anaesthetic had been employed. Following a switch over to much lighter premedication and a shorter-acting local anaesthetic (tetracaine), only one instance of spread was noted thereafter by Gaensler and Watson. Penicillin was given prophylactically as a routine, and the importance was stressed of ensuring the re-establishment of a vigorous cough reflex as soon as possible after completion of the procedure. Bronchospirometry was implicated as a causal factor in the sole death which was met with in their series, bronchogenic spread occurring in a tuberculous patient and producing a progressive downhill trend to a fatal termination.

Jahn and Kaufman (1952) noted the complications ensuing from 219 examinations in their series, 191 out of which were cases of pulmonary tuberculosis. The main object of these authors was to detect any deleterious effect on the patient's disease, with particular reference to reactivation and dissemination of such disease. Using either a Zavod or Gebauer catheter, and keeping it in position for periods of from six to ten minutes, significant radiological changes were observed within a short period after bronchospirometry in four cases. These changes consisted of the re-opening of a closed ("blocked") tension tuberculous cavity in one case, while the other three developed definite spread of disease after bronchospirometry (a redeeming feature here was that these three had very extensive tuberculous involvement of both lungs). A transient increase in the quantity of sputum occurred in most of their patients, but this settled within the space of 24 to 36 hours. One patient developed a haemoptysis after bronchospirometry, and as the bleeding persisted, an extra-pleural pneumothorax was carried out in an effort to control it. The patient, however, died from post-operative complications. This haemoptysis was of such magnitude that it must have originated from a Rasmussen aneurysm contained in the wall of a cavity, rupture of the aneurysm being precipitated either by the trauma of the endoscopic examination or more probably by the coughing which followed the procedure.

Mild pyrexia, sore throat, and trauma to the larynx (of a very transient character) were other features noted by Jahn and Kaufman, those being more in the nature of unpleasant side-effects rather than actual complications.

Gaensler (1953) X-rayed his patients one day before carrying out bronchospirometry, one week after the procedure, and six weeks later. He concluded after careful scrutiny of all these films that "an adverse effect on the subsequent course of the disease may, in rare instances, be directly attributable to bronchospirometry, and bad results, when they occur, are not due to intubation but to excessive pre-operative medication, intensive topical anaesthesia, and inadequate post-operative care." He expounded on the latter question, showing quite clearly that the occasional unfavourable effect of tracheal intubation on the course of pulmonary tuberculosis was due not to the endoscopic examination per se but rather to the retention of purulent material, with subsequent implantation of bacillus-laden secretions in previously unaffected parts of the lung.

Fleming and West (1954), reporting the first major series of cases in this country, found no complications at all in 125 examinations. There was no instance of haemoptysis, fever, or any adverse radiological appearance, and the hoarseness and sore throat which 25 of their cases complained of lasted only one to two days.

One further possible complication not mentioned in the literature on bronchospirometry is mediastinal emphysema. This has been recorded following bronchoscopy, particularly where a bronchial biopsy has been effected, the mechanism being simply that a small leakage is produced in the bronchus at the site of biopsy or pressure by the bronchoscope. The leak permits air to escape into the mediastinium, whence it may tract into either pleural cavity creating a pneumothorax, or up into the tissues of the neck presenting there as a prominent swelling of the face and neck due to surgical emphysema. If the perforation in the bronchus is small, it usually seals off spontaneously, and the extravasated air is gradually absorbed over the course of several days. If, however, it does not seal off, air may continue to pass out into the mediastinum, producing bilateral pneumothoraces; or the air may remain confined in the mediastinum under increasing tension, and eventually cause compression of the heart and great vessels. Cardiac tamponade may ensue thereafter, due to interference with the filling of the heart, and if this is not dealt with promptly, circulatory failure and death result.

It has been the experience of the present author to encounter one case of mediastinal emphysema following bronchoscopy with a bronchial biopsy, the only instance of this complication in Mearnskirk Thoracic Unit in the many thousand bronchoscopies which have been done. The occurrence, though somewhat alarming and disturbing at the time, had a fortunate outcome in that the small perforation sealed off spontaneously, without necessitating recourse to more active measures, and the patient was fully recovered within three days.

Such a complication might conceivably follow bronchospirometry, though not so easily as after bronchoscopy with biopsy of a breaking-down bronchial carcinoma. No instance of mediastinal emphysema, however, occurred after bronchospirometry in this series.

II. Fatality.

In the literature, as mentioned above, two deaths took place which were in effect related to bronchospirometry. However, in both instances extensive pulmonary tuberculosis was present, and death due to spread or haemoptysis might have happened at any time in the course of their illness, irrespective of whether bronchospirometry had been done or not.

In the present series there have been no fatal results consequent on bronchospirometry, directly or indirectly.

III. Complications in Present Series.

Several of these have been referred to already, such as bronchospasm and damage to the vocal cords, but it is proposed to deal now with the complications and pit-falls met with in the present series, mentioning them individually and discussing them in more detail. Ways and means of preventing their happening will be presented.

A. Complications occurring during actual performance of bronchospirometry.

1. Reactions to local anaesthetic.

These comprise such minor side-effects as tachycardia, pallor, nausea, and a sensation of faintness. More alarming from the patients' point of view are actual vomiting and syncope.

Even death may occur where the patient is unduly hypersensitive to the local anaesthetic. Several patients in this series experienced minor side-effects, but in no instance was there any serious toxic reaction. This can be attributed to the use of the minimum amount of local anaesthetic necessary to obtain satisfactory anaesthesia (in most cases between 6-8 ml.), and to the use of a very dilute solution of anaesthetic (1 per cent. amethocaine).

One patient was actively sick just as the catheter was being inserted between the cords, and the examination had to be abandoned. No harm resulted, but the emesis, in retrospect, was due to over-pre-medication in this case, with the local anaesthetic as a supplementary cause. This was the only case in the whole series with a side-effect from the topical reagent of sufficient severity to necessitate cessation of the investigation.

2. Trauma to the Vocal Cords.

The majority of patients complained of sore throat or hoarseness or both on the day after bronchospirometry had been performed. These were of varying degree, and in many cases the patient confessed to feeling slightly hoarse only on direct questioning. The hoarseness or sore throat was of a very transitory nature, and completely subsided in a matter of 24 to 36 hours. In two patients, however, hoarseness persisted for several weeks, due to a moderately severe degree of traumatic damage inflicted on the cords. With appropriate therapy the hoarseness gradually settled, and ultimately cleared entirely, with no residual effects or any evidence of scarring or other permanent damage to the cords.

3. Tetany.

No case of tetany due to hyperventilation was encountered in this series.

4. Damage to teeth and gums.

It might be expected that in patients with small mouths, full sets of teeth, and tight jaws, that damage to the teeth with the blade of the laryngoscope could readily take place. Fortunately, no patient in the present series sustained any damage to teeth, but occasionally in such patients intubation presented not a little difficulty, and superficial abrasion of the gums and buccal mucosa occurred. This responded promptly to local measures, and produced no serious upset in any instance.

5. Bronchospasm.

The incidence of this troublesome, and potentially dangerous, complication was almost negligible, owing to administration beforehand of antispasmodics, combined with postural drainage, in cases with a proclivity to bronchitis and bronchospasm. When bronchospasm occurs during bronchospirometry apart from causing alarm and distress to the patient, it raises doubts as to the validity and correctness of the readings obtained.

Six patients in this series (1.9 per cent.) did in fact develop bronchospasm during bronchospirometry, but in all six it was recognised quickly, and administration of 8-16 minims (0.5 - 1 ml.) of 1 : 1,000 adrenaline subcutaneously abolished the spasm very effectively in a very short time. In no case did it prevent satisfactory readings being secured. Of these six patients, two were known asthmatics, and the fact that the examination was completed successfully was most rewarding. These cases were all done fairly early in the series, and since then with careful pre-operative preparation no further instances of bronchospasm have been met with during the procedure.

6. Anoxaemia and dyspnoea.

These difficulties might be envisaged in patients with poor respiratory reserve who were being subjected to an examination involving intubation. Suffice to say that no case was encountered here.

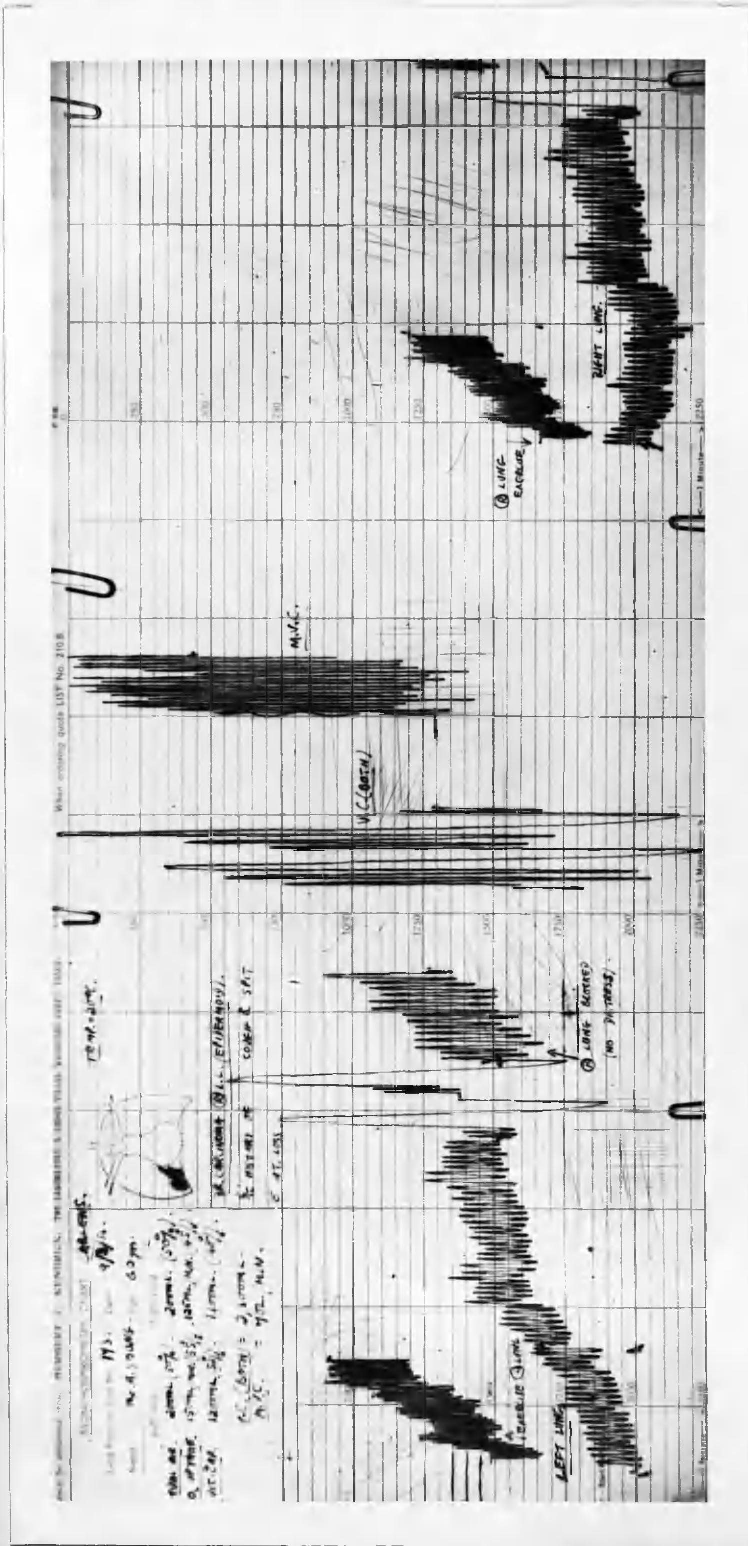
B. Complications arising after bronchospirometry.

1. Haemoptysis.

Two cases developed this complication following the examination. Haemoptysis in this instance infers a distinct amount of blood in the sputum persisting for one or more days, and occurring within one to ten days after performance of bronchospirometry, or else a single brisk haemorrhage taking place within the same period. It does not refer to a slight tinge of blood appearing in the sputum immediately after completion of the test, which is due simply to superficial abrasion of the gums or buccal mucosa.

It is the policy in this unit not to undertake bronchospirometry on any patient who has had a definite haemoptysis within the preceding eight weeks, because of the danger of precipitating a recurrence of the bleeding by the endoscopic examination. In the two cases in whom haemoptysis occurred in this series, the bleeding was not of a serious nature, and responded to simple measures within a few days. One of the cases had a large chronic cavity situated at the apex of the right upper lobe, and had been admitted to Mearnskirk for surgical treatment of this lesion. There had been previous bleeding from this cavity. A right thoracoplasty carried out subsequently effected complete control of the disease, with cavity closure (Case 42). In the other case there had been no haemoptysis previously, but a small haemorrhage occurred two days after bronchospirometry which settled quickly with no untoward sequelae.

Haemoptysis can be of fatal consequence, and the injunction by many previous authors (including Pinner et al.,1945) not to carry out bronchospirometry in the presence of recent bleeding cannot be reiterated too often. Apart from the risk of a fatal issue due to asphyxiation or blood loss, there is the almost equally grave danger of incurring spread of disease in such circumstances.



CASE 173.

PRE.-OP.CHART.
BRONCHIAL CARCINOMA
- FIT FOR LOBECTOMY
ONLY.

2. Bronchitis.

An increase in cough and spit can be observed in many cases after bronchospirometry, but this lasts only a matter of one day or so, and is not of any importance. There were 12 cases (4 per cent.) in over 300 examinations who developed what was in effect a bronchitis after the examination. Bronchitis is taken here to mean that the patient expectorates more sputum than usual, the sputum being muco-purulent in character, and this lasts for several days, being accompanied by one or more of the following: pyrexia, general malaise, searing retrosternal pain on coughing, and accompanied by adventiae, such as rhonchi, on auscultation of the chest. Of the 12 cases who developed this complication six were known asthmatics, and bronchitis developed post-operatively despite prior attention to postural drainage along with antispasmodics. In none of the 12 was there any radiological change which might have been regarded as a flare-up or spread of disease. Eight cases were tuberculous, three were bronchial carcinoma (with retention of secretions distal to the obstructing growth), and the last one was a case of bronchiectasis.

The treatment adopted in these cases was identical with that used for any other case of acute bronchitis. The sputum was cultured to ascertain the predominant organisms and the sensitivity of these to the usual antibiotics (penicillin, tetracycline, oxytetracycline, and chloramphenicol), the appropriate drug being administered thereafter. Where bronchospasm was also present, ephedrine was given. In all cases the infection had subsided within several days.

It is perhaps congruous at this point to discuss the timing of a bronchospirometric examination in relation to the date of operation. In most cases awaiting thoracic surgery who have little or no cough and spit, any endoscopic procedure, including bronchoscopy and bronchospirometry, can be performed without causing any upset, and operation can be carried out safely three or four days later. However, in patients with a moderate amount of sputum, whether they be cases of tubercle or bronchiectasis or a breaking-down lung cancer, if broncho-spirometry is done too near the time of operation (within two to three days), there is a potential risk of the patient developing a respiratory infection in the early post-operative phase. Such an event occurring in a patient with a low respiratory capacity, by augmenting an already existent degree of anoxaemia, can precipitate a very perilous state for the patient, with a fatal termination from respiratory insufficiency quite frequently.

The following case brings out these points quite succinctly.

<u>Clinical Case Report.</u> <u>Case 173.</u> A male patient, aged 60 years, presented with a bronchial carcinoma of the right lower lobe bronchus, proven to be squamous-cell (epidermoid) in type from bronchial biopsy. Bronchospirometry was carried out three days

before operation, confirming his fitness for such from a lung function point of view. At operation excision of the right lower and middle lobes was effected relatively easily, and next day chest X-ray confirmed that the remainder of the right lung had re-expanded, and he was generally well. However, three days later he developed troublesome cough accompanied by purulent sputum, occasioning great distress to the patient, with quite obvious cyanosis and dyspnoea. His sputum was cultured and the appropriate antibiotic administered. After a very stormy passage, he gradually improved, and was finally discharged in fairly good general condition, but only after a prolonged convalescence in comparison to the customary period.

In retrospect operation was embarked upon in this patient too soon after bronchospirometry, and the purulent bronchitis arising in the early post-operative period was without doubt related to this fact. So precarious did his condition become at this stage, indeed, that he might easily have succumbed from respiratory failure.

The policy now adopted in all cases, irrespective of diagnosis or presence or otherwise of cough and spit, is to have an interval of between seven to ten days between bronchospirometry and operation. This topic has been dealt with insufficiently, if at all, by previous writers, but it is one which was brought home very forcibly to the present author by the case quoted above. A period of seven to ten days is considered the minimum interval that should elapse between lung function studies and operation.

3. <u>Re-opening of Tension Cavity.</u>

Two cases in the present series developed this complication. In the first case (Case 85) the patient had a tension cavity of the left upper lobe which had been present for several months, and had an artificial pneumothorax still in being on the contra-lateral side. Bronchospirometry was done to determine the suitability of performing a left thoracoplasty with the right pneumothorax still being maintained. The cavity in the left upper lobe had been reduced in diameter by means of drug therapy and postural retention, but was still present. Several weeks after bronchospirometry, the cavity had increased to its former size. It would be unfair and unwise, however, to attribute this solely to bronchospirometry, as tension cavities are notoriously renowned for re-opening, especially if, after closure achieved by postural retention, some more definitive treatment in the form of thoracoplasty or lobectomy is not carried out fairly promptly.

Similarly with the second case (Case 18), in whom a course of postural retention had been completed at another hospital in the area, bronchospirometry was carried out to assess fitness for a thoracoplasty. At this stage a "blocked" tension cavity was present, and the patient had been allowed three hours ambulation daily while awaiting surgery. One week after spirometry, the patient developed a transient pyrexia, a return of cough and spit, and chest X-ray showed the tension cavity had re-opened. This necessitated a return to postural retention therapy for a further two months to re-establish cavity closure, following which a one-stage thoracoplasty was carried out uneventfully.

Thus, in both cases quoted, there is very serious doubt as to whether bronchospirometry did in actual fact contribute towards this complication. In the first instance the cavity had never been satisfactorily closed even with postural retention, and in the second case the fact that the patient had been allowed three hours' ambulation daily following postural retention treatment was very probably the cause of the "blocked" cavity becoming re-opened.

The present regime adopted in this unit is for any patient who has completed a course of postural retention and who is awaiting surgery to remain confined to bed till operation has been performed. This is the only effective way of ensuring that the cavity does not re-open. Adhering to these principles, there has been no instance of this complication recently, during which several cases with "blocked" cavities have been subjected to bronchospirometry.

In conclusion it may be stated that in cases with cavities "blocked" as a result of postural retention, but in whom operation is doubtful on account of poor respiratory reserve, bronchospirometry can be carried out with impunity. The information derived from the procedure more than outweighs any remote chance that a closed cavity might be re-opened as a result.

4. Atelectasis.

This event has not been mentioned before as a complication of bronchospirometry, but it happened in one case in the present series. This was in a female patient, aged 30 years (Case 156), who had developed a right-sided tuberculous pyopneumothorax from rupture of a cavity nine months previously. She had had continuous anti-tuberculous drug therapy during this period, and drainage of the empyema had been established by means of an intercostal tube. Partial re-expansion of the underlying lung had been achieved to the extent of 75 per cent., and the amount of pus draining through the tube had gradually decreased. It was proposed to undertake decortication of the lung with resection of the lobe containing the cavity, or else to effect a total pleuro-pneumonectomy, dependant on the results of lung function studies.

Bronchospirometry demonstrated that the affected side contributed a mere 15 - 20 per cent. of total function, which was in itself quite severely impaired. One week after broncho-spirometry the lung on the empysema side became completely atelectatic, due undoubtedly to bronchospirometry, carried out in the presence of known tuberculous endobronchitis (confirmed earlier at bronchoscopy).

Usually in the presence of tuberculous endobronchitis it is better not to undertake bronchospirometry, because of the very real danger of aggravating the condition, and thereby initiating dissemination of the disease, or causing atelectasis of a segment, lobe, or entire lung. In the case above, however, she was regarded as being in as good a condition as could possibly be achieved with conservative measures, and surgical intervention was considered to be justifiable at that point. In view of the spirometry findings and the resultant atelectasis, pleuro-pneumonectomy seemed the most feasible proposition.

5. Spread of Disease.

This refers to deterioration in the clinical and radiological pictures within several weeks after carrying out bronchospirometry. Gaensler and Watson (1952) recorded nine cases of spread out of 1,000 bronchospirometric examinations, while Jahn and Kaufman (1952) had an incidence of three cases out of 219 examinations.

No case of spread of disease or reactivation was met with in this series of 316 investigations. One case, a girl aged 18 years, with extensive bilateral pulmonary tuberculosis, might possibly be mentioned in this connection. Acutely ill when first admitted to Mearnskirk with extensive disease, and cavitation in both lung apices, she improved for a period initially, under the influence of chemotherapy and bed-rest, supplemented by a non-selective pneumoperitoneum. At this point bronchospirometry was undertaken in the off-chance that surgical treatment might be considered at a later stage. Lung function studies ruled out the question of any operation completely. For five months after this, she remained reasonably well, but then her condition began to deteriorate steadily, punctuated by recurrent haemoptyses. The tubercle bacilli in her sputum were by this time resistant to all the effective anti-tuberculous drugs, and she ultimately died.

In no way could bronchospirometry be indicted as the causal factor of the deterioration in this patient. In the first place, her general state remained unchanged for the five months succeeding the examination, and it was only then that regression commenced - too long an interval by far for any relationship to exist between the two. In addition her disease was such that, while a transient improvement occurred initially, the dominant trend was towards deterioration, particularly as her sputum ultimately became resistant to the usual chemotherapeutic drugs.

Conclusion.

There remains to be considered finally the risk attached to those actually involved in carrying out lung function studies, both medical and nursing personnel. This question has not been reported by previous authors, but it is worth recording our experience in Mearnskirk. As described previously, lung function studies are performed in a room set apart specifically for the purpose, with a screening unit in an adjacent room. The operators and assistants are all clothed in sterile gowns, caps, and masks, as protection against infection. (These precautions are similarly observed when bronchoscopies and bronchograms are being done.). The room after use is adequately ventilated.

In conclusion it is obvious that the major complications mentioned above are most likely to occur in tuberculous patients, particularly if there is copious sputum, and the subjects are premedicated too heavily. This depresses the normal cough reflex, makes expectoration more difficult, and by inducing a somnolent state after the procedure predisposes to retention of secretions. All of these may lead to bronchitis, retention pneumonitis, and dissemination of disease.

However, with an adequate period of drug therapy and bed-rest to obtain quiescence of the disease, complications are reduced to a bare minimum. In cases of bronchiectasis and lung cancer with secretions retained distal to the obstruction, preliminary postural drainage and antibiotics if thought necessary will obviate any danger of untoward sequelae. If premedication is kept to a minimum, not only is the patient fully co-operative during the proeedure, but afterwards there is not the tendency for him to lapse into a semi-comatose state as is the case when he has been heavily sedated.

Bronchospirometry is then an investigational procedure which gives very useful information with regard to lung function, and if attention is paid to the requisites discussed above, it is free from any dangerous complications or sequelae.

* * * * * * *

Summary:

The complications encountered after bronchospirometry by previous authors are dealt with fully, and reference is made to two deaths attributable to the examination which are recorded in the literature. There were no deaths in the present series of 316 examinations.

The complications met with in this series comprise mainly two cases of haemoptysis, 12 of bronchitis, and one of atelectasis, none of which proved serious. Minor transient sequelae, such as hoarseness and bronchospasm, are mentioned. No case of spread of disease occurred.

Heavy premedication prior to bronchospirometry is condemned, as it interferes with the normal cough reflex and predisposes to retention of secretions, with the attendant risks of pneumonitis and spread of disease.

The timing of a bronchospirometric examination in relation to subsequent surgical intervention is important. Leaving only an interval of two or three days between the two, incurs the danger of an acute respiratory infection developing in the early post-operative phase. This may precipitate death from respiratory failure, particularly where the respiratory reserve is low. Ten to 14 days, it is suggested, is the minimum period

which should elapse between bronchospirometry and any operation.

With these provisos, and adhering strictly to the indications and contra-indications dealt with in a previous chapter, bronchospirometry is a very safe procedure to undertake.

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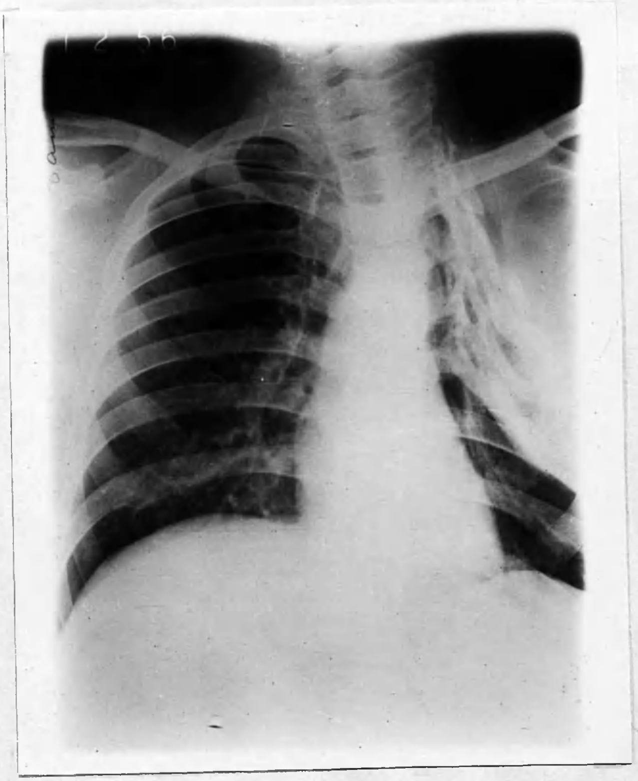
CORRELATION OF BRONCHOSPIROMETRIC RESULTS.

A. Correlation with Clinical and Radiological Pictures.

This subject has been referred to briefly in Chapter IV, when discussing the assessment of lung function from clinical examination of the chest and radiological study of the heart and lungs, this including fluoroscopy. Jacobaeus et al. (1932) and Vaccarezza et al. (1947) found discrepancies between the broncho-spirometric findings and the radiological appearances in several of their cases. The latter authors mentioned possible causes for these differences, such as the presence of pulmonary emphysema which could lead to a greater reduction in ventilation and oxygen consumption than expected. Bronchostenosis and bronchial obstruction might produce similar effects. The presence of diaphragmatic paralysis or atrophy of the inter-costal muscles might impair ventilatory function without there being much in the way of abnormality radiologically, while symphysis, or gross thickening, of the pleura could reduce respiratory capacity markedly. Pinner et al. (1945) emphasised the importance of pleural involvement, whether due to old pleurisy or pneumothorax therapy complicated by effusion, as a potent cause of impaired function of the underlying lung, particularly in regard to oxygen uptake. This might not be manifest by X-ray examination, but bronchospirometry demonstrated the impairment quite conclusively.

Visualization of the pulmonary circulation and great vessels by intravenous injection of 70 per cent. Diodrast (angiocardio-



CASE 119.

ILLUSTRATIVE OF OLD TYPE THORACOPLASTY (COMPARE CASE 23 OPPOSITE PAGE 150).

graphy), as described by Robb and Steinberg (1940), may display a decrease in the pulmonary circulation of a lung subjected to pneumothorax therapy, in which incomplete re-expansion has occurred or an effusion supervened. McCoy, Steinberg, and Dotter (1951) showed by this method that in cases of re-expanded artificial pneumothorax there was a diminution of vascularity, this depending on the degree of collapse that had been maintained. Crowding, distortion, and displacement of pulmonary vessels, and delay in blood flow on the affected side, were the common findings.

The experience in the present series has been that there is a close relationship between the clinical, radiological and bronchospirometric findings. In support of this, two very potent examples are portrayed, with illustrative cases. As will be demonstrated in the succeeding chapter, the loss of function produced by the modern type of one-stage, five-rib thoracoplasty as performed at Mearnskirk is minimal in comparison to that ensuing after the old type of "fillet" or crash-in thoracoplasty. This latter operation was non-selective, was performed in two or three stages, with the removal in part or whole of the first seven to ten ribs, and caused severe loss of function. These points are illustrated by the following case.

Clinical Case Report. Case 119. A male patient, aged 32 years, had had a left-sided thoracoplasty in two stages carried out at another hospital two years previously. This operation was of

CASE 119.

PRE-OP.CHART.
FUNCTIONLESS
LEFT LUNG UNDER
OLD TYPE
THORACOPLASTY.

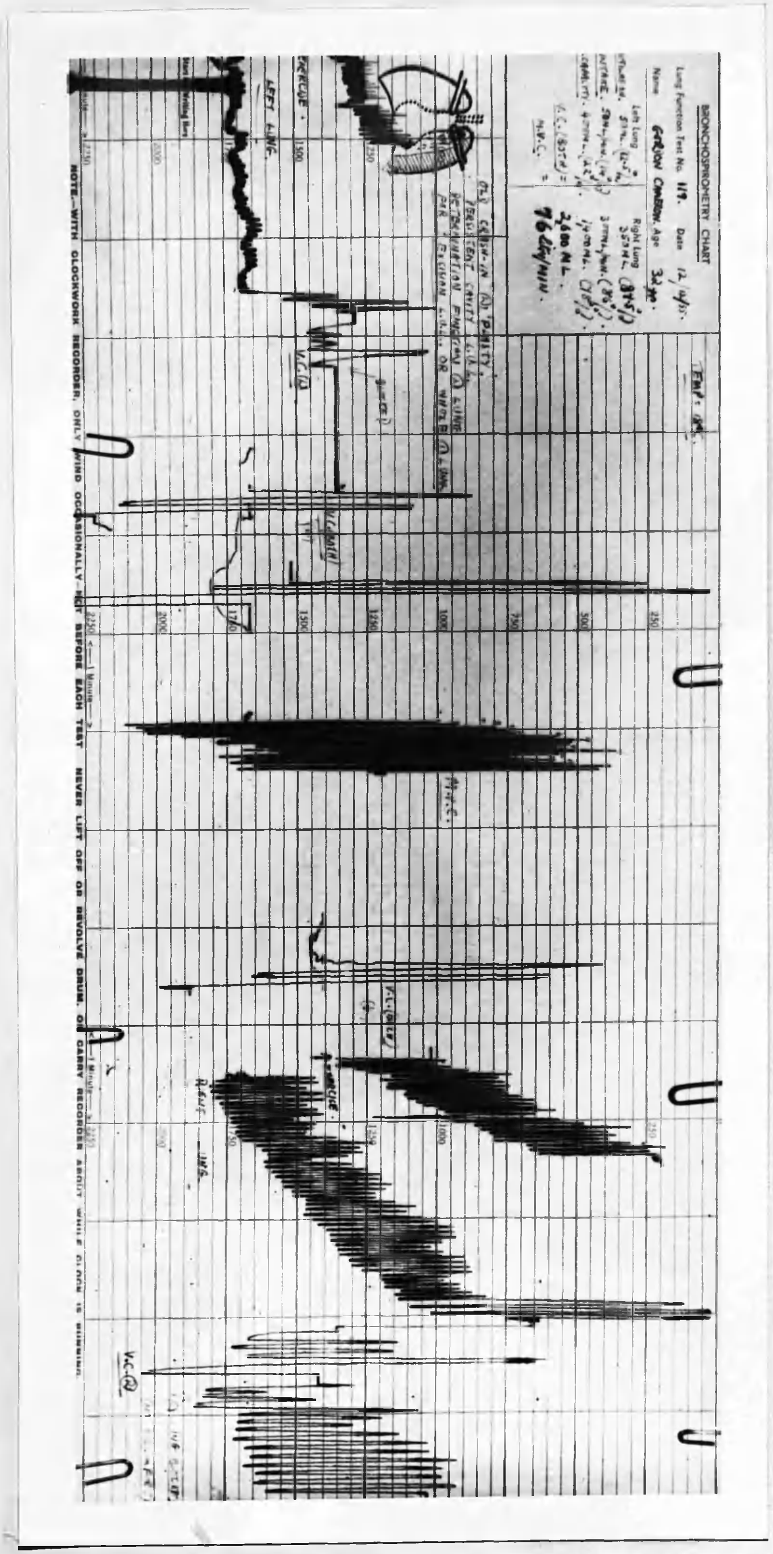
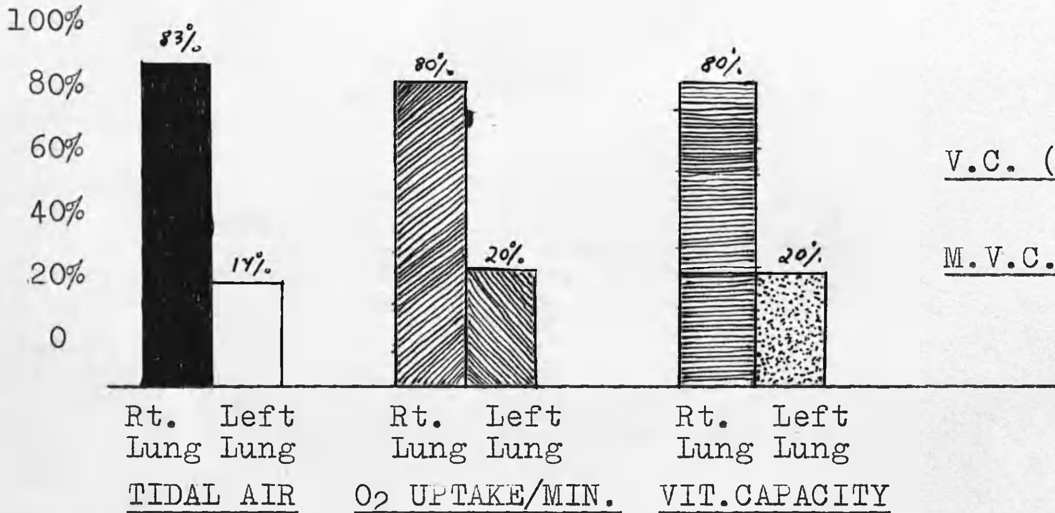


Figure VI.

Case 119, Post-Operative Findings



V.C. (Both) = 2,250 ml.

M.V.C. = 70 litres/min.

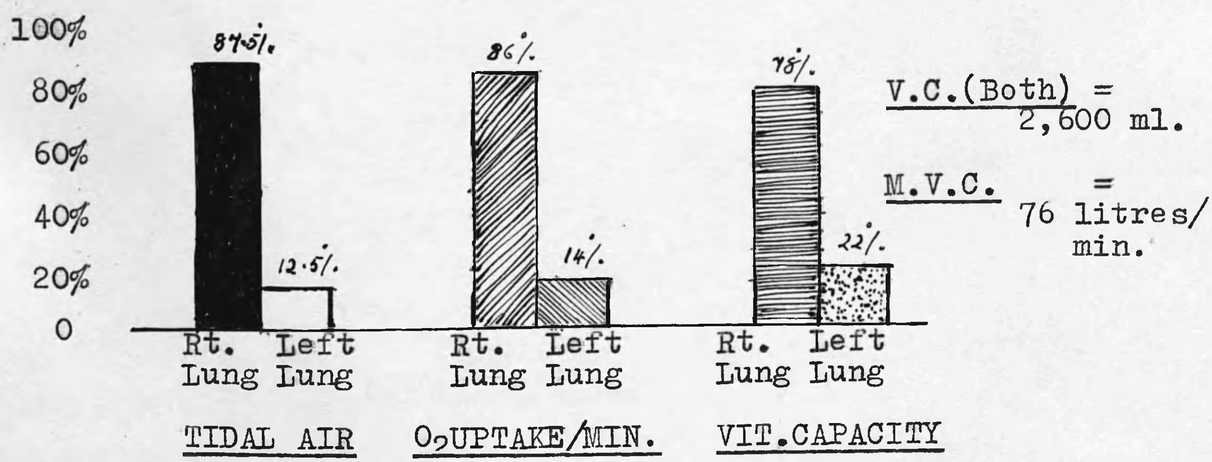
(Fig.V demonstrated very little function in the left lung under the thoracoplasty. However, in preference to total left pneumonectomy, excision of the left upper lobe containing the cavity was carried out, the lower lobe being retained for the dual purpose of filling the left hemithorax and because it was free from any demonstrable disease.

Fig.VI shows the post-operative findings, with little alternation in overall or differential lung function.)

the old type, and involved the removal of parts of ribs one to nine. Chest X-ray and fluoroscopy suggested little function remaining in the underlying lung, while a cavity was still present at the left apex under the thoracoplasty. Lung function tests were carried out to assess fitness for further left sided surgery (See Fig.V).

Figure V.

Case 119, Pre-Operative Findings.



The experience in the present series has been that in all cases of the old extensive "crash-in" type of thoracoplasty, the function of the underlying lung is as severely impaired as in the case quoted above. So constant has been this loss of function on the thoracoplasty side that it is now our policy not to undertake bronchospirometry in these cases, except on a very rare occasion, as it can be assumed that the underlying lung contributes little to pulmonary function. However, where

CASE 83. PRE-OP.

SHOWING DESTROYED TUBERCULOUS LEFT LUNG.

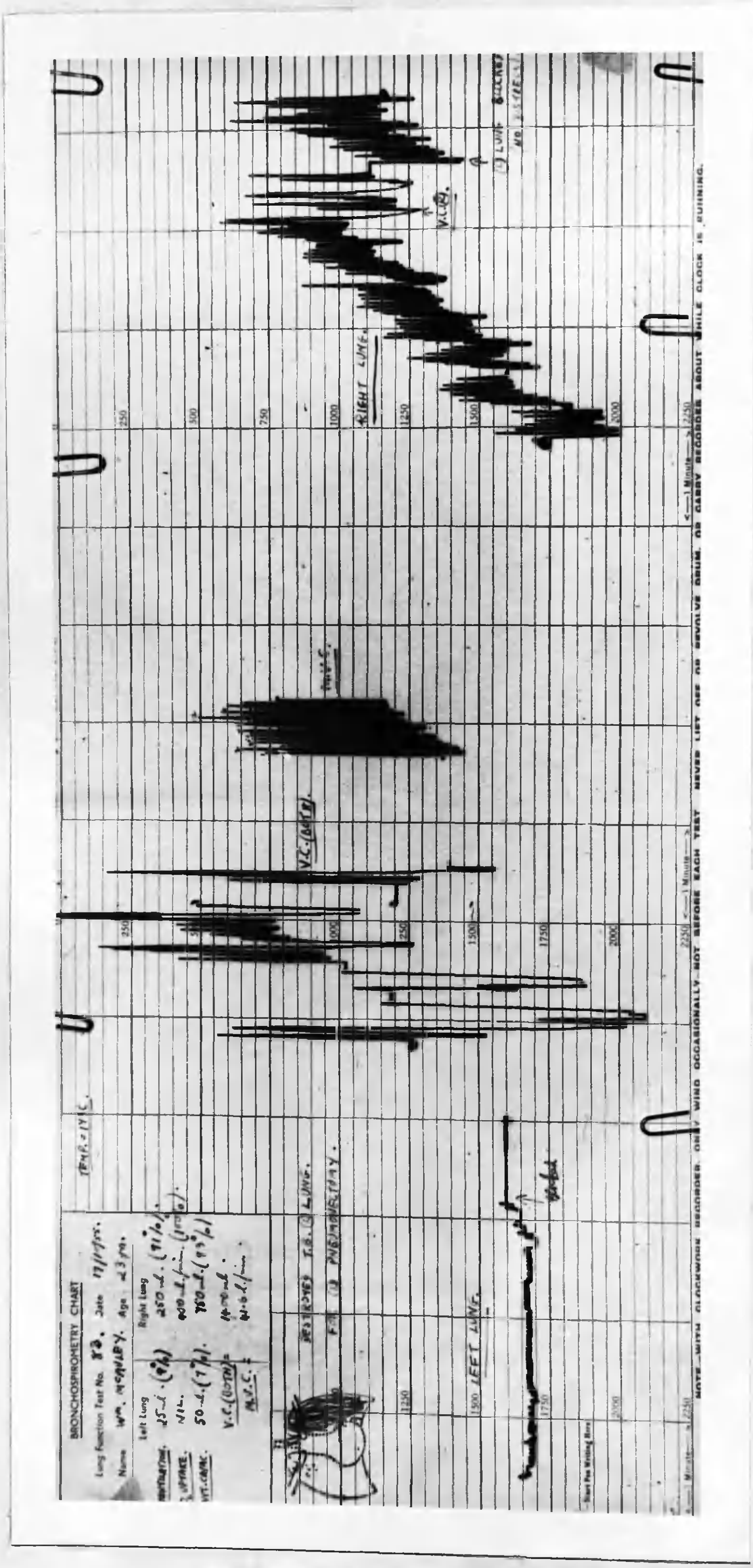
CASE 83. POST-OP.

LEFT PNEUMONECTOMY.

further surgery is contemplated in these cases, external spirometry (including the combined vital capacity of both lungs and the maximum ventilatory capacity) is very necessary. Only if that were good would surgery to the contralateral side be considered, and at that of a very conservative nature, such as an extra-pleural pneumothorax or a plombage operation.

Similarly in patients with one lung which appears clinically and radiologically destroyed (be it due to pulmonary tuberculosis, cystic disease, or gross bronchiectasis), broncho-spirometry confirms the almost total absence of function in that lung, as in the following case.

Clinical Case Report. Case 83. Pulmonary tuberculosis was first diagnosed in this patient when he was a boy of 14 years. He spent several years in Mearnskirk then under observation, with bed-rest the sole form of treatment. The tuberculous lesion involved only the left lung, but progressive destruction of that lung ensued over the course of several years. In an attempt to halt this process, a left phrenic crush and pneumoperitoneum were carried out, and refills maintained for four years (1949-1953). However, after 1953 the patient became progressively disabled by increasing dyspnoea on exertion and by a troublesome, productive cough. He was readmitted to Mearnskirk in 1955, now aged 23 years, with a view to judging the suitability for left sided surgery. Slight dyspnoea and cyanosis were present at rest, and chest X-ray showed the left lung to be almost opaque,



CASE 83.

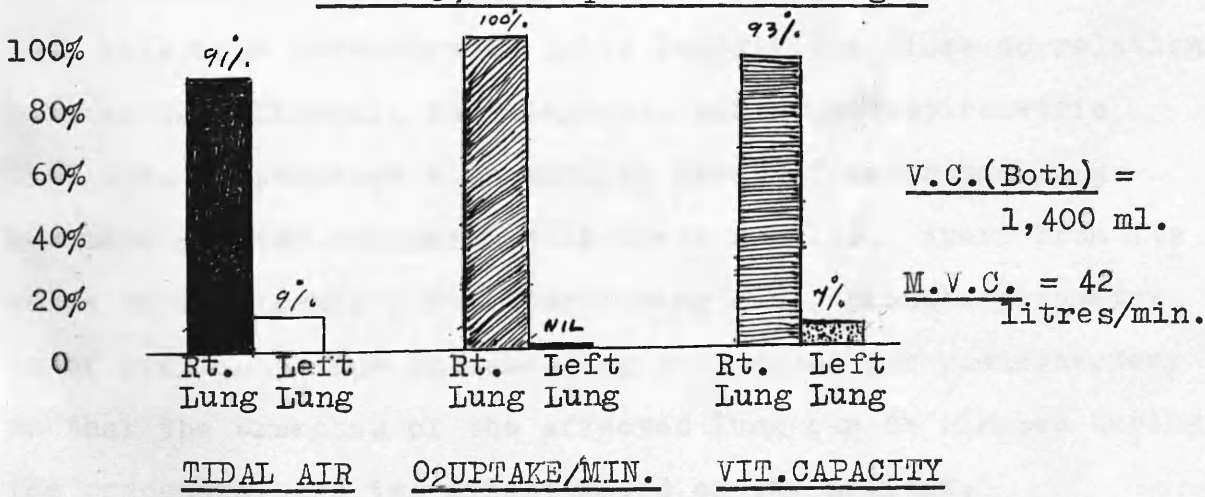
PRE-OP.CHART.
FUNCTIONLESS
LEFT LUNG.

with marked mediastinal and tracheal displacement to the left; a picture characteristic of a grossly destroyed, shrunken, and partially atelectatic lung, with a thickened pleura. The right lung appeared to be completely free from disease.

Lung function studies are as in Figure VII.

Figure VII.

Case 83, Pre-Operative Findings.



These figures confirmed a destroyed and virtually functionless left lung. Manifestly the cause of the slight cyanosis and dyspnoea at rest was the atelectatic left lung, through which some blood was still circulating, though certainly in a greatly diminished flow. This blood was then entering the systemic circulation only partially oxygenated, and this resulted in the slight degree of anoxia detectable clinically. (These statements are based on facts demonstrated both in humans and experimental dogs by Bjork and Salen, 1950).

Left pneumonectomy was accomplished with very little upset, and convalescence was remarkably smooth. The degree of anoxia, which had been detectable clinically pre-operatively, disappeared, and exercise tolerance improved. (Unfortunately, for reasons mentioned before, arterial oxygen saturation estimations were not carried out either before or after operation.). External spirometry post-operatively showed very little reduction in overall ventilatory function.

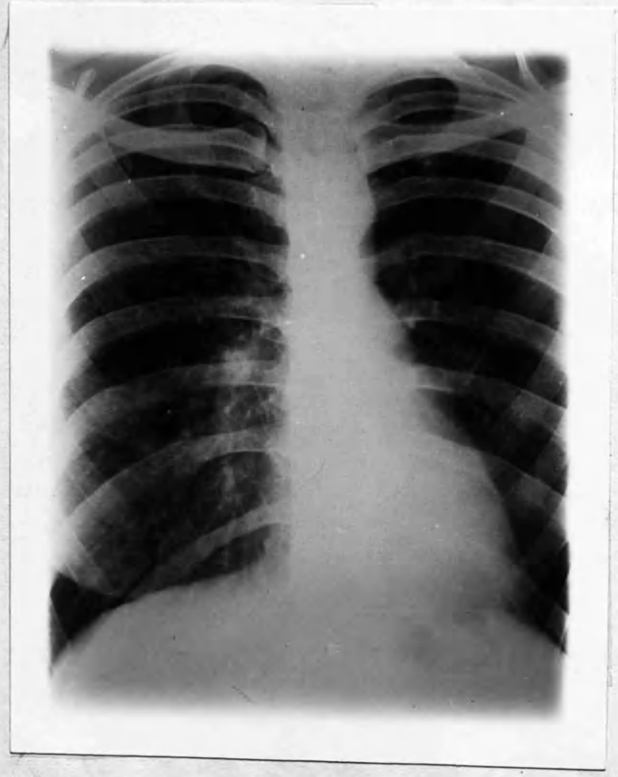
This case demonstrates quite lucidly the close correlation between the clinical, radiological, and bronchospirometric findings. Experience with similar cases of destroyed lungs has more or less concurred with these results. Apart from its value in confirming a non-functioning lung, bronchospirometry is of additional use in assessing such cases for pneumonectomy in that the bronchus of the affected lung can be clamped during the procedure, and its effect noted on the patient.

Although bronchospirometric findings have agreed on the whole with clinico-radiological impressions, occasionally anomalies have occurred. Cases of bronchiectasis confined to one lobe only have usually an impairment of function on the affected side to the extent of 5-10 per cent. Nevertheless, in the case cited below the functional loss as determined by bronchospirometry was much less than anticipated from radiological appearances.

<u>Clinical Case Report.</u> <u>Case 304.</u> A woman, aged 30 years, had had a chronic cough and spit for very many years, punctuated

CASE 304.

BRONCHIECTASIS
L.L.L. + BULLOUS
CHANGES L.BASE.

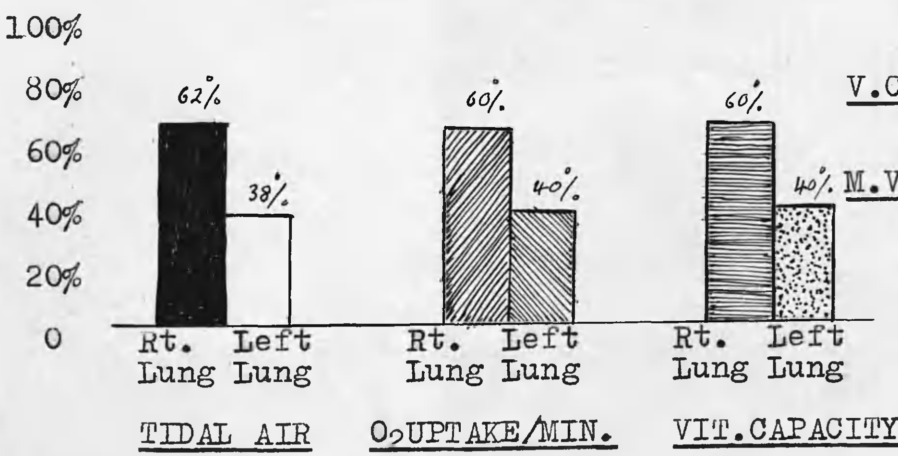


by recurrent episodes of acute respiratory infection. A straight chest X-ray revealed evidence of bullous degeneration at the left base. Bilateral bronchography disclosed mild bronchiectasis of the middle and posterior basic segments of the right lower lobe, with a grossly bronchiectatic, atelectatic left lower lobe. The bullous appearance at the left base was due presumably to associated degenerative emphysematous change in the surrounding lung.

It was thought that there would be marked reduction in the function of the left lung, but Figure VIII shows that this lung still contributed 40 per cent. of total function (normally it is in the region of 45 per cent., as pointed out in 1939 by Gebauer).

Figure VIII.

Pre-Operative Findings in Case 304.



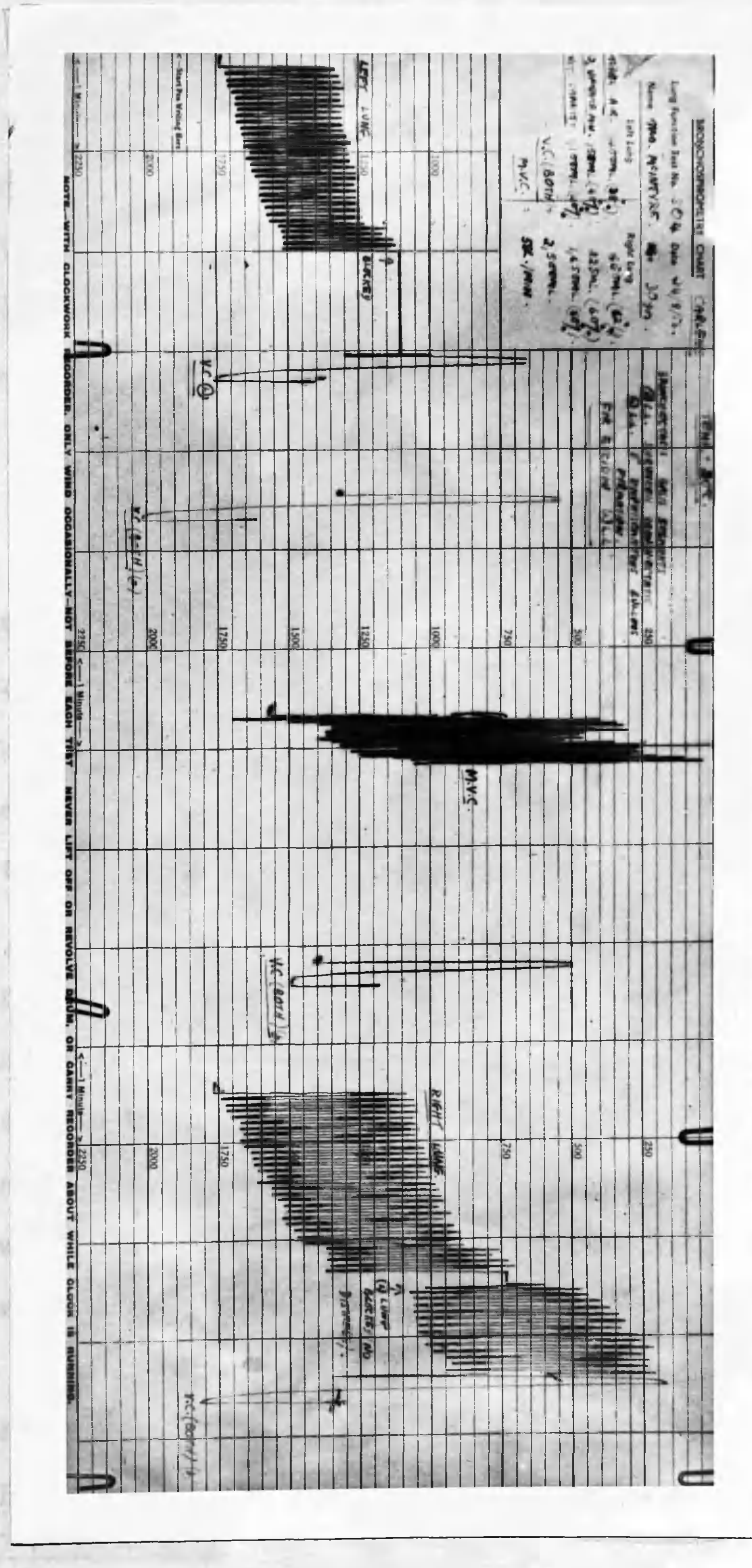
V.C. (Both) = 2,500 ml.

M.V.C. = 58 litres/min.

So the reduction of function in the left lung only amounted to 5 per cent., despite the gross disorganisation of the left

CASE 304.

PRE-OP. CHART.



lower lobe and compensatory changes. Oxygen consumption was no more impaired than ventilation (tidal air), although Long et al. (1950) found in a series of 39 cases of bronchiectasis that oxygen absorption was usually reduced to a greater extent than ventilation where the disease was unilateral.

Excision of the left lower lobe was carried out uneventfully in the above patient, and she is now very much improved.

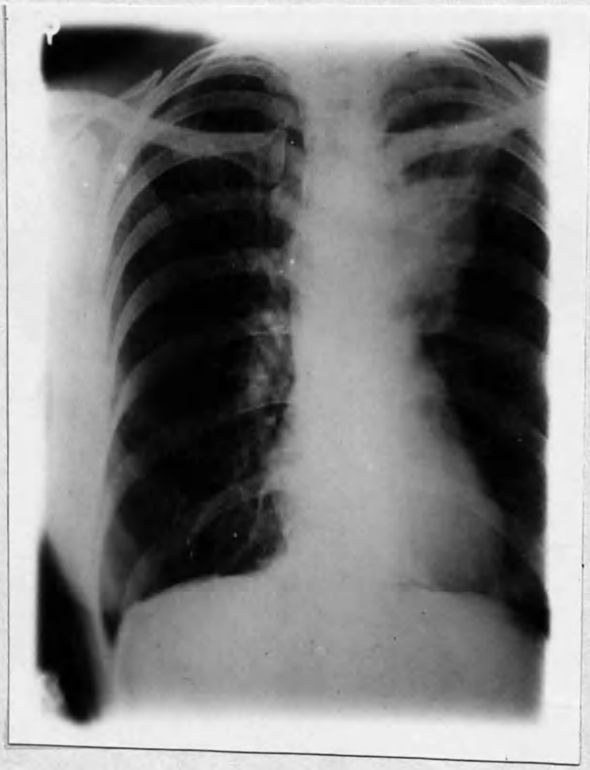
In most cases, then, in the present series bronchospirometric results have been in close agreement with clinico-radiological findings. Frenckner (1936), however, while admitting that physical examination of the lungs and study of skiagrams could provide some information as to respiratory function, stated that bronchospirometry gave much more reliable and detailed information on this subject, although the results often differed from the clinical and X-ray findings. But bronchospirometry and knowledge of lung function in general were only in their infancy at that time, certainly in regard to their clinical application, and the types of catheters employed were at best rather primitive, with the additional disadvantage of a fairly high degree of air resistance. The modern type of catheter (Carlens) overcomes these technical difficulties, and in this way provides much more accurate readings.

B. Correlation of Bronchospirometric Findings with Operative and Post-Operative Results.

Several cases, in whom lung function studies including bronchospirometry showed clearly an impaired respiratory capacity, withstood the actual surgical procedure without any mishap, but thereafter underwent a very stormy post-operative course. In a few instances, indeed, death ensued from respiratory failure (these are detailed and discussed at length in the succeeding chapter). Operation was undertaken in these doubtful cases, however, in full knowledge of the danger entailed. The majority of them were patients with lung cancer or tubercle of such gravity (for example, chronic tuberculous pyopneumothorax) that without surgical intervention the prognosis was poor in the extreme.

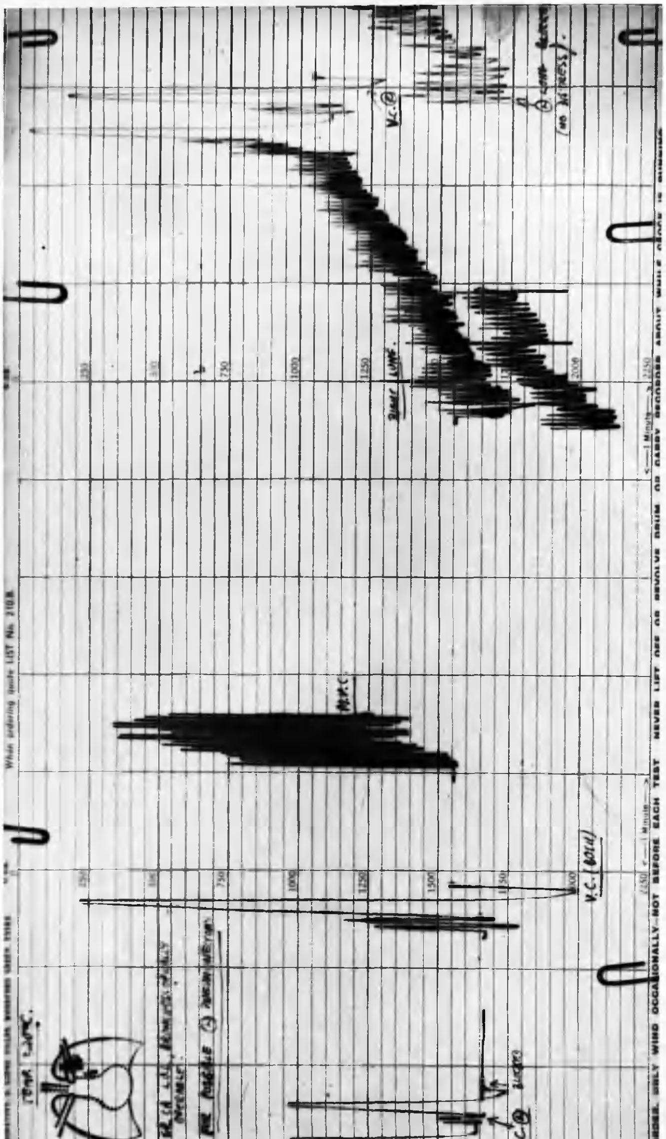
The important point to be stressed at this stage is that pre-operative lung function tests are not so much a pointer as to a patient's fitness for a particular type of operation per se, as with modern advances in anaesthesia and surgical technique almost any patient can be carried through the operative phase; but in his ability and fitness to be able to survive the post-operative phase, when he is no longer breathing an artificially-enriched oxygenated atmosphere, and when several adaptive processes are in being, resultant from and compensatory to his operation.

The maximum ventilatory capacity (M.V.C.), as stated previously, is a much more accurate estimation of overall ventilatory function than the vital capacity, particularly in cases with accompanying generalised pulmonary emphysema. An



CASE 272.

BRONCHIAL CARCINOMA
L.U.L.



CASE 272.

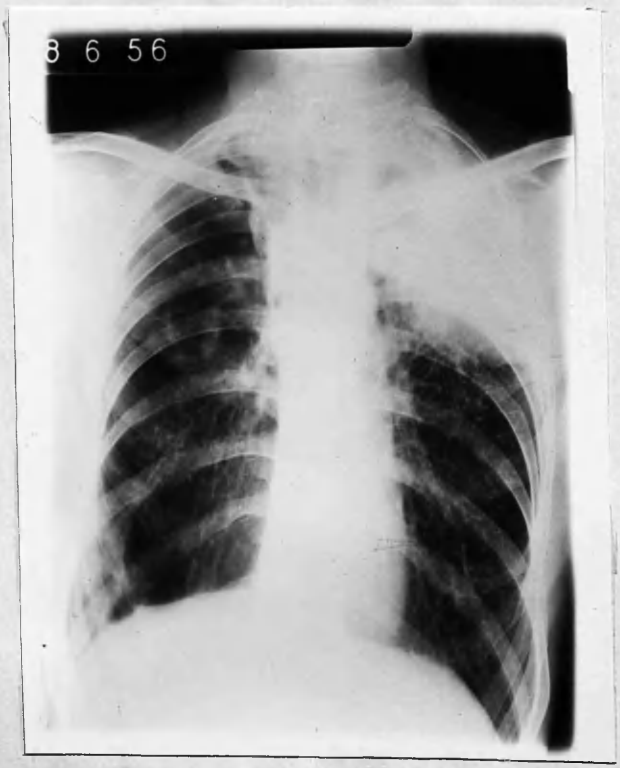
PRE-OP. CHART.
SHOWING NO OXYGEN
UPTAKE BY LEFT
LUNG.

At operation the left main pulmonary artery was found to be compressed from without by mediastinal and hilar lymphatic glands, allowing little or no blood to pass through the artery. This accounted for the complete absence of oxygen uptake by the left lung as determined by bronchospirometry. Pneumonectomy was accomplished successfully, though the operation entailed a very tedious and extensive dissection of the surrounding lymphatic glands involved by the tumour mass. Her post-operative was smooth from a respiratory viewpoint, but she developed pre-renal azotaemia due to dehydration associated with persistent vomiting. This responded satisfactorily to intravenous therapy, and the patient is now discharged home in generally good condition.

The exercise test, using a simple ergometer with attached pedals as described by Bjorkman and Carlens (1951), carried out during bronchospirometry, has proved helpful in judging the respiratory reserve in patients with doubtful lung function. Where any distress in the way of cyanosis or dyspnoea has occurred during or shortly after cessation of the test, the respiratory reserve has been regarded as markedly reduced. This, in combination with a low vital capacity and maximum ventilatory capacity as determined by external spirometry, indicates that the patient would be a poor surgical risk, and if surgery were undertaken in such a case it would need to be of the most conservative type (for example, an extra-pleural

CASE 73.

PRE-OP. BILATERAL UPPER LOBE DISEASE. EMPHYSEMA OF LOWER LOBES.



CASE 73.

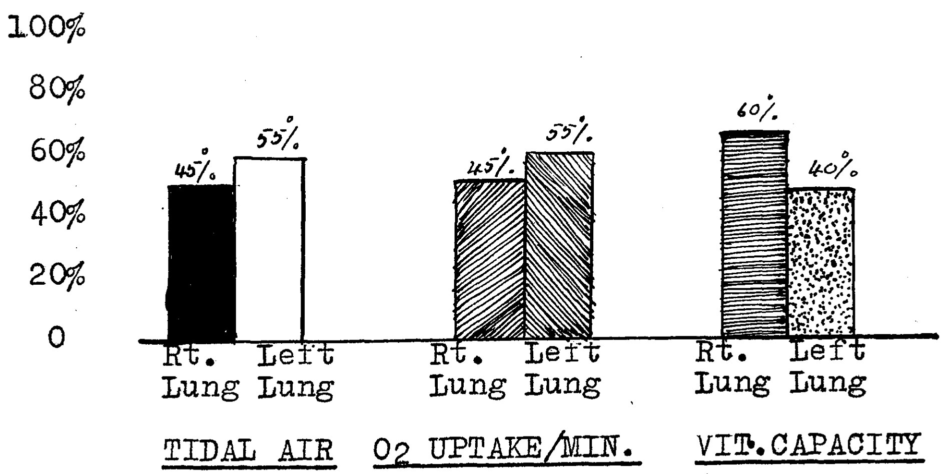
AFTER L.PLOMBAGE.

pneumothorax). In addition a stormy post-operative could be anticipated, as exemplified in this case.

<u>Clinical Case Report.</u> <u>Case 73.</u> A male patient, aged 32 years, had bilateral upper lobe tuberculosis of several years standing. He had had prolonged courses of various anti-tuberculous drugs combined with bed-rest, and improved to some extent with this regime. However, he now presented with a contracted upper lobe on each side, with bilateral apical cavitation. Marked emphysema of both lower lobes was present, presumably as a compensatory mechanism, and there was a marked tendency to bronchospasm. Lung function studies were carried out (See Figure IX), with a view to undertaking probable bilateral collapse surgery.

Figure IX.

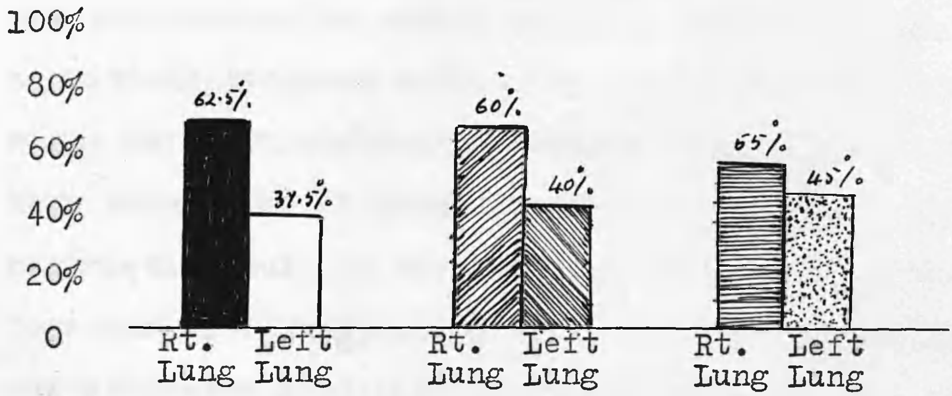
Pre-Operative (Case 73).



Pre-Operative Bronchospirometry

Figure X.

Post-Operative (Case 73).



Post-Operative Bronchospirometry

(after left plombage)

TABLE VII.

External Spirometry before and after Operation (Case 73)

	Combined Vit.Cap.	M.V.C.
Pre-Operative	2,700 ml.	70 litres/min.
Post-Operative	2,200 ml.	60 litres/min.

Although the resting values appeared reasonable, including a pre-operative M.V.C. of 70 litres/minute, on exercising the patient with the ergometer during bronchospirometry dyspnoea and distress were produced. It was decided to carry out the more conservative plombage operation first on the left, and then review the position with regard to possible surgery for the right side.

A left plombage operation was accordingly effected, but the post-operative course was very stormy indeed. There was persistent dyspnoea associated with cyanosis over the first eight days, punctuated by attacks of copious frothy sputum very suggestive of subacute pulmonary oedema. By means of restricting salt in the diet and administering ammonium chloride, together with omnopon and aminophylline for the acute attacks, the patient's condition gradually improved, the cyanosis and dyspnoea subsided, and he ultimately made a good recovery.

Repeat lung function studies 12 weeks after operation (See Figure X and Table VII) showed minimal loss of function from the plombe, but, in view of the patient's precarious state post-operatively, it was resolved not to tackle the right side.

This case serves to illustrate several important points. Firstly, the pre-operative exercise test performed during bronchospirometry showed a very limited respiratory reserve, and this was more than confirmed in the immediate post-operative phase. Secondly, it seems clear that the cause of the dyspnoea and distress on exercise pre-operatively was identical with that producing the perilous state after operation. It was in an attempt to correlate these findings and explain their meaning that Harvey, Ferrer, Richards, and Cournand (1951) made a study of patients with generalised pulmonary emphysema. They found in these cases that the pulmonary vascular bed becomes greatly limited in extent over a period of time as a result of destruction of small vascular channels together with an endarteritis of the remaining vessels. Initially, with the increased resistance, the pulmonary artery pressure rises on exercise, but as the emphysema becomes more marked pulmonary hypertension is present even at rest, with a further rise on exercise.

In normal subjects an increased pulmonary blood flow, as demanded by exercise, incites a widening in the calibre of the already existing vascular channels and opening up of new ones which are not in use in the resting state. This obviates any rise in the pulmonary artery pressure, and thus this pressure remains unchanged at rest and on exercise. In emphysematous subjects, however, with the destructive changes present as outlined above, no such increase in the capacity of the pulmonary vascular bed can take place, and hence a rise in pulmonary artery pressure occurs on exercise. These facts were all amply confirmed by Hickam and Cargill (1948).

Case 73, as noted, had bilateral pulmonary emphysema due to his long-standing tuberculosis and concomitant bronchitis, and this was of sufficient severity to cause dyspnoea and cyanosis on exercise. Although cardiac catheterization, with measurement of the pulmonary pressure at rest and on exercise, was not performed in this patient, it is reasonable to assume that pulmonary hypertension occurred on exercise and also in the immediate post-operative phase, precipitating the degree of respiratory insufficiency associated with attacks of frothy sputum.

Estimation of the pressure in the pulmonary circulation at rest and on exercise is a most informative procedure in the study of lung function, particularly in cases with generalised emphysema and where respiratory capacity, as judged by simple tests, is found to be low. In this series it has been possible to carry out this examination only in two patients (Cases 151 and 251), whose case histories and findings have been fully dealt with in preceding chapters.

With modern and recent advances in anaesthesia combined with improvements and refinements in surgical skill and technique, it is now possible for the thoracic surgeon to tackle almost any pathological lesion inside the chest, no matter how ill the patient or how poor his respiratory capacity. However, the danger of subjecting such patients to major chest surgery is that though they may survive operation, they may be left as respiratory cripples. In a similar category are those who, though able to resume activity in a modified form after operation, become progressively disabled over the succeeding years, this picture culminating in cor pulmonale with cardio-respiratory failure. It is in such cases that careful selection for operation is of extreme importance. Estimation of pulmonary artery pressure should provide an additional aid in this selection, in combination with other lung function tests. In those operated on the examination could be repeated at varying intervals thereafter, and valuable data could thus be derived both for the prognosis of the individual patient himself and for the selection of similar cases for lung surgery. Such an investigation also might conceivably help in the elucidation of certain factors, at present rather obscure, which are related to the aetiology of pulmonary hypertension.

During bronchospirometry blockage of the bronchus by a pair of forceps on the side for proposed pneumonectomy, and observing the patient's reaction to this for one to two minutes, has been found of definite value in the present series. It has been carried out routinely in every case for probable lung resection, whether it be tubercle, bronchial carcinoma, or bronchiectasis. Seventy-seven cases underwent this procedure, and of these, 21 were considered unfit for pneumnectomy because of either distress occasioned on producing the blockage or poor overall respiratory capacity, or else a combination of the two. Of the 56 cases who were considered suitable for lung resection and who were operated on subsequently, 22 were cases of bronchial carcinoma, 30 were tubercle, and the other four were miscellaneous (three gross bronchiectasis involving one lung, the other a case of anthracosis operated on because of a hilar mass thought to be neoplastic).

Five deaths occurred in the 56 cases who had surgery. These will be considered more fully in the next chapter. Suffice to relate at this point that two deaths were from other causes; only three were directly attributable to cardio-respiratory insufficiency.

It is perhaps pertinent to discuss briefly the dire effects of any respiratory infection supervening in the immediate post-operative period in these poor risk cases, precipitating as it does respiratory insufficiency and death in many instances. It has been noted earlier that lung function studies measure only the amount of functioning lung tissue present in patients with long-standing disease or with co-existing emphysema. They cannot foretell what will happen if the added burden of a respiratory infection supervenes in the early post-operative phase. Assuming that a degree of pulmonary hypertension is already present in these cases, the advent of a respiratory infection after operation will accentuate the anoxaemia, and produce a further rise in the pulmonary artery pressure. This may well tip the balance, and cause death from cardio-respiratory failure (Baldwin, Cournand, and Richards, 1949; Bassinger, 1955; Carlens and Hanson, 1955). Carlens and Hanson indicated in their article that tracheotomy with bronchial suction of any secretions, combined with oxygen therapy, may well tide these patients over this precarious stage. In addition appropriate antibiotic therapy is essential, but the mortality will still be fairly high.

Gaensler, Cugell, Lindgren, Verstraeten, Smith, and

Streider (1955) examined a series of 460 patients subjected to various forms of thoracic surgery (including pneumonectomy, lobectomy, thoracoplasty, plombage, and extra-pleural pneumothorax), and found a total of eight deaths attributable to respiratory insufficiency in the early post-operative phase (up to 30 days following operation). Pre-operative emphysema and a low maximum ventilatory capacity were considered to be the two most potent factors related to these deaths.

Excluding the three cases in the present series who died from respiratory failure, the other 51 cases in whom blockage of the bronchus was carried out pre-operatively underwent operation, and encountered no difficulty in either the early or late post-operative stages. Hence blockage of the bronchus on the side for porposed pneumonectomy offers an additional aid in the assessment of dubious cases for lung resection. It is realised that the procedure gives what is at best only a crude estimate of the functional capacity of the good lung. Another criticism which may be entertained is that the patient is breathing pure oxygen during bronchospirometry, and that this does not give a true picture of how he would react when breathing ordinary atmospheric air. However, during bronchospirometry the airway is considerably narrowed due to the width of the catheter lumen, thus producing a degree of air resistance which is still present, though in much smaller degree, with the Carlens tube (Gaensler, Maloney, and Bjork, 1952). These latter two factors thus would appear to counter-balance each other. Certainly in practice the procedure has stood in very good stead.

* * * * * * *

Summary:

It is noted that in the series under discussion the bronchospirometric results tend to run closely parallel with the clinico-radiological findings. This does not, however, in any way detract from the importance of carrying out bronchospirometry in cases where it is indicated. Three cases are described in full to illustrate these various facets.

The bronchospirometric findings are correlated with the operative and post-operative results. Where pre-operative function studies are impaired to any marked degree, a stormy period in the early post-operative phase can be anticipated. The value of the M.V.C. in this respect is particularly stressed.

The value of the exercise test during bronchospirometry, using an ergometer, as an estimate of the respiratory reserve is demonstrated.

Pulmonary hypertension in relation to cases with impaired function, due to long-standing disease, concomitant pulmonary emphysema, or previous thoracic surgery, is fully discussed. The danger of respiratory infection occurring soon after surgery in these cases is mentioned, and methods of therapy for the

condition are outlined.

* * * * * * *

CHAPTER VII

RESULTS

I. VITAL STATISTICS.

Age, sex, numbers subjected to bronchospirometry before and after operation. Total numbers of tubercle, bronchial carcinoma, etc.

II. FUNCTIONAL LOSS FROM EACH TYPE OF PROCEDURE.

A. Pulmonary Tuberculosis.

1. Thoracoplasty.
2. Resection. (a) Lobectomy. (b) Segmentectomy. (c) Bilobectomy.
3. Plombage.
4. Extra-pleural pneumothorax.
5. Apicolysis with fixation.
6. Old type thoracoplasty ("crash-in" or fillet).
7. Artificial pneumothorax.
8. Phrenic crush and pneumoperitoneum.

B. Bronchial Carcinoma.

1. Pneumonectomy.
2. Lobectomy.

C. Bronchiectasis.

1. Pneumonectomy.
2. Lobectomy.

D. Miscellaneous (emphrematous bullous cysts, etc.).

III. IMPORTANCE OF LUNG FUNCTION STUDIES IN THORACIC SURGERY.

Including analysis of deaths in present series, and numbers rejected because of poor respiratory function.

* * * * * * *

RESULTS

I. VITAL STATISTICS.

There were altogether 316 bronchospirometric examinations performed in the present series. Of these, 192 were in males, 124 in females. The youngest was 16 years old, the oldest was 67 years. The majority, however, fell into the age group 25 - 55 years. Of these 316 examinations, 253 patients were involved - that is, in 63 patients bronchospirometry was carried out before surgery or collapse measures and repeated afterwards, thus accounting for 126 examinations. These 63 cases will be discussed fully in a later section of this chapter.

The following Table (Table VIII) divides the number of cases and the total number of examinations into the various disease categories, and from this it is manifest that pulmonary tuberculosis comprised the majority of cases, with bronchial carcinoma next in precedence. This is easily explicable from the fact that tubercle still accounts for most of the cases requiring surgery in a thoracic surgical unit. Bronchiectasis, contrarily, is not nearly so common as pulmonary tuberculosis, and in addition many such cases referred for possible surgery are fairly young and relatively healthy, so that the need for lung function studies does not arise so frequently. In tuberculous patients, on the other hand, who require major surgery, very often there has been previously extensive bilateral disease, which leaves irreversible lung damage in its wake. Also some fall into the older age groups (45 - 55 years), where cardio-respiratory dysfunction, particularly from emphysema, is much more likely to be present. This factor also applies to most cases of lung cancer, in whom lung function studies offer a valuable contribution to their assessment for operation.

TABLE VIII

Disease	Pre-Op. Br.Spir. only.	Total Pre-Op. Br.-Spir.	Pre + Post Op. Br.-Spir.	Total no. of exams.
Pulmonary Tuberculosis.	144	200	56	256
Bronchial Carcinoma.	30	32	2	34
Bronchiect-asis.	11	15	4	19
Emphysematous Cysts.	3	3	1	4
Miscellaneous.	2	2	-	2
Anthracosis.	1	1	-	1

This Table also demonstrates that the vast majority of cases who had both pre- and post-operative bronchospirometry were tuberculous (56 out of 63). This was intentional, to estimate in as precise a manner as possible the functional loss from the various forms of surgical treatment and medical collapse measures (artificial pneumothorax and pneumoperitoneum) employed in pulmonary tuberculosis.

The two cases listed under the heading "Miscellaneous" were both chronic bronchitics under observation for exclusion of underlying bronchial carcinoma. Bronchoscopy proved negative in both instances, and the suspicious opacity cleared completely in each case without the necessity of surgical intervention. The solitary case of anthracosis is worthy of comment in passing. A male patient, aged 64 years, presented with a left hilar mass radiologically, along with retention pneumonitis of the left upper lobe. Bronchoscopy was quite normal, but thoracotomy seemed justifiable as the only means of excluding neoplasm. Lung function tests were satisfactory, and operation was undertaken. However, at thoracotomy the only abnormality found was some enlargement of the left hilar glands, but these were soft and not of the stony hardness characteristic of neoplasm. The glands were removed, and the chest closed. Histopathology of the excised lymph nodes revealed anthracosis only, with no evidence of any tumour involvement.

Duration of Study. The first case to be subjected to bronchospirometry in the Thoracic Unit, Mearnskirk Hospital, was in February, 1955, and the last examination for inclusion in the present series was performed in October, 1956; a period of 20 months' study. Lung function studies are continuing in the unit, as their application and use in assessing patients for major lung surgery is of ever-growing importance.

II. FUNCTIONAL LOSS FROM EACH TYPE OF PROCEDURE.

Some preliminary observations are apposite before describing fully this aspect of the subject. Firstly, it is imperative to leave an interval of 10 to 14 days between performing any endoscopic procedure, including bronchospirometry and bronchoscopy, and undertaking any chest surgery. This allows any cough and spit resultant from the examination to subside, and for any chemotherapy to be administered if required. In this manner the likelihood of a respiratory infection arising in the post-operative period is minimised.

To estimate functional loss after each procedure, it has been the custom to conduct bronchospirometry and other function tests before the procedure, and then 10 to 12 weeks after operation. By this time the patient is fully recovered, and adequate time has elapsed for the necessary compensatory changes to take place inside the thorax. Other authors have differed in the time at which post-operative respiratory function tests have been carried out. Leiner (1946), for example, left an interval of three months after operation (as in the present series), while Landis and Weisel (1954) preferred to wait a minimum of six months after a thoracoplasty operation. Lindahl (1954) went so far as to leave an interval of one to three or four years after five-rib thoracoplasties, as he maintained that this period was necessary for the adaptive and compensatory mechanisms of the lungs and thoracic cage to develop fully

TABLE IX

56 CASES OF P.T.B. STUDIED BEFORE AND AFTER EACH PROCEDURE LISTED

	Resection						
Thoraco-plasty	Segment-ectomy	Lobectomy	Bilobectomy	Plombage	Apicolysis with Fixation	A.P.	P.P. and phrenic crush
27 (one had crush-in type).	5	6	1	9	2	3	4

after this type of operation.

A. Pulmonary Tuberculosis.

Fifty-six cases with tubercle were studied before and after various surgical and medical procedures. Table IX enumerates the numbers involved in each form of therapy.

The total number in this Table is 57. This is due to one patient (Case 6, already described in full) in whom both a plombage operation and thoracoplasty were carried out, which makes altogether 57 procedures in 56 cases.

Thoracoplasty, with 27 cases, forms by far the largest number in this series, which is due to this operation being the predominant procedure carried out in this unit for the treatment of pulmonary tuberculosis. Resection, which includes segmentectomy, lobectomy, bilobectomy, and pneumonectomy (considered separately), comes next in precedence (12 cases), with plombage (9), pneumoperitoneum and phrenic crush (4), pneumothorax therapy (3), and apicolysis with fixation (2) completing the total. The most suitable method is to deal with each procedure singly, mentioning indications, resultant functional loss, and any complications which may ensue, and their detrimental effect on function.

1. Thoracoplasty.

This operation has withstood the test of time, since its first description early this century by Sauerbruch. It has undergone many variations and modifications throughout the years.

The old type of "crash-in" or "fillet" operation, involving two or three stages, and with no attempt at freeing the lung apex (apicolysis), was non-selective in character. While admittedly it led to arrest and finally cure of disease in many patients, it did so at the cost of very marked loss of function in the underlying lung (See Case 119, Chapter VI).

Powers and Himmelstein (1951) pointed out that scoliosis was a common late manifestation of the old type of thoracoplasty, and this led to a significant reduction in ventilatory function (as judged by the total vital capacity and M.V.C.). They maintained that it was not so much a question of the number of ribs removed as the removal of the anterior rib segments which produced the scoliotic deformity with its accompanying impairment of function. Cournand, Richards, and Maier (1941) described a patient subjected to this operation, as a result of which gross kypho-scoliosis was produced. Ultimately pulmonary hypertension developed, which led to respiratory insufficiency with anoxaemia from which the patient succumbed.

The modern type of thoracoplasty performed in Mearnskirk Hospital comprises a one-stage procedure, and involves removal of the whole of the first rib, with parts of ribs 2 - 5, inclusive. An apicolysis is carried out, with complete freeing of the lung apex from the upper mediastinal and thoracic structures, and a very selective collapse of the upper lobe is thereby achieved.

The indication par excellence for this type of operation is unilateral upper lobe cavitated disease of at least six months' duration, in which an adequate period of drug therapy and bed-rest has failed to effect cavity closure. Scadding (1955), while acquiescing with this, included disease extending below the upper third of the lung field as being suitable. This, however, would involve a fairly extensive operation, with probable removal of more than five ribs and a two-stage procedure. Other indications are for bilateral apical cavitated disease, where the patient's respiratory capacity is sufficient to withstand a five-rib thoracoplasty on both sides. For an incompletely filled pleural space after lobectomy, where the remainder of the lung has failed to re-expand fully; and to obliterate an empyema space, thoracoplasty offers an excellent chance of success. Chamberlain (1945) favoured thoracoplasty over lobectomy in all cases of upper lobe disease because it prevented overdistension of the underlying lung. He reserved upper lobectomy for the "failed thoracoplasty", cases in which cavity closure was not achieved by the initial operation.

For disease situated in the apex of lower lobe obviously the modern type of thoracoplasty has little or no application. Either local excision or a plombage operation is the form of surgery adopted for this type of lesion in this unit.

Twenty-seven cases in this series were studied before and after thoracoplasty, one of these having in addition a plombe

ABBREVIATIONS USED IN ALL THE FOLLOWING TABLES

T.A.	=	TIDAL AIR
O.U.	=	OXYGEN UPTAKE PER MINUTE
V.C.	=	VITAL CAPACITY
M.V.C.	=	MAXIMUM VENTILATORY CAPACITY
A.P.	=	ARTIFICIAL PNEUMOTHORAX
E.P.P.	=	EXTRA PLEURAL PNEUMOTHORAX
CAV.	=	CAVITY
CAVIT.	=	CAVITATION
BILAT.	=	BILATERAL
PNEUM.	=	PNEUMONECTOMY
U.L.	=	UPPER LOBE

TABLE X

27 CASES OF 5-RIB THORACOPLASTY - FUNCTION STUDIES BEFORE OPERATION

CASE	HISTORY & X-RAY APPEARANCES	RIGHT			LEFT			BOTH	
		T.A.	O.U.	V.C.	T.A.	O.U.	V.C.	V.C. (Ml.)	M.V.C. (L/min)
2	Old L.T.B.Empyema. Cavity R.U.L.	70%	33%	32%	30%	67%	68%	2500	-
6	Bilateral Apical Cav.	63%	87%	69%	37%	13%	31%	3600	-
8	Old Bilat.Disease	61%	63%	59%	39%	37%	41%	1900	-
18	Cavity L.U.L.	44%	53%	39%	56%	47%	61%	2500	-
19	Cavity R.U.L.	56%	64%	58%	44%	36%	42%	2000	-
22	Old L.A.P. Cavity R.U.L.	59%	69%	65%	41%	31%	35%	1900	60
23	Cavity L.U.L.	53%	41%	47%	47%	59%	53%	2000	80
29	Old R.A.P. Cavity L.U.L.	55%	57%	53%	45%	43%	47%	1950	-
42	Cavity R.U.L.	50%	44%	53%	50%	56%	47%	3200	-
43	Cavity R.U.L.	50%	45%	39%	50%	55%	61%	1900	72
47	Bilateral Apical Cav.	57%	57%	58%	43%	43%	42%	2250	-
48	Old Bil.A.P.S. Cav.L.U.L.	67%	80%	60%	33%	20%	40%	2250	86
56	Cavity R.U.L.	67%	60%	67%	33%	40%	33%	2250	64
77	Old Bil.Dis. Cav.R.U.L.	50%	50%	63%	50%	50%	37%	2100	60
84	Cavity R.U.L.	45%	38%	35%	55%	62%	65%	3100	84
87	Cavity R.U.L.	47%	45%	48%	53%	55%	52%	2000	61
92	Cavity R.U.L.	57%	54%	52%	43%	46%	48%	2400	58
94	Old L.A.P.+L.Phrenic +P.P. Still Cavity L.U.L.	55%	56%	53%	45%	44%	47%	3900	85
99	Cavity L.U.L.	50%	50%	55%	50%	50%	45%	2850	68
114	Old L.E.P.P. Cav.R.U.L.	47%	71%	49%	53%	29%	51%	4150	97
148	Old L.A.P. Cav.L.U.L.	53%	60%	59%	47%	40%	41%	3450	95
159	Old R.A.P. Cav. R.U.L.	60%	53%	57%	40%	47%	43%	1850	60
162	Cavity R.U.L.	67%	43%	55%	33%	57%	45%	2400	66
188	Cav.L.U.L. with stenosis L.U.L. Bronchus	73%	71%	74%	27%	29%	26%	2750	66
221	Old L.E.P.P.Cav.R.U.L.	53%	60%	55%	47%	40%	45%	2950	60
241	Cavity R.U.L.	43%	50%	47%	57%	50%	53%	3000	60
246	Cavity R.U.L.	53%	50%	50%	47%	50%	50%	3800	70

In all cases the indication for operation was Upper Lobe Cavity.
A.P. = Artificial Pneumothorax. E.P.P.= Extra-pleural Pneumothorax.

TABLE XI

27 CASES OF 5-RIB THORACOPLASTY - FUNCTION AFTER OPERATION

CASE	SIDE	POST OP. COMPLICATIONS	RIGHT T.A.	RIGHT O.U.	RIGHT V.C.	LEFT T.A.	LEFT O.U.	LEFT V.C.	BOTH V.C. (Ml.)	BOTH M.V.C. (L/min)
2	R.	-	18%	17%	29%	82%	83%	71%	1350	-
6	L.	Atelectasis	65%	80%	80%	35%	20%	20%	1950	58
8	L.	-	67%	71%	71%	33%	29%	29%	1300	-
18	L.	Pleural tear with haemothorax	57%	83%	60%	43%	17%	40%	2600	50
19	R.	-	53%	46%	57%	47%	54%	43%	2100	-
22	R.	-	45%	41%	47%	55%	59%	53%	2350	71
23	L.	Semb's Space Empyema	64%	67%	68%	36%	33%	32%	2400	84
29	L.	-	75%	83%	74%	25%	17%	26%	1650	62
42	R.	-	42%	43%	46%	58%	57%	54%	3500	84
43	R.	-	45%	45%	42%	55%	55%	58%	2600	78
47	R.+ L.	-	53%	50%	48%	47%	50%	52%	2750	100
48	L.	-	64%	67%	72%	36%	33%	28%	2550	89
56	R.	-	47%	47%	47%	53%	53%	53%	2600	64
77	R.	Stormy course ?Pulm.Hypertension	19%	13%	22%	81%	87%	78%	1825	63
84	R.	-	27%	23%	34%	73%	77%	66%	2450	78
87	R.	-	29%	31%	25%	71%	69%	75%	1600	48
92	R.	-	50%	37%	47%	50%	63%	53%	2200	70
94	L.	-	60%	67%	62%	40%	33%	38%	3600	78
99	L.	-	75%	73%	65%	25%	27%	35%	2300	66
114	R.	-	30%	17%	30%	73%	83%	70%	3300	90
148	L.	-	68%	67%	67%	32%	33%	33%	2900	90
159	R.	-	61%	58%	50%	39%	42%	50%	1950	64
162	R.	-	50%	60%	46%	50%	40%	54%	1700	48
188	L.	-	77%	75%	77%	23%	25%	23%	1850	60
221	R.	-	50%	50%	56%	50%	50%	44%	2150	48
241	R.	-	50%	48%	46%	50%	52%	54%	2550	66
246	R.	Pulm. Embolism	50%	47%	45%	50%	53%	55%	2750	63

TABLE XII

27 CASES OF 5-RIB THORACOPLASTY - LOSS OF FUNCTION

	LOSS OF FUNCTION					
	OPERATED SIDE			OVERALL		
Case	T.A.	O.U.	V.C.	V.C. (ml.+ %)	M.V.C. (L./min.+ %)	Comments
2	- 52%	- 16%	- 3%	- 1,150 (-46%)	-	AA
6	- 2%	+ 7%	- 11%	- 1,650 (-46%)	-	A
8	- 6%	- 8%	- 12%	- 600 (-31%)	-	A
18	- 13%	- 30%	- 21%	+ 100 (+ 4%)	-	AA
19	- 3%	- 18%	- 1%	+ 100 (+ 5%)	-	A
22	- 14%	- 28%	- 18%	+ 450 (+24%)	+ 11 (+18%)	A
23	- 11%	- 26%	- 21%	+ 400 (+10%)	+ 4 (+ 5%)	G
29	- 20%	- 26%	- 21%	- 300 (-15%)	-	A
42	- 8%	- 1%	- 7%	+ 300 (+ 9%)	-	A
43	- 5%	- 0%	+ 3%	+ 700 (+37%)	-	G
47	-	-	-	+ 550 (+24%)	-	G (Despite bi-lateral surgery)
48	+ 3%	+ 13%	- 12%	+ 300 (+13%)	+ 3 (+ 4%)	G
56	- 20%	- 13%	- 20%	+ 250 (+11%)	+ 0 (0%)	A
77	- 31%	- 37%	- 41%	- 275 (-13%)	+ 3 (+ 5%)	A
84	- 18%	- 15%	- 1%	- 650 (-21%)	- 6 (- 8%)	A
87	- 18%	- 14%	- 23%	- 400 (-20%)	- 13 (-21%)	A
92	- 7%	- 17%	- 5%	- 200 (- 8%)	+ 12 (+21%)	A
94	- 5%	- 11%	- 9%	- 300 (- 8%)	- 7 (- 8%)	A
99	- 25%	- 23%	- 10%	- 550 (-19%)	- 2 (- 3%)	A
114	- 17%	- 54%	- 19%	- 850 (-20%)	- 7 (- 7%)	A
148	- 15%	- 7%	- 8%	- 550 (-16%)	- 5 (- 5%)	A
159	+ 1%	+ 5%	- 7%	+ 100 (+ 5%)	+ 4 (+ 7%)	A
162	- 17%	+ 17%	- 9%	- 700 (-29%)	- 18 (-27%)	A
188	- 4%	- 4%	- 3%	- 900 (-33%)	- 6 (- 9%)	A
221	- 3%	- 10%	+ 1%	- 800 (-27%)	- 12 (-20%)	A
241	+ 7%	- 2%	- 1%	- 450 (-15%)	+ 6 (+10%)	A
246	- 3%	- 3%	- 5%	- 1,050 (-28%)	- 7 (-10%)	A

- = LOSS. + = GAIN.
A = AVERAGE LOSS.
AA = GREATER THAN AVERAGE LOSS.
G = SLIGHT GAIN.

(expressed in the combined vital capacity of both lungs and the maximum ventilatory capacity) in these 27 cases.

TABLE XIII.

MEAN FUNCTIONAL LOSS IN THORACOPLASTY (27).

Tidal Air.	O_2 Uptake per min.	Vital Capacity.	V.C. (both lungs).	M.V.C.
- 12%	- 14%	- 12%	- 336 ml. (-10.5%)	- 3%

These Tables (XII and XIII) demonstrate the impairment of function that can be expected after a standard five-rib thoracoplasty. Manifestly this predicted value for loss of function will be greater if any complications supervene. Case 18 exemplifies the detrimental effect of a haemothorax. This patient sustained a pleural tear at operation, which necessitated the insertion of an intercostal drainage tube post-operatively to drain the resultant haemothorax. Although the tube was removed on the fourth post-operative day by which time the pleural tear had sealed off and the underlying lung re-expanded, some pleural thickening remained at the left base. This caused quite marked impairment of the function of the underlying lung, particularly in regard to oxygen uptake which was reduced from a pre-operative level of 47 per cent. to 17 per cent. Watson and Gaensler (1952) noted similar findings in their cases where pleural complications developed.

CASE 23.

MODERN 5-RIB L.THORACO-
PLASTY (COMPARE WITH
CASE 119, OPPOSITE
PAGE 121).

Case 23 developed an empyema of the Sembs' space post-operatively, the offending organism being the staphylococcus aureus. However, with adequate drainage and drug therapy, the infection was eradicated completely, and the end result was excellent, with satisfactory collapse of the diseased area in the left upper lobe. The functional loss was no more than average, despite the Sembs' space empyema.

The other complications which occurred (Cases 6 and 246) are of interest. Case 6 had bilateral apical cavitation, with the left lung contributing only 25 per cent. of total function. Thoracoplasty was carried out first of all on this side, following which a transient atelectasis of the left lung developed. Bronchoscopic suction of retained secretions resulted in complete re-expansion, and three months later a plombage operation was performed on the right without any upset. The final lung function figures showed no more than the predicted loss of function. Case 246 developed acute cor pulmonale on the 12th post-operative day, with marked dyspnoea and cyanosis, due to a large pulmonary embolism. Fortunately, with prompt treatment (oxygen, sedation, and intravenous heparin, followed by oral anticoagulants) he made a full and successful recovery from a near-fatal complication. The lack of any radiological evidence of pulmonary infarction presupposed that the embolism had lodged in one branch of the main pulmonary artery, but that total occlusion had not occurred. Repeat lung function tests ten weeks later showed minimal impairment.

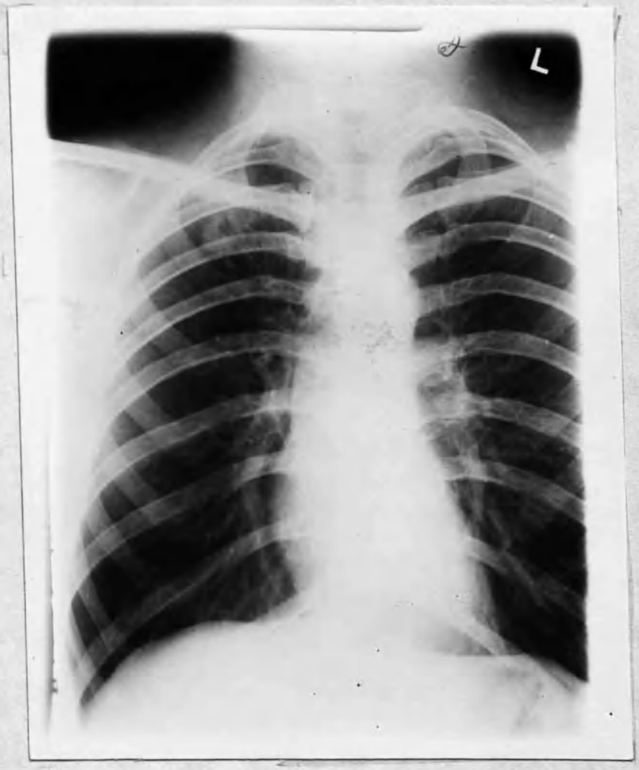
These were the only four complications in the 27 cases. Only one (Case 18) had any permanent detrimental effect on lung function, and in none was there any other lasting defect. Although this may seem an unduly high incidence of complications (four in 27 cases), it bears no relation to the true occurrence of such. Out of many hundred thoracoplasties performed in Mearnskirk over the past few years, the complications have been few indeed. No deaths were encountered in this series.

Comparing the figures found in the cases quoted above with the loss of function recorded by other authors after thoracoplasty, Leiner (1946) found a drop in the total vital capacity of 22 per cent. and ten per cent. in the M.V.C. The ventilation, oxygen consumption, and vital capacity decreased by 20 per cent. on the operated side. These figures were obtained from a study of 26 cases before and after a two or three-staged thoracoplasty. Gaensler and Streider (1950) observed severe functional impairment - 35 per cent. and 26 per cent. reductions in the total vital capacity and M.V.C., respectively. This they attributed to atelectasis and parodoxical breathing, associated with destruction of the thoracic cage, but they were dealing with the old type of "crash-in" operation.

The immediate effects of a thoracoplasty (as portrayed by the vital capacity, M.V.C., and arterial oxygen and carbon dioxide saturations) were reported by Stead and Soucheray (1952), who found a mild degree of anoxaemia and tachypnoea in all cases within 24 hours of each stage of the procedure. The loss recorded by Lindahl (1954), who examined his cases one to three years after a five-rib thoracoplasty, is more in agreement with that found in the present series. The M.V.C. was reduced by five per cent., the total vital capacity by 16 per cent.

Landis and Weisel (1954) compared the functional loss between a standard five-rib thoracoplasty and a segmental or wedge resection. The vital capacity decreased by 25 per cent. after a thoracoplasty, 11 per cent. after a segmental resection, and 8 per cent. after a wedge excision. The M.V.C. decreased by 11 per cent. after a thoracoplasty, and only 6 per cent. after a segmental resection. They concluded the loss in the former to be twice that in a segmental resection, thrice that in a wedge excision.

In conclusion the loss in this series has been much less than that previously reported, with the exception of that recorded by Lindahl and referred to above. Atelectasis and paradoxical respiration mentioned by Gaensler and Streider no longer occur in the modern type of operation, and scoliosis, a very common manifestation in the older thoracoplasty, is of no significance now. Selective in its collapse of the diseased area only, the modern operation occupies a very important place in the surgical management of upper lobe cavitated disease. The



CASE 224.

SMALL THICK-WALLED CAVITY R.U.L. - SUITABLE FOR SEGMENTAL RESECTION.

loss of function produced is minimal, and complications are rare and never serious if dealt with promptly and effectively.

2. Resection.

In all, 12 cases of resection were studied before and after operation (comprising five segmentals, six lobectomies, and one bilobectomy). In none was thoracoplasty performed simultaneously, as the impression in this unit is that combined lobectomy and thoracoplasty produce marked respiratory embarassment (Stead reported similar findings in 1953). Rather is thoracoplasty reserved for the case where the remainder of the lung fails to fill the space completely following an upper lobectomy. This was not required in any of the cases under discussion.

Scadding (1955) listed the indications for resection as: strictly localised disease, particularly where there was persistent cavitation, or disease situated in the apex of the lower lobe (the latter being unsuitable for collapse surgery). Broncho-stenosis of a major bronchus, tuberculous bronchiectasis, and tuberculous empyema were also cited as indications by Thompson, Savage, and Rosser (1954). These are generally recognised and accepted pre-requisites for resection surgery, but from experience in this unit over many years one important proviso must be added. The disease must be of two years' duration, to avoid the danger of spread post-operatively or reactivation at a later date, as a result of embarking on this form of surgery when the disease is still too active and not

TABLE XIV

12 CASES OF RESECTION FUNCTION STUDIES BEFORE OPERATION

CASE	PREVIOUS HISTORY AND X-RAY APPEARANCES	RIGHT T.A.	RIGHT O.U.	RIGHT V.C.	LEFT T.A.	LEFT O.U.	LEFT V.C.	BOTH V.C. (ml.)	BOTH M.V.C. (L/min)	
137	Cavity R.U.L.	47%	57%	49%	53%	43%	51%	2,500	50	
154	Previous L. Pleurisy. Cavity L.U.L.	64%	64%	62%	36%	36%	38%	3,700	95	
210	Previous L. Phrenic + P.P. Still Tuberculoma L.U.L.	54%	62%	59%	46%	38%	41%	2,650	54	(a)
224	Cavity R.U.L.	53%	53%	51%	47%	47%	49%	4,600	96	
259	Previous R.A.P. Still Cav.R.U.L.	47%	46%	45%	53%	54%	55%	2,750	68	
31	Tuberculoma L.U.L.	50%	55%	56%	50%	45%	44%	1,950	46	
50	Cavity L.U.L.	57%	73%	61%	43%	27%	39%	2,250	72	
52	Cavity L.U.L.	56%	55%	50%	44%	45%	50%	2,250	45	(b)
55	Old Disease Apex R.L.L. Cav. R.U.L.	43%	44%	49%	57%	56%	51%	5,000	100	
119	Cavity L.U.L. Under old 'plasty	87%	86%	78%	13%	14%	22%	2,600	76	
267	Previous R.A.P. Cavity L.U.L.	62%	83%	55%	38%	17%	45%	2,750	62	
144	Previous R. Phrenic + P.P. Still Cav. R.L.L.	43%	40%	38%	59%	60%	62%	3,900	120	(c)

(a) = 5 cases who had a segmental resection.

(b) = 6 cases who had resection of an entire lobe.

(c) = 1 case who had a bilobectomy.

A.P. = Artificial pneumothorax.

TABLE XV

12 CASES OF RESECTION FUNCTION AFTER OPERATION

			RIGHT			LEFT			BOTH		
CASE	OPERATION	POST OP. COMPLICATIONS	T.A.	O.U.	V.C.	T.A.	O.U.	V.C.	V.C. (ml.)	M.V.C. (L/min)	
137	S.R.	-	23%	33%	26%	77%	67%	74%	1,900	51	
154	S.L.	-	67%	75%	71%	33%	25%	29%	2,600	72	
210	S.L.	-	63%	60%	69%	37%	40%	31%	2,250	60	(a)
224	S.R.	H.S.J.	38%	36%	38%	62%	64%	62%	3,300	90	
259	S.R.	-	40%	33%	34%	60%	67%	60%	2,100	70	
31	LO.L.	-	57%	54%	65%	43%	46%	35%	1,800	44	
50	LO.L.	Atelectasis	78%	86%	87%	22%	14%	13%	1,500	56	
52	LO.L.	Pulm. Embol.	67%	80%	75%	33%	20%	25%	1,950	65	(b)
55	LO.R.	-	31%	33%	31%	69%	67%	69%	4,250	84	
119	LO.L.	-	83%	80%	80%	17%	20%	20%	2,250	70	
267	L.O.L.	Delayed Re-expansion	87%	80%	75%	13%	20%	25%	1,900	49	
144	Bilob.R.	-	33%	30%	35%	67%	70%	65%	3,200	90	(c)

H.S.J. = Homol. Ser. Jaundice

S. = Segmentectomy

LO. = Lobectomy

BILOB. = Bilobectomy

L. = Left

R. = Right

TABLE XVI

12 CASES OF RESECTION LOSS OF FUNCTION

	LOSS OF FUNCTION				
	OPERATED SIDE			OVERALL	
CASE	T.A.	O.U.	V.C.	V.C. (Ml. + %)	M.V.C. (L./Min. + %)
137	- 24%	- 24%	- 23%	- 600 (- 24%)	+ 1 (+ 2%)
154	- 3%	- 11%	- 9%	- 1,100 (- 29%)	- 21 (- 22%)
210	- 9%	+ 2%	- 10%	- 400 (- 15%)	+ 6 (+ 11%)
224	- 15%	- 17%	- 13%	- 1,300 (- 28%)	- 22 (- 23%)
259	- 7%	- 13%	- 11%	- 650 (- 24%)	+ 2 (+ 3%)
31	- 7%	+ 1%	- 9%	- 150 (- 7%)	- 2 (- 4%)
50	- 21%	- 13%	- 26%	- 750 (- 33%)	- 16 (- 22%)
52	- 11%	- 25%	- 25%	- 300 (- 13%)	+ 20 (+ 44%)
55	- 12%	- 11%	- 18%	- 750 (- 15%)	- 16 (- 16%)
119	+ 4%	+ 6%	- 2%	- 350 (- 13%)	- 6 (- 8%)
267	- 25%	+ 3%	- 20%	- 850 (- 31%)	- 13 (- 21%)
144	- 10%	- 10%	- 3%	- 700 (- 18%)	- 30 (- 25%)

\- = Loss

\+ = Gain

yet fully mature.

Two other conditions warrant resection, the first being in the "failed" thoracoplasty, where cavity closure is not achieved. The second is the so-called "tuberculoma". Many of these tuberculomata are in fact blocked cavities, and they remain a potential danger to patients. Some of these lesions, however, show evidence of calcification at the periphery, and can possibly be left alone. In most, resection is the best policy, particularly as one can never exclude a single, small, rounded opacity as being an early peripheral bronchial carcinoma.

Tables XIV, XV and XVI summarise the 12 cases, with particular reference to the indications for resection, and the complications which ensued.

In Table XVII the mean functional loss after segmentectomy, lobectomy, and bilobectomy is recorded separately.

TABLE XVII

Operation	Tidal Air	O_2 Uptake per min.	Vital Capacity	V.C. (both lungs)	M.V.C.
Segmental (5)	- 10%	- 12%	- 13%	- 810 -(24%)	- 4 -(6%)
Lobectomy (6)	- 12%	- 6.5%	- 20%	- 525 - (18%)	- 5.5 -(5%)
Bilobectomy (1)	- 10%	- 10%	- 3%	- 700 -(18%)	- 30 -(25%)

MEAN FUNCTIONAL LOSS IN 12 CASES OF RESECTION.

This Table shows that the functional loss even after excision of one segment of a lobe is quite considerable, certainly greater than after a five-rib thoracoplasty. (See Table XIII).

The most feared of all complications following resection surgery is spread of disease. This should rarely occur if the specific indications for the operation and its limitations are adhered to strictly. No spread occurred in any case in this series. The complications encountered in these 12 cases comprised one case of atelectasis (Case 50), which necessitated bronchoscopic suction on two occasions. Although complete re-expansion eventually occurred, final lung function studies showed considerable loss of function. Pulmonary embolism with infarction was met with in one case (Case 52), but this did not materially affect final lung function. The marked reduction of function on the operated side in Case 267 can be attributed to a combination of two factors - delayed re-expansion of the remainder of the left lung, and paralysis of the phrenic nerve which was done intentionally at operation to prevent over-distension of the remainder of the lung.

Case 224 presented an interesting complication not related directly to the operation itself, but to the blood transfusion given at the time of operation, namely homologous serum jaundice. A complete recovery was made from the jaundice.

All four cases who developed the complications discussed were finally discharged in excellent condition, with complete eradication of their disease.

Other possible complications of resection surgery are: haemorrhage, haemothorax, empyema, and broncho-pleural fistula (Thompson, Savage, and Rosser, 1954). None of these was met with in this series, and there were no deaths.

Gaensler (1953) and Taylor, Roos, and Burford (1950) reported that the functional loss after resection (lobectomy or segmenectomy) was greater than after thoracoplasty, the findings in the present series being in complete agreement with this. Landis and Weissel (1954), as mentioned above, found the reverse to be true in their cases. Gaensler attributed the greater loss after resection to be due to post-operative haemothorax, which even in small degree could lead to eventual pleural fixation with fibrothorax. It is obvious how important it is then not to let any blood remain in the pleural space after operation. If any fluid remains when the intercostal drainage tube is removed 48 hours after operation, it must be aspirated assiduously, repeatedly if necessary.

<u>Factors Influencing Impairment of Lung Function Pre-Operatively.</u>

Gaensler (1953) discussed fully this aspect of the subject, and mentioned four factors which might possibly affect pulmonary function as a result of previous or existing disease. These factors were: parenchymal disease, pleural complications, bronchial involvement, and pulmonary artery obstruction. Any of these singly or in combination might seriously impair lung function, although pleural complications were found to be the most detrimental to function.

In the present series previous pneumothorax therapy had little or no effect on respiratory capacity. However, bronchostenosis of a main bronchus in Case 188 (Table X) did limit the function of the ipsilateral lung pre-operatively, subsequent thoracoplasty causing little decrease in function. The effect of extensive parenchymatous disease was well illustrated in Case 77, where there was reduced function on both sides before operation, and post-operatively the course proved very stormy indeed. The limiting effect of a previous phrenic crush and pneumoperitoneum was demonstrated in Case 144 pre-operatively (Table XIV), where the function of the right lung was ten per cent. less than the predicted value.

3. Plombage Operation.

Nine cases of this form of therapy were studied before and after operation. One of these, as already mentioned, had a thoracoplasty performed first of all on the left, followed later by a right plombe, and has been included in the thoracoplasty series (Case 6), too.

The operation of plombage consists of the insertion of a polystan plombe, with the object of producing a selective compression collapse of the diseased area. Various objects, such as leucite spheres, have been tried previously, but the polystan pack has been chosen in Mearnskirk because it appears to be the safest and most effective material available at present. The plombe itself is of varying sizes; small, medium, and large, respectively. By simple preparation beforehand, it can be moulded into any shape and size to meet the individual requirements of each patient.

Morriston-Davies, Temple, and Stalatos (1951) indicated the main uses of this operation. Free of the risk of producing paradoxical breathing and any scoliotic deformity of the spine, it is essentially suited for the poor-risk patients, those with diminished respiratory capacity of marked degree, and for bilateral cases. It should not be carried out for large tension cavities, thick-walled cavities, or tuberculomata.

The indications in this series have been in cases of upper lobe cavitation where lung function was poor (either from previous collapse surgery or extensive parenchymal disease), where bilateral surgery was contemplated, and in cavitation situated in the apex of lower lobe ("dorsal lobe"). This latter type of lesion is not readily amenable to any other therapy apart from plombage or local excision of the part.

Other uses, in which the polystan pack has been employed, are for basal bronchiectasis and for filling the space left after pneumonectomy, particularly in cases of bronchial carcinoma. (Gaensler and Streider, 1951).

TABLE XVIII

9 CASES OF PLOMBAGE OPERATION PRE-OPERATIVE STUDIES

CASE	PREVIOUS HISTORY AND X RAY APPEARANCES	RIGHT			LEFT			BOTH	
		T.A.	O.U.	V.C.	T.A.	O.U.	V.C.	V.C. (ml.)	M.V.C. (L/min)
6	Old L. 'Plasty Cavity R.U.L.	63%	87%	69%	37%	13%	31%	3,600	-
44	Old L. 'Plasty Cavity R.U.L.	67%	56%	57%	33%	44%	43%	2,250	48
54	Previous Bilateral A.P.S. + L. Phrenic Cavity R.U.L.	78%	73%	73%	22%	27%	27%	1,200	57
61	Previous L.A.P. + L. Phrenic. Still Cav. L.U.L.	78%	75%	79%	22%	25%	21%	1,450	56
73	Bilat. Upper Lobe Cavitation	45%	45%	40%	55%	55%	60%	2,700	70
75	Previous L. Phrenic. Still Cav. L.U.L.	55%	71%	67%	45%	29%	33%	2,000	64
108	Old L. Pleurisy Cavity L.U.L.	50%	25%	50%	50%	75%	50%	2,250	70
123	Previous R. Phrenic. Still Cav. R.L.L.	34%	41%	50%	66%	59%	50%	1,700	50
133	Previous L. Phrenic. Still Cav. L.U.L.	57%	73%	57%	43%	27%	43%	1,650	67

(A.P. = Artificial pneumothorax. In all cases of phrenic crush, there was a co-incident pneumoperitoneum.)

TABLE XIX

9 CASES OF PLOMBAGE OPERATION POST-OP. STUDIES

CASE	SIDE + SIZE	RIGHT			LEFT			BOTH	
		T.A.	O.U.	V.C.	T.A.	O.U.	V.C.	V.C. (Ml.)	M.V.C. (L/Min)
6	R. M.	65%	80%	80%	35%	20%	20%	1,950	58
44	R. M.	67%	50%	62%	33%	50%	38%	2,400	67
54	R. M.	31%	25%	33%	69%	75%	67%	1,150	55
61	L. M.	75%	83%	72%	25%	17%	28%	1,550	47
73	L. LA.	38%	40%	45%	62%	60%	55%	2,200	60
75	L. LA.	87%	83%	87%	13%	17%	13%	1,700	60
108	L. M.	83%	86%	81%	17%	14%	19%	2,700	70
123	R. M.	36%	36%	40%	64%	64%	60%	1,750	50
133	L. LA.	86%	80%	90%	14%	20%	10%	1,750	58

R. = Right

L. = Left

LA. = Large Plombe

M. = Medium Plombe

No complications were encountered.

TABLE XX

9 CASES OF PLOMBAGE OPERATION LOSS OF FUNCTION

	LOSS OF FUNCTION				
	OPERATED			OVERALL	
CASE	T.A.	O.U.	V.C.	V.C. (Ml. + %)	M.V.C. (L./Min. + %)
6	+ 2%	- 7%	+ 11%	-1,650 (-46%)	-
44	0%	- 6%	+ 5%	+ 150 (+ 7%)	- 10 (- 21%)
54	- 47%	- 48%	- 40%	- 50 (- 4%)	+ 1 (+ 2%)
61	+ 3%	- 8%	+ 7%	+ 100 (+ 7%	- 9 (- 16%)
73	+ 7%	+ 5%	- 5%	- 500 (-18%)	- 10 (- 14%)
75	- 32%	- 12%	- 20%	- 300 (-15%)	- 4 (- 6%)
108	- 33%	- 61%	- 31%	+ 450 (+20%)	0 (0%)
123	+ 2%	- 5%	- 10%	+ 50 (+ 3%)	0 (0%)
133	- 29%	- 7%	- 33%	+ 100 (+ 6%)	- 9 (- 13%)

TABLE XXII

3 CASES OF EXTRA-PLEURAL PNEUMOTHORAX (AFTER RE-EXPANSION ONLY)

	RIGHT			LEFT			BOTH			
CASE	T.A.	O.U.	V.C.	T.A.	O.U.	V.C.	V.C. (ML.)	M.V.C. (L/Min)	SIDE OF E.P.P.	PRESENT CONDITION + PROPOSED TREATMENT
114	47%	71%	49%	53%	29%	51%	4,150	97	L.	Cav. R.U.L. R. 'Plasty
221	53%	60%	55%	47%	40%	45%	2,950	60	L.	Cav. R.U.L. R. 'Plasty
230	50%	50%	45%	50%	50%	55%	2,250	50	R.	Cav. R.U.L. R. 'Plasty

(Cases 114 and 221 required contralateral therapy, Case 230 ipsilateral for a "failed E.P.P.").

TABLE XXI

Tidal Air.	O_2 Uptake per min.	Vital Capacity.	Vital Capacity (Both)	M.V.C.
- 14%	- 16%	- 13%	- 4.5%	- 8.5%

MEAN FUNCTIONAL LOSS IN 9 CASES OF PLOMBAGE.

As can be seen from Table XVIII most of the cases had long-standing disease, fairly extensive in character. Cases 6 and 44 had contralateral thoracoplasties, and function was conserved as much as possible on the diseased side by use of the polystan plombe.

Cases 54 and 61 had markedly reduced function pre-operatively, as the combined result of previous extensive bilateral disease and medical collapse measures (phrenic crush, pneumoperitoneum, and artificial pneumothorax). Case 108 had a plombage done for a cavity in the left upper lobe in preference to a thoracoplasty, on account of his age (50 years) and rather bronchitic chest. A right phrenic crush and pneumoperitoneum had failed to close a rather large cavity in the apex of right lower lobe in Case 123, in addition to which there was scattered disease throughout the rest of the right lung. Because local excision was contra-indicated in the presence of this scattered disease, and pneumonectomy was precluded because of impaired respiratory capacity, plombage appeared to be the operation of choice. This was accomplished uneventfully, with resultant cavity closure.

Case 73 had bilateral upper lobe cavitation with emphysema of both lower lobes and a marked bronchitic chest. The intention was to carry out bilateral plombage, but the right side was left in abeyance as he had a very difficult course after a left plombage. (See Chapter VI).

There were no complications whatever in these cases, and no deaths. The complications which may arise after this operation were mentioned by Morriston-Davies et al. (1951), and include atelectasis, haemorrhage, and infection occurring in or around the plombe.

As regards loss of function, Dressler, Bronfin, and Grow (1950) found a decrease of 5.9 per cent. in the M.V.C. and 12 per cent. in the total vital capacity, figures corresponding with the ones detailed above.

4. <u>Extra-pleural pneumothorax.</u>

No cases were subjected to this procedure during the course of the present study. However, three cases were studied following completion of refills and re-expansion of the underlying lung, with a view to their having further surgery. The results are presented in Table XXII.

All three cases had good function on the side of the abandoned extra-pleural pneumothorax, confirming the contention made by Gaensler and Streider (1950) as to this operation being

CASE 114.

POST-OP. FILM, SHOWING
ABANDONED L.E.P.P. +
RECENT R.SIDED 5-RIB
THORACOPLASTY.

CASE 114.

PRE-OP. CHART.

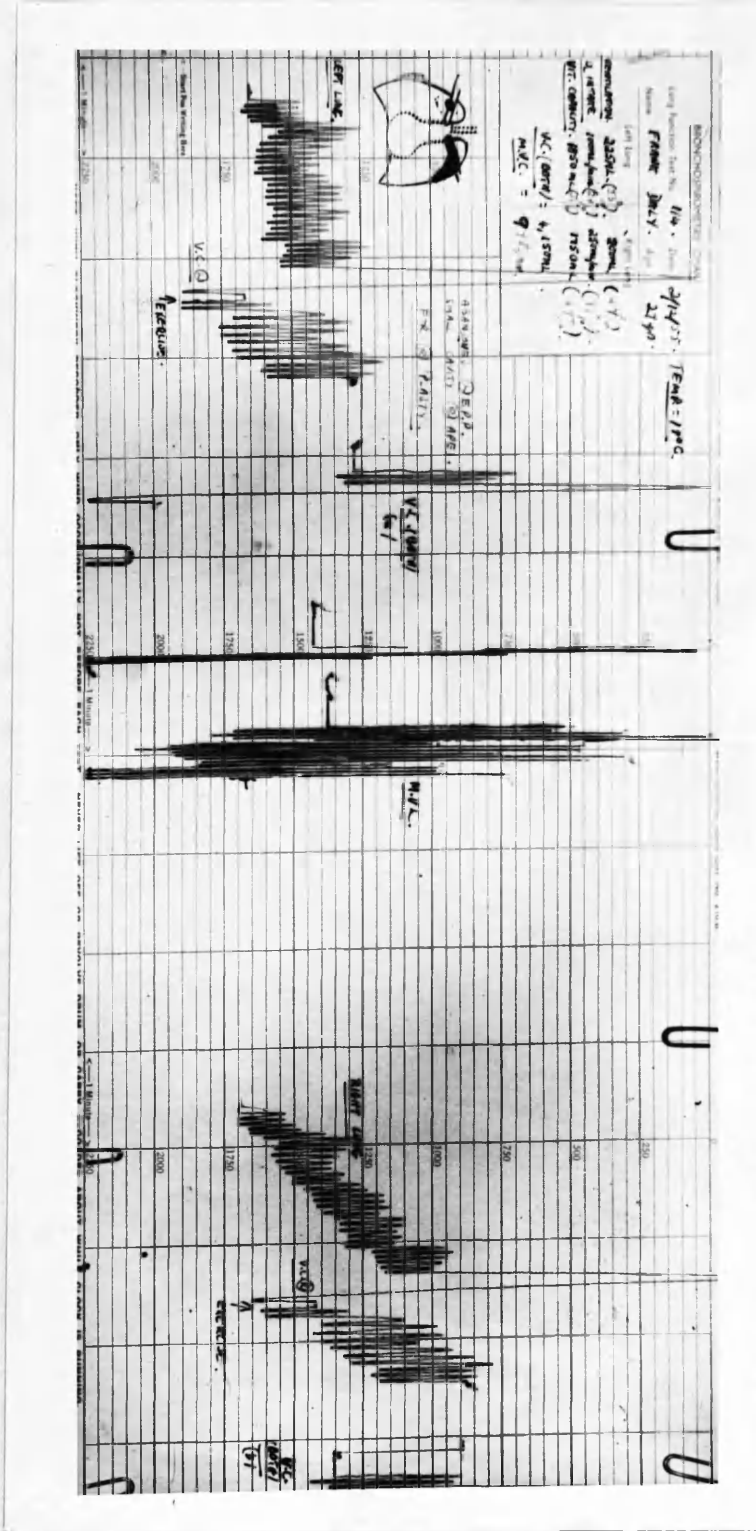


TABLE XXIII

2 CASES OF APICOLYSIS WITH FIXATION PRE-OP. STUDIES

CASE	PREVIOUS HISTORY AND X-RAY APPEARANCES	RIGHT T.A.	RIGHT O.U.	RIGHT V.C.	LEFT T.A.	LEFT O.U.	LEFT V.C.	BOTH V.C. (Ml.)	BOTH M.V.C. (L/Min)
142	Bilateral Disease Cavity L.U.L.	57%	58%	57%	43%	42%	43%	2,300	72
163	Old R.A.P. Still Cavity R.U.L.	48%	45%	46%	52%	55%	54%	4,100	60

(A.P. = Artificial pneumothorax).

TABLE XXIV

2 CASES OF APICOLYSIS WITH FIXATION POST-OP. STUDIES

CASE	SIDE	RIGHT T.A.	RIGHT O.U.	RIGHT V.C.	LEFT T.A.	LEFT O.U.	LEFT V.C.	BOTH V.C. (Ml.)	BOTH M.V.C. (L/Min)
142	L.	50%	100%	50%	50%	Nil	50%	1,500	47
163	R.	48%	50%	43%	52%	50%	57%	3,400	70

the most function-conserving of all.

The three cases subsequently underwent thoracoplasty with no upset whatever. Two of the thoracoplasties were done on the contralateral side, the other on the ipsilateral.

5. Apicolysis with Fixation.

This is a very recent procedure introduced to this unit, and it consists of a standard apicolysis in the extra-pleural plane (as opposed to the extra-fascial one in thoracoplasty). No ribs are removed, and the apicolysis is supported by securing and suturing the fascial layer over the lung apex, leaving what is in effect an extra-pleural pneumothorax but without the need for air refills. The space fills with blood which helps in maintaining an apical collapse on a semi-permanent basis.

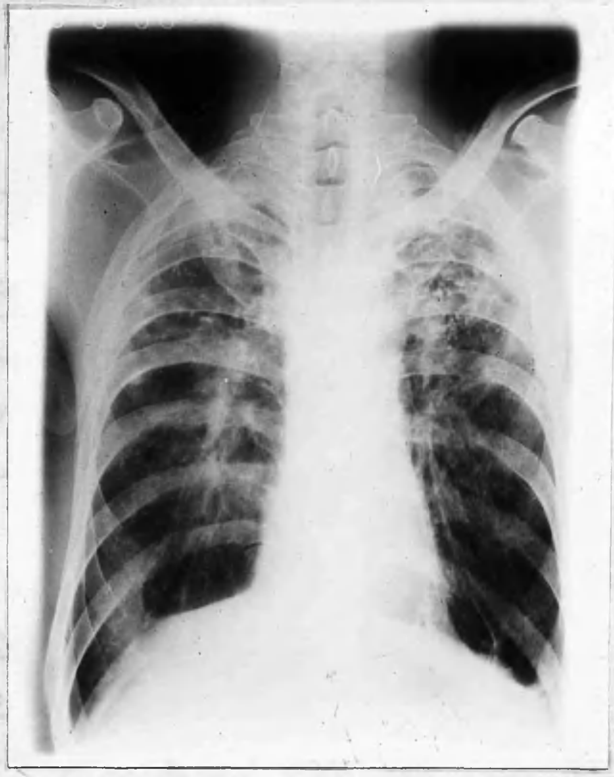
Its application is limited at present to minimal apical disease in which there is a small cavity, particularly in adolescents to avoid the deformity that might ensue after a thoracoplasty done at a time when the thoracic cage has not yet completed its full growth. Poor respiratory capacity is another indication.

Only two cases have had this operation performed in Mearnskirk to date. The appropriate findings are tabulated opposite. (Tables XXIII, XXIV, and XXV).

Case 142 was a patient with long-standing pulmonary tuberculosis and superimposed chronic bronchitis. There was disease in both upper lobes, with definite cavitation in the

CASE 142.

PRE-OP.
BILATERAL UPPER
LOBE DISEASE.
CAVITY L. APEX.



CASE 142.

POST-OP. SHOWING
L.APICOLYSIS WITH
FIXATION.

TABLE XXV

2 CASES OF APICOLYSIS WITH FIXATION LOSS OF FUNCTION

	LOSS OF FUNCTION				
	OPERATED SIDE			OVERALL	
CASE	T.A.	O.U.	V.C.	V.C. (Ml. + %)	M.V.C. (L/Min. + %)
142	+ 7%	-42%	+ 7%	- 800 (- 35%)	-25 (- 35%)
163	0%	+ 5%	- 3%	- 700 (- 17%)	+11 (+ 18%)

− = Loss

\+ = Gain

TABLE XXVI

6 CASES OF OLD-TYPE THORACOPLASTY

		RIGHT			LEFT			BOTH		
CASE	'PLASTY	T.A.	O.U.	V.C.	T.A.	O.U.	V.C.	V.C. (Ml.)	M.V.C. (L/Min)	Present condition and proposed treatment
1	R.	18%	Nil	39%	82%	100%	61%	1,650	-	Cav. Apex R.L.L. R. Pneum.
3	R.	11%	Nil	19%	89%	100%	81%	1,450	-	Cav. R.U.L. R. Pneum.
57	R.	40%	45%	46%	60%	55%	54%	1,950	58	Cav. R.U.L. R.U. Lobectomy
119	L.	87%	86%	78%	13%	14%	22%	2,600	76	Cav. L.U.L. L.U. Lobectomy
138	L.	76%	86%	87%	24%	14%	13%	2,600	82	Cav. L.U.L. L. Pneum.
273	L.	93%	91%	88%	7%	9%	12%	2,250	56	Cav. R.U.L. R. Plombage

CAV. = Cavity

PNEUM. = Pneumonectomy

left. Some form of function-conserving operation seemed imperative, but post-operative tests showed total absence of participation in oxygen uptake by the left lung. This might possibly be due to thrombosis of the left pulmonary artery.

Although two cases are insufficient evidence on which to pass any judgement, functional loss in both cases was far from negligible. This tends to cast doubt on the wisdom of subjecting patients with diminished lung function to such a procedure.

6. Old type thoracoplasty (so-called "crash-in" or "fillet").

This operation entailed a fairly extensive removal of ribs (up to ten in number), and involved two or three stages. Its use has been abandoned long since in most centres, including Mearnskirk. It is of interest, however, to record the end results of such an operation many years after its completion, as six such cases presented themselves for assessment for further surgery.

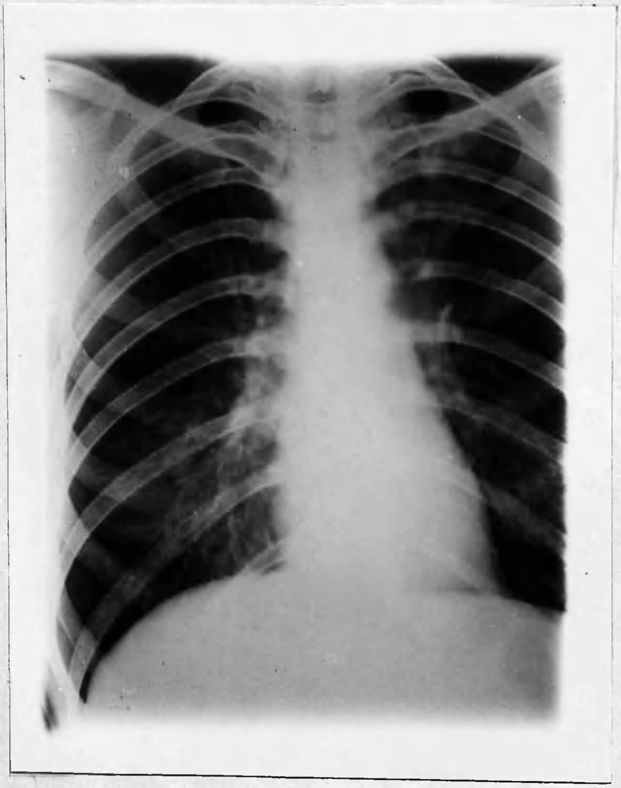
Table XXVI presents the relevant details of these patients, and summarises their subsequent progress and treatment.

From this Table it is quite obvious that on the thoracoplasty side the lung was virtually functionless, with the exception of Case 57. Cases 1, 3, and 138 underwent total pneumonectomy on the thoracoplasty side because of persistent disease. Cases 57 and 119, however, had excision of the upper lobe only, the reason in Case 57 being that the thoracoplasty side still contributed nearly half the total function, and in both cases the lower lobes were left because they appeared free from any disease.

Case 273 presented a particular problem in that, whereas in the other five cases active disease was present on the thoracoplasty side with the contralateral side clear, in this instance a cavity was present in the upper lobe of the contralateral lung. In view of the functionless state of the left lung (less than ten per cent. of total function), a right plombage was deemed the most suitable form of therapy to conserve right lung function as much as possible.

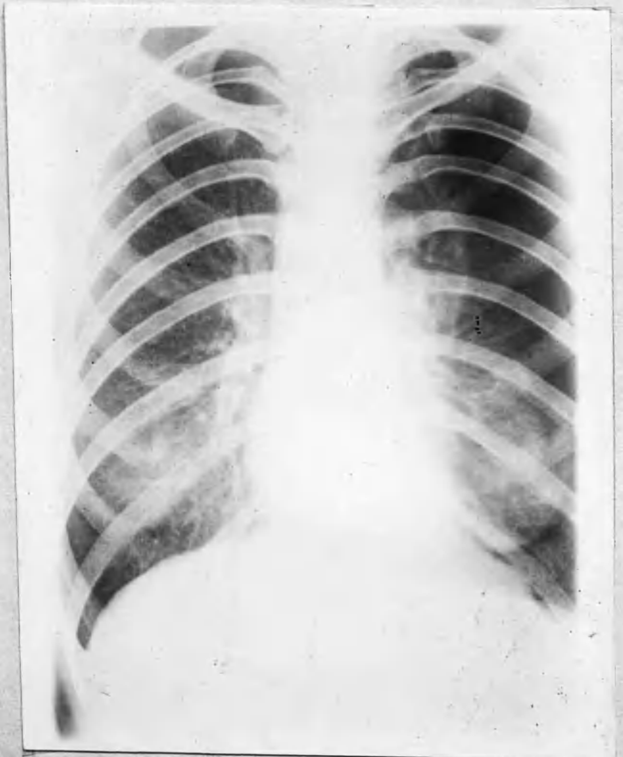
All six cases underwent the additional treatment outlined without any appreciable disturbance whatever.

Thus the old type of thoracoplasty has been abandoned rightly in the modern treatment of pulmonary tuberculosis. Apart from the deformity it produced, with the possibility of the development at a future date of pulmonary hypertension, cor pulmonale, and right heart failure, it caused a decrease in function as great as after total pneumonectomy. Also, on account of its non-selective nature, it very often failed to control the underlying disease as in five of the cases cited above. The modern five-rib thoracoplasty with apicolysis overcomes all these problems, producing a very selective collapse of upper lobe disease with a minimum loss of function.



CASE 41.

CAVITATED LESION
OF L.U.L.



CASE 41.

GOOD L. ARTIFICIAL
PNEUMOTHORAX, WITH
CONTROL OF DISEASE.

7. Artificial Pneumothorax.

Pneumothorax therapy was in great vogue not so many years ago. Enthusiasm for it was carried too far at times, with the result that it was induced in some cases which were unsuitable, and continued in other cases where it should have been abandoned, (for example, non-closure of a cavity in a pneumothorax, atelectasis of a lobe or whole lung, long tenuous adhesions originating in or around the diseased area, and commencing pleural effusion). This often led to a tuberculous empyema, with eventual fibrothorax and a lung encased in a grossly thickened pleura, with little or no function in the lung (Birath, 1952; Gaensler, Watson, and Paton, 1951).

Artificial pneumothorax fell into great disrepute as a consequence, and many clinicians refuse to conside inducing a pneumothorax at the present time. However, it probably still has a part to play in the treatment of pulmonary tuberculosis, provided it is induced in the absence of any such contra-indications as endobronchitis, tension cavity, and very recent, exudative disease, and is carefully supervised. It should be abandoned immediately if any of the complications discussed above develop at any time.

Only three cases have been studied before and after pneumothorax induction in this series. Five additional cases were studied before induction, but the pneumothorax was abandoned shortly afterwards because it was unsuccessful.

TABLE XXVII

18 CASES OF A.P. STUDIED ONLY AFTER ABANDONMENT

		RIGHT			LEFT			BOTH		
CASE	SIDE	T.A.	O.U.	V.C.	T.A.	O.U.	V.C.	V.C. (Ml.)	M.V.C (L/Min)	PRESENT CONDITION AND PROPOSED TREATMENT
4	L.	64%	80%	72%	36%	20%	28%	1,400	-	Cav. L.U.L. L. 'Plasty.
7	R. + L.	80%	87%	75%	20%	13%	25%	2,300	-	Destroyed L. Lung. L. Pneum.
9	R. + L.	67%	57%	57%	33%	43%	43%	1,300	-	Cav. R.U.L. R. 'Plasty.
14	L.	50%	36%	36%	50%	64%	50%	1,800	-	Cav. L.U.L. L. 'Plasty
22	L.	59%	69%	65%	41%	31%	35%	1,900	60	Cav. R.U.L. R. 'Plasty
29	R.	55%	57%	53%	45%	43%	47%	1,950	56	Cav. L.U.L. L. 'Plasty
30	R.	80%	91%	81%	20%	9%	19%	1,150	48	Destroyed L. Lung. L. Pneum.
48	R. + L.	67%	80%	60%	33%	20%	40%	2,250	86	Cav. L.U.L. L. 'Plasty.
54	R.	22%	27%	27%	78%	73%	73%	1,200	57	Cav. R.U.L. R. Plombage
85	R.	53%	50%	50%	47%	50%	50%	1,650	50	Cav. L.U.L. L.U. Lobectomy
140	R.	50%	43%	46%	50%	57%	54%	2,550	76	Cav. R.U.L. R.U. Lobectomy + R.'Plasty
143	L.	45%	57%	60%	55%	43%	40%	2,650	62	Cav. Apex L.L.L. L. Plombage
146	R.	43%	50%	43%	57%	50%	57%	1,400	42	Cav. L.U.L. Nil.
148	L.	53%	60%	59%	47%	40%	41%	3,450	95	Cav.L.U.L. L.'Plasty
159	R.	60%	53%	57%	40%	47%	43%	1,850	60	Cav.R.U.L. R.'Plasty
163	R.	48%	45%	46%	52%	55%	54%	4,100	60	Cav.R.U.L. R.'Plasty
169	L.	67%	73%	60%	33%	27%	40%	3,200	75	Cav.L.U.L. L.'Plasty
176	L.	45%	46%	55%	55%	54%	45%	2,900	90	Cav.L.U.L. L.'Plasty

(A.P. = Artificial pneumothorax.)

Pneum. = Pneumectomy.

TABLE XXVIII

3 CASES OF A.P. PRE-INDUCTION

		RIGHT			LEFT			BOTH	
CASE	INDICATIONS	T.A.	O.U.	V.C.	T.A.	O.U.	V.C.	V.C. (Ml.)	M.V.C (L/Min)
37	Cav. R.U.L.	56%	56%	52%	44%	44%	48%	3,200	96
41	Small Cav. L.U.L.	56%	50%	52%	44%	50%	48%	3,500	96
53	Cav. L.U.L.	66%	66%	66%	34%	34%	34%	2,300	80

TABLE XXIX

3 CASES OF A.P. AFTER INDUCTION

		RIGHT			LEFT			BOTH	
CASE	SIDE	T.A.	O.U.	V.C.	T.A.	O.U.	V.C.	V.C. (Ml.)	M.V.C. (L/Min)
37	R.	42%	50%	50%	58%	50%	50%	2,900	86
41	L.	67%	85%	62%	33%	15%	38%	2,600	90
53	L.	60%	64%	60%	40%	36%	40%	1,600	53

TABLE XXX

3 CASES OF A.P. LOSS OF FUNCTION

	LOSS OF FUNCTION				
	A.P. SIDE			OVERALL	
CASE	T.A.	O.U.	V.C.	V.C. (ML. + %)	M.V.C. (L./Min. + %)
37	-14%	- 6%	- 2%	- 300 (- 9%)	- 10 (- 10%)
41	-11%	-35%	-10%	- 900 (-26%)	- 6 (- 6%)
53	+ 6%	+ 2%	+ 6%	- 900 (-39%)	- 27 (- 34%)

\- = loss

\+ = Gain

The paucity of cases is due to the strict criteria for selection of cases.

Eighteen further cases of abandoned pneumothorax, who were being assessed for surgical treatment, are included in Table XXVII.

TABLE XXXI.

Tidal Air.	O_2 Uptake per Min.	Vital Capacity.	Vit.Cap. (Both)	M.V.C.
- 6%	- 13%	- 2%	- 25%	- 17%

MEAN LOSS IN CASES 37, 41, and 53 (A.P.S.)

The overall function in these three cases was reduced by 20 - 25 per cent., with the pneumothorax still in being. On completion of the collapse and after re-expansion of the lung, an increase in overall function can be anticipated.

Of the 18 cases studied only after the artificial pneumothorax had been abandoned, only four (Cases 4, 7, 48, and 54) showed marked impairment of function on the pneumothorax side. Case 4 showed a grossly thickened pleural on the left radiologically, while Cases 7 and 48 had had bilateral pneumothorax therapy. A contributory cause to the reduced function on the pneumothorax side in Case 54 was that the phrenic nerve had been crushed on the same side.

These figures disagree wholly with those of Leiner (1944), who found a loss of 40 per cent. in the total vital capacity after pneumothorax therapy in 18 cases, and with those of Birath (1947), who noted severe functional impairment and dyspnoea in many cases after completion of their collapse treatment. Bruce (1946) made a more studied and accurate appraisal of the subject, finding little decrease in function in uncomplicated artificial pneumothorax. The occurrence of pleural exudation, however, caused a marked reduction in overall function, and in oxygen consumption by the affected lung.

Mitchell (1951) followed up a series of 557 cases of artificial pneumothorax between 1930-1939, which was before there was any effective drug therapy in the treatment of tuberculosis, and he found 145 cases of reactivation on the homolateral side. In 10 of the 18 cases in the present series reactivation occurred on the old pneumothorax side, necessitating further treatment by surgical means. However, these are only ten out of many hundred successful pneumothoraces performed in Glasgow in whom no further treatment was required. That is, only the cases in whom artificial pneumothorax failed to control the disease were referred to Mearnskirk Thoracic Unit for further treatment.

Only one of the 18 cases was judged unfit for surgery (Case 146). The remainder were operated on, Case 30 having in fact a pneumonectomy performed on the side opposite to the

TABLE XXXII

4 CASES OF PHRENIC CRUSH + P.P. BEFORE INDUCTION

CASE	INDICATIONS	RIGHT T.A.	RIGHT O.U.	RIGHT V.C.	LEFT T.A.	LEFT O.U.	LEFT V.C.	BOTH V.C. (Ml.)	BOTH M.V.C. (L/Min)
102	Cav. L.U.L.	56%	58%	56%	44%	42%	44%	3,450	84
126	Cav. R.U.L. (Failed A.P.)	53%	45%	50%	47%	55%	50%	3,050	77
150	Cav. R.L.L.	50%	53%	53%	50%	47%	47%	3,700	86
232	Cav. L.L.L.	59%	64%	64%	41%	36%	36%	3,600	90

TABLE XXXIII

4 CASES OF PHRENIC CRUSH + P.P. AFTER INDUCTION

CASE	SIDE OF PHRENIC	RIGHT T.A.	RIGHT O.U.	RIGHT V.C.	LEFT T.A.	LEFT O.U.	LEFT V.C.	BOTH V.C. (Ml.)	BOTH M.V.C. (L/Min)
102	L.	55%	58%	53%	45%	42%	47%	2,900	80
126	R.	27%	25%	20%	73%	75%	80%	2,250	74
150	R.	25%	25%	15%	75%	75%	85%	2,900	72
232	L.	60%	67%	68%	40%	33%	32%	3,000	90

TABLE XXXIV

4 CASES OF PHRENIC CRUSH + P.P. LOSS OF FUNCTION

CASE	LOSS OF FUNCTION: PHRENIC + P.P. SIDE T.A.	O.U.	V.C.	OVERALL V.C. (Ml. + %)	OVERALL M.V.C. (L./Min. + %)
102	+ 1%	0%	+ 3%	- 550 (- 16%)	- 4 (- 5%)
126	-26%	-20%	-30%	- 800 (- 26%)	- 3 (- 4%)
150	-25%	-28%	-38%	- 800 (- 22%)	- 14 (- 16%)
232	- 1%	- 3%	- 4%	- 600 (- 17%)	0%

\- = Loss

\+ = Gain

abandoned pneumothorax without any disturbance.

One death (Case 85) occurred after operation, but this will be discussed at a later stage in this chapter.

Artificial pneumothorax thus still appears to occupy a role in tuberculous therapy, but only in very selected cases, at the correct phase of the disease, and with careful supervision and adequate drug therapy. The end functional result in such cases should compare more than favourably with most other forms of collapse measures (medical and surgical).

8. Phrenic Crush and Pneumoperitoneum.

Scadding (1955) reserved this form of treatment for acute exudative disease in the lower lobe to aid either in its healing or in its subsidence preparatory to subsequent excision of the lower lobe. He also mentioned its use for predominantly unilateral disease scattered throughout one lung.

With effective drug therapy combined with bed-rest, phrenic crush and pneumoperitoneum are rarely required at the present time. A mere four cases have been studied at Mearnskirk before and after induction. The indications for, and the functional loss in, this form of therapy are summarised in Tables XXXII, XXXIII, XXXIV, and XXXV.

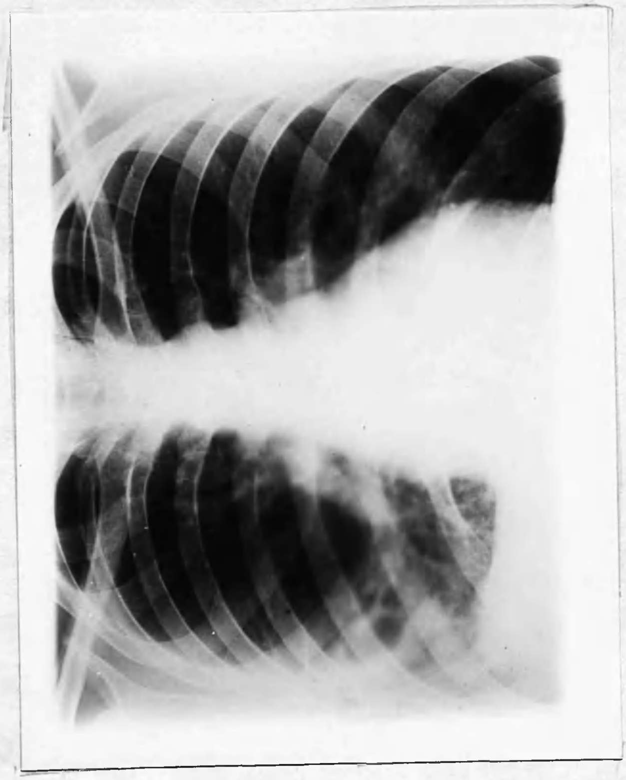
TABLE XXXV.

FUNCTIONAL LOSS (MEAN) IN CASES OF PHRENIC CRUSH + P.P.

Tidal Air.	O_2 Uptake per min.	Vital Capacity.	Vital Capacity.(Both)	M.V.C.
- 13%	- 13%	- 17%	- 20%	- 5%

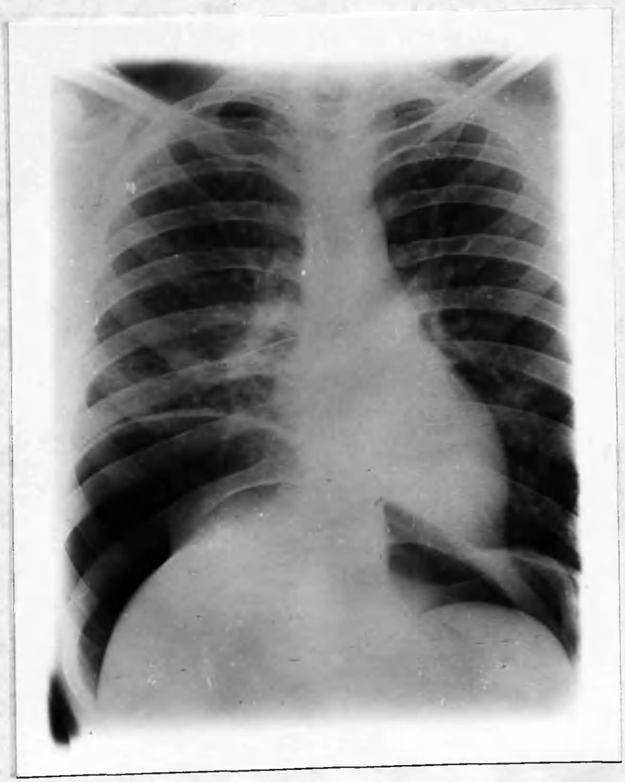
CASE 150.

CAVITATED DISEASE
R.L.L.



CASE 150.

R.PHRENIC CRUSH -
PNEUMOPERITONEUM
HAVE EFFECTED
CAVITY CLOSURE.



Lindskog and Friedman (1936) reported a decrease in the total vital capacity of 395 ml. after phrenic crush and pneumoperitoneum, but the vital capacity rose to normal subsequently. Sarnoff, Gaensler, and Maloney (1950) found a decrease of ten per cent. in the M.V.C. and of 16 per cent. in the total vital capacity.

Two cases in the present series (102 and 232) had minimal loss from their therapy, while in Cases 126 and 150 there was quite marked loss. This may be partially accounted for in Case 126 as being due to a recent pneumothorax induction on the same side, this having to be abandoned because of indivisible adhesions at thoracoscopy.

No complications arose in any of these cases, and indeed complications are very few and rarely occur. Air embolism, peritoneal effusion, and spontaneous pneumothorax (due to air leakage through a patent channel leading from the peritoneal cavity to the mediastinum via the diaphragm) have all been mentioned by previous writers.

The only place for pneumoperitoneum alone without phrenic nerve crush appears to be in the treatment of pulmonary emphysema. (Becklake, Golman, and McGregor, 1954). Even here its use is of very dubious value, as it produces little or no improvement in the breathing capacity. Of interest is the fact that no reduction in the vital capacity or M.V.C. occurs in these emphysematous patients following pneumoperitoneum induction.

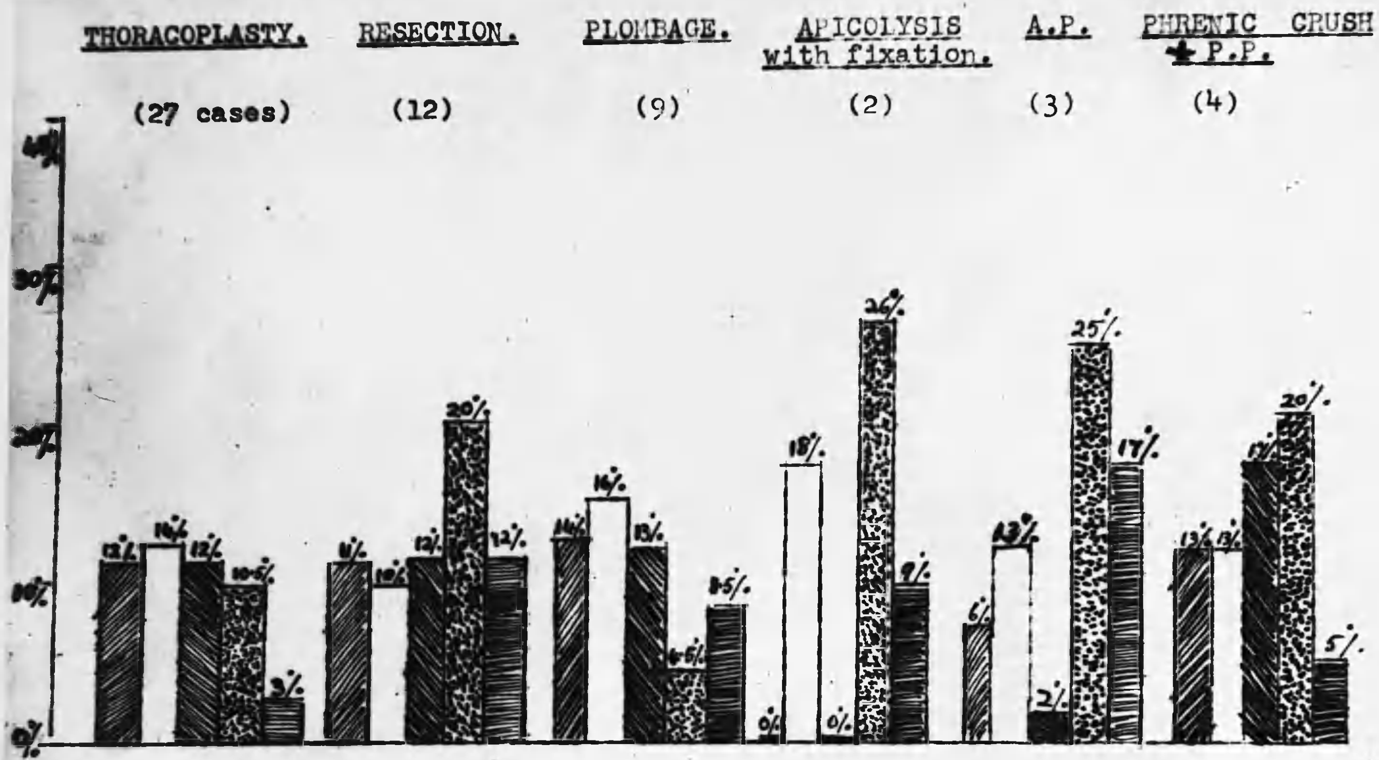


FIG. XI. Comparison of functional loss on operated side and of total function loss (combined V.C. + M.V.C.) in Thoracoplasty, Resection, Plombage, Apicolysis with fixation, Artificial Pneumothorax, and Phrenic Crush with Pneumoperitoneum.

- Tidal air loss on operated side.
- O_2 loss on operated side.
- V.C. loss on operated side.
- Total V.C. loss.
- Loss of M.V.C.

Figure XI presents in a diagrammatic fashion the functional loss from thoracoplasty (modern 5-rib operation), resection (bilobectomy, lobectomy, segmentectomy), plombage, apicolysis with fixation, artificial pneumothorax, and phrenic crush with pneumoperitoneum. The main conclusions to be derived are, firstly, that all the forms of therapy outlined above produce a loss of function in close relation to the amount of functioning lung tissue removed or otherwise rendered functionless by collapse measures. This is particularly so when the procedure in question is undertaken only when indicated, and provided no complications ensue. Lastly, thoracoplasty, as performed now, compares more than favourably with the other measures listed, the loss in the present series, both on the operated side and in overall function, being the smallest of all the procedures listed, even less than with plombage.

Before completing this review of the procedures now available for treating pulmonary tuberculosis, a few words are apposite regarding pneumonectomy. In this series lung function tests, including bronchospirometry, were carried out only before operation in most cases of pneumonectomy, though in some external spirometry (vital capacity and M.V.C.) was repeated post-operatively. The results of these post-operative studies in pneumonectomy cases are not recorded here, as quite manifestly the loss of function following this procedure will vary considerably, depending largely on the amount of function contributed pre-operatively by the lung in question. Where this is minimal, as in most instances of pulmonary tuberculosis in the present series, the anticipated loss following operation will be small, as confirmed in the cases examined by external spirometry post-operatively.

The value of lung function studies, including broncho-spirometry, in cases for proposed pneumonectomy, be they tubercular, carcinomatous, or bronchiectatic, is in measuring accurately the function contributed by the lung in question. If this approximates to 50 per cent. of the total function, which is in itself impaired, then pneumonectomy would tend to be contra-indicated and more conservative measures would be undertaken. This point is dealt with more fully at the end of the chapter.

B. Bronchial Carcinoma.

Thirty-four of the 316 examinations in this series were carried out in cases of bronchial carcinoma. Only two of the cases had repeat lung function studies (including broncho-spirometry) after operation, mainly because most of the cases underwent pneumonectomy. In addition it was considered unjustifiable to readmit cancer lobectomy cases for repeat tests. With tubercle patients, most of whom are retained in hospital for a minimum of three months after operation, there is no difficulty in repeating the tests before final discharge. This

TABLE XXXVI

2 CASES OF BRONCHIAL CARCINOMA PRE-OP. STUDIES

CASE	X-RAY APPEARANCES	RIGHT T.A.	RIGHT O.U.	RIGHT V.C.	LEFT T.A.	LEFT O.U.	LEFT V.C.	BOTH V.C. (Ml.)	BOTH M.V.C. (L/Min)
81	Br. Ca. L.L.L.	57%	57%	58%	43%	43%	42%	3,750	64
117	Br. Ca. L.L.L. Gross Emphysema	59%	54%	56%	41%	46%	44%	2,250	63

TABLE XXXVII

2 CASES OF BRONCHIAL CARCINOMA POST OP. STUDIES

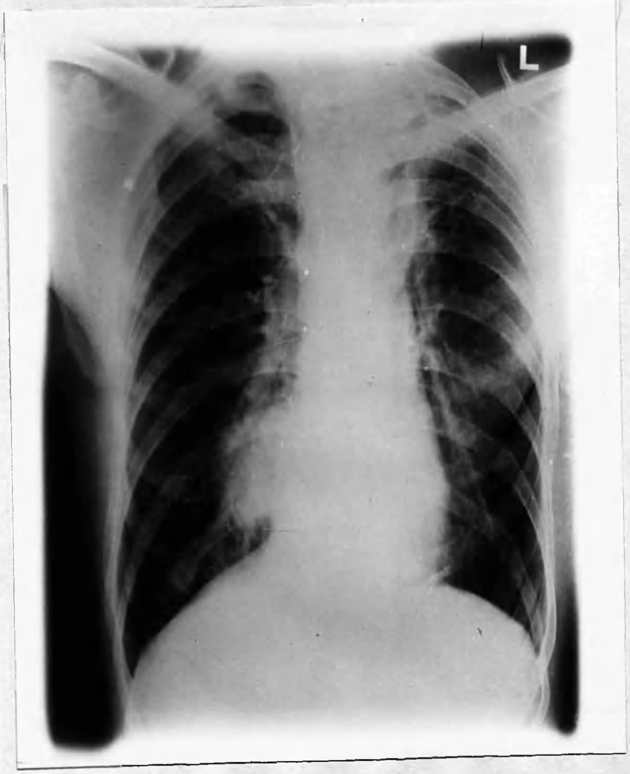
CASE	OPERATION AND COMPLICATIONS	RIGHT T.A.	RIGHT O.U.	RIGHT V.C.	LEFT T.A.	LEFT O.U.	LEFT V.C.	BOTH V.C. (Ml.)	BOTH M.V.C. (L/Min)
81	L.L. Lobectomy Atelectasis	69%	83%	75%	31%	19%	25%	3,050	68
117	R.L. Lobectomy Nil	53%	0%	38%	47%	100%	62%	1,600	55

is not so in cases of lung cancer, most of whom are discharged home two to three weeks after operation.

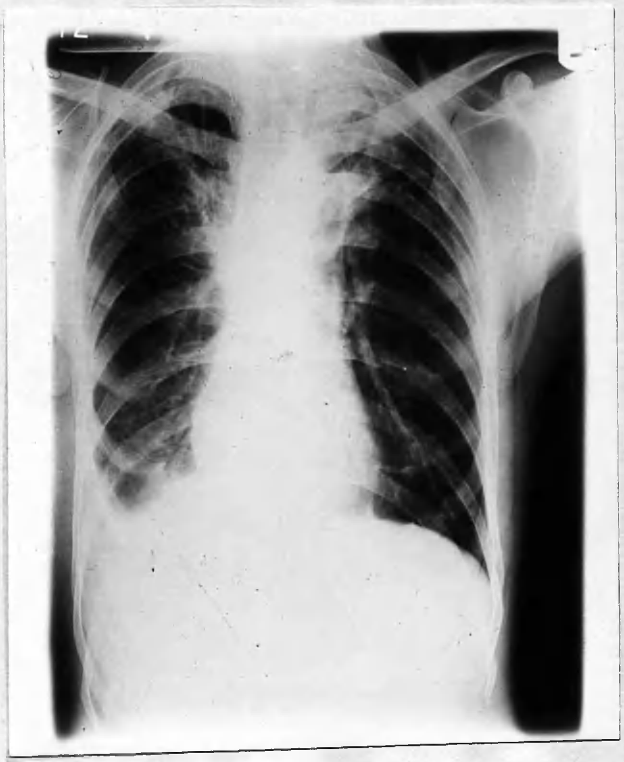
Bronchospirometry has then in lung cancer cases been used mainly in assessing fitness for operation, which in the majority of cases consists of pneumonectomy. Thirty-two cases were studied pre-operatively (which including the two who were studied post-operatively, makes a total of 34 examinations). Tables XXXVI and XXXVII record the relevant data in the two cases studied before and after operation.

As mentioned before, most cases for proposed pneumonectomy were subjected to blockage of the affected lung during broncho-spirometry, in an attempt to gauge the patient's reaction to breathing with the good lung by itself. Blockage of the bronchus was performed in 27 of the 32 cases of bronchial carcinoma. The reasons for its omission in the other five were due to several factors. Firstly, in the early cases the value of the procedure was not fully realised, while in one overall function studies declared that surgery of any description was not feasible, and lastly one case had such copious secretions during intubation that it was thought inadvisable to possibly add to his embarassment by blocking one bronchus.

All cases of lung cancer, before having lung function studies, are assessed for operability on general clinical, radiological, and bronchoscopic findings. Of the 32 cases examined, six were deemed unfit for surgery because of poor

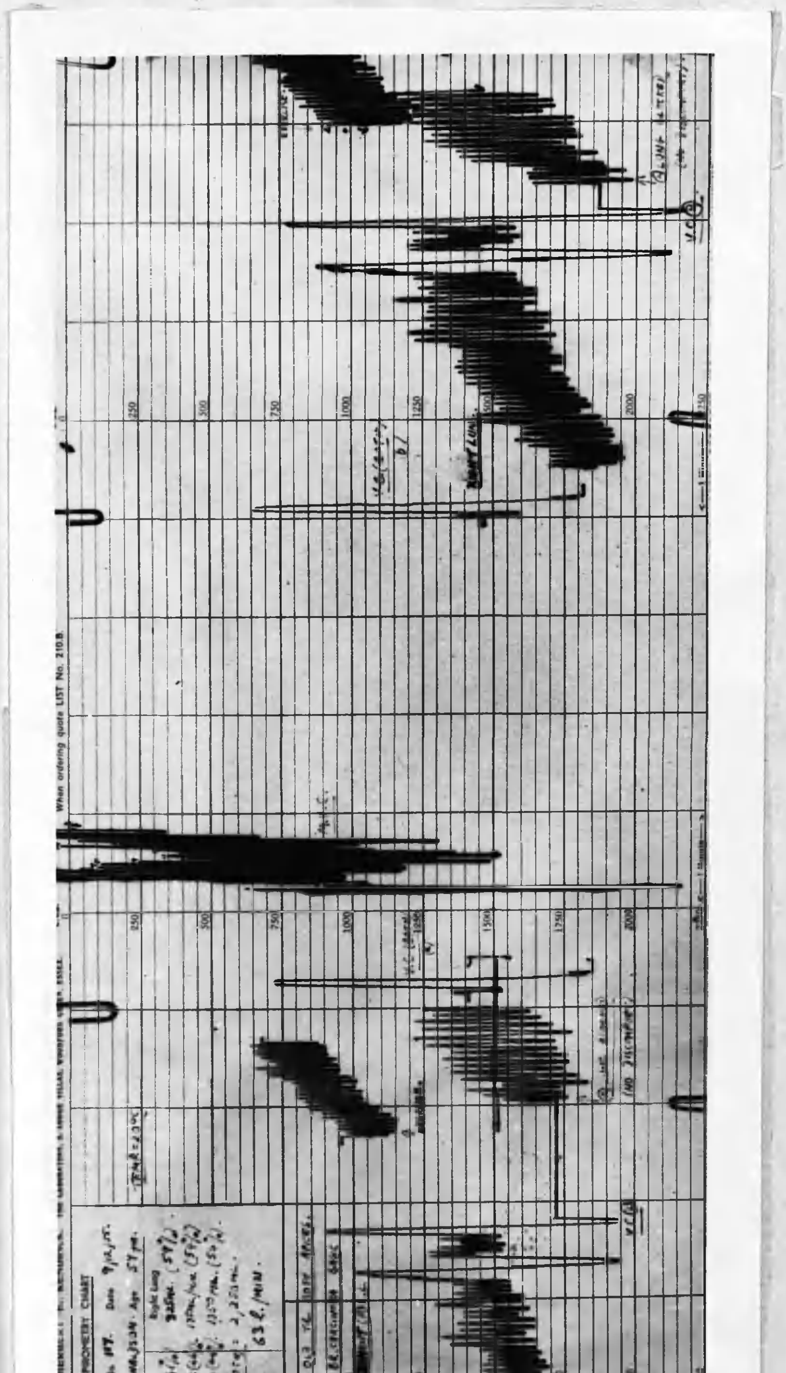


CASE 117.
PRE-OP. BRONCHIAL
CARCINOMA R.L.L.



CASE 117.
POST-OP. EXCISION
OF R.L.L. ONLY.

CASE 117. PRE-OPERATIVE CHART.



overall respiratory capacity, which in most instances was accompanied by distress on occlusion of the affected lung, indicating the contralateral lung had insufficient reserve to sustain the patient by itself.

Table XXXVIII indicates the type of operation undertaken in each case, and the four deaths which occurred. These are considered later.

TABLE XXXVIII.

26 CASES OF BR. CARCINOMA OPERATED ON.

Total No. operated on.	Pneumo-nectomy.	Lobectomy or Bilobectomy.	Mortality Lobectomy.	Mortality Pneumo-nectomy.
26	18	8	2	2

In most cases operation resolves itself into removal of the entire lung, in order to excise the growth and regional lymphatic glands as completely as possible. Certain tumours situated in the lower lobe, particularly if not too close to the hilum, can be suitably treated by lobectomy or bilobectomy. This is of the greatest importance in those with poor respiratory capacity who, though unfit for pneumonectomy, can often withstand the lesser procedure of a lobectomy.

Four deaths out of 26 cases operated on for lung cancer may seem a surprisingly high mortality. But in such a dire disease this must always remain a fairly formidable figure, particularly as the majority of cases occur in the age group 45-65 years, where unhealthy arterioscerotic vessels, an ischaemic myocardium, and commencing pulmonary emphysema are often present. Such factors alone or in summation can very easily tip the balance post-operatively, no matter how meticulous the anaesthesia, how careful the surgery, or how well the patient is tended after operation.

It seems clear that in some cases additional information is required, apart from that derived from clinical, radiological, and lung function studies. Bronchospirometry fills an important role in the pre-operative assessment, but on occasion cardiac catheterization with measurement of the pulmonary artery pressure at rest and on exercise will be helpful. Combined bronchospirometry with clamping of the bronchus on the affected side, along with simultaneous blockage of the ipsilateral pulmonary artery by means of an inflatable balloon at the tip of a cardiac catheter, may prove to be the nearest physiological approach to what may be expected after pneumonectomy has been performed (Dotter and Lucas, 1951). At present this investigation is not without risk, is very time-consuming, requires a great deal of skill, and has probably only a limited application.

Oximetry may also be valuable, not only in judging fitness for surgery, but in assisting in the immediate post-operative management. By this means a rapid estimation of arterial oxygen saturation can be obtained, and anoxaemia can be detected at an early stage and treated, often before it is manifest clinically. Pre-operatively a lowered arterial oxygen saturation at rest, or a marked fall on moderate exercise, may indicate a fairly marked degree of pulmonary emphysema, and may thus preclude any surgery (Bjork, Michas, and Uggla, 1953; Carlens, Hanson, and Uggla, 1955).

C. Bronchiectasis.

Fifteen cases of bronchiectasis are included in this study, four of whom had both pre- and post-operative bronchospirometry making a total of 19 examinations. Thirteen of the cases were operated on, three having a pneumonectomy for bronchiectasis involving the entire lung, and ten having a lobectomy. The remaining two were considered unfit for surgery; in one because of poor overall respiratory capacity, while in the other because the apparently good side had the poorer function of the two as determined by bronchospirometry.

In only one of the cases was the bronchiectasis bilateral (Case 304), in which there was a shrunken grossly bronchiectatic left lower lobe with emphysematous bullous changes at the left base, and mild bronchiectasis of the basic segments of the right lower lobe. Excision of the left lower lobe only was carried out, as this seemed the more seriously affected part.

The complications which may follow operation in cases of bronchiectasis comprise atelectasis, haemothorax, broncho-

TABLE XXXIX

4 CASES OF LOBECTOMY FOR BRONCHIECTASIS PRE-OP. STUDIES

CASE	EXTENT OF LESION	RIGHT T.A.	RIGHT O.U.	RIGHT V.C.	LEFT T.A.	LEFT O.U.	LEFT V.C.	BOTH V.C. (Ml.)	BOTH M.V.C. (L/Min)
90	Bronchiectasis L.L.L. only	50%	60%	50%	50%	40%	50%	2,000	50
103	Bronchiectasis L.L.L. + Ling.	45%	64%	44%	55%	36%	56%	2,750	49
164	Bronchiectasis L.L.L. only	56%	56%	56%	44%	44%	44%	3,250	90
207	Bronchiestasis R.M.L.	50%	50%	50%	50%	50%	50%	3,150	60

LING. = lingula

TABLE XL

4 CASES OF LOBECTOMY FOR BRONCHIECTASIS POST-OP. STUDIES

CASE	OPERATION AND COMPLICATIONS	RIGHT T.A.	RIGHT O.U.	RIGHT V.C.	LEFT T.A.	LEFT O.U.	LEFT V.C.	BOTH V.C. (Ml.)	BOTH M.V.C. (L/Min)
90	L.L. Lobectomy Atelectasis	58%	50%	63%	42%	50%	37%	1,550	52
103	L.L. Lobectomy + Ling. Nil	60%	71%	71%	40%	29%	29%	1,700	48
164	L.L. Lobectomy Nil.	70%	77%	73%	30%	23%	27%	2,450	75
207	R.M. Lobectomy Nil.	43%	36%	37%	57%	64%	63%	2,650	60

TABLE XLI

4 CASES OF LOBECTOMY FOR BRONCHIECTASIS LOSS OF FUNCTION

CASE	LOSS OF FUNCTION				
	OPERATED SIDE			OVERALL	
	T.A.	O.U.	V.C.	V.C. (Ml. + %)	M.V.C. (L./Min. + %)
90	- 8%	+10%	-13%	- 450 (- 23%)	+ 2 (+ 4%)
103	-15%	- 7%	-27%	-1,050 (- 38%)	- 1 (- 2%)
164	-14%	-21%	-17%	- 800 (- 24%)	- 15 (- 17%)
207	- 7%	-14%	-13%	- 500 (- 16%)	0 0%

- = Loss

+ = Gain

pleural fistula, and pulmonary embolism. Case 90 developed atelectasis post-operatively, but full re-expansion followed bronchoscopic aspiration. One other case had a small pulmonary infarct from a phlebothrombosis in a calf vein, but this responded quickly to anticoagulant therapy.

Tables XXXIX, XL and XLI depict the four cases who had pre- and post-operative studies, while Table XLII shows the mean functional loss in these four.

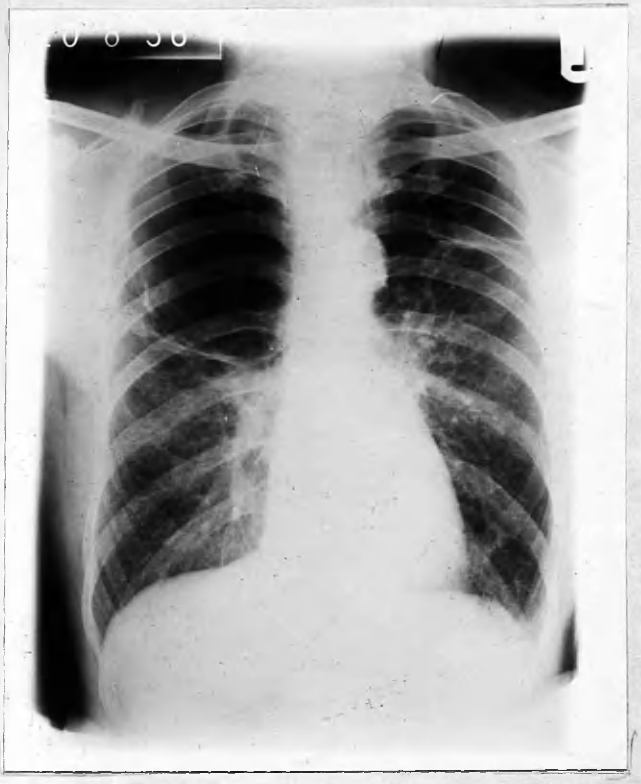
TABLE XLII.

FUNCTIONAL LOSS (MEAN) IN ABOVE

Tidal Air.	O_2 Uptake per min.	Vital Capacity.	V.C. (Both).	M.V.C.
- 11%	- 8%	- 17%	- 25%	- 4%

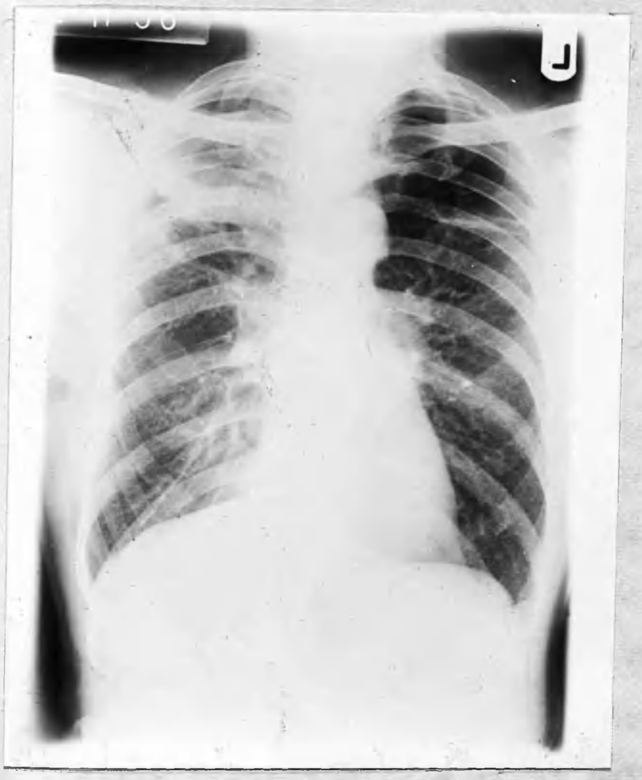
The only complication (aetlectasis in Case 90) resolved completely following bronchoscopic suction.

These Tables show the average loss of function to be minimal in the four cases, three of whom were in the age group 18-35 years, while the other was aged 57 years (Case 207). Normally major surgery is not undertaken for bronchiectasis occurring at this age, but the patient was markedly disabled by recurrent haemoptyses. Bronchoscopy and chest X-rays were both negative, but bronchography demonstrated bronchiectasis of the middle lobe. The remainder of the bronchial tree being



CASE 284.

PRE-OP. LARGE
BULLA R.U.L.



CASE 284.

BULLA OBLITERATED
AFTER PLEURODESIS +
DEFLATION.

normal, excision of the middle lobe was carried out, and the patient is now very well indeed.

Long, Norris, Burnett, and Wester (1950), in a series of 39 cases examined before and after lobectomy for bronchiectasis, obtained results very similar to the present series. Kay, Meade, and Hughes (1947) found the loss to be minimal in such cases, unless haemothorax, empyema, or broncho-pleural fistula developed, when loss of function was reduced further.

The usual indications for surgery in this disease are strictly observed in this centre. They include localised disease (bronchiectasis of one or two lobes on the same side or involvement of the whole lung, provided the other lung is normal) and the presence of definite symptoms, in the way of chronic productive cough, recurrent attacks of pneumonitis, or recurrent haemoptyses.

D. Miscellaneous.

Under this heading are included six cases, one of anthracosis already discussed, two of chronic bronchitis suspected of neoplasm also discussed at the beginning of this chapter, and three cases of emphysematous cysts. One of the latter had pre- and post-operative function studies (Case 284), making a total of seven examinations in this group.

Of these three cases of emphysematous cysts, Case 265 had resection of the diseased area; while the second (Case 284), an older patient with a giant bullous cyst occupying the right upper lobe, had a preliminary localised pleurodesis, followed by suction of the bulla continuously for two weeks through an indwelling intercostal tube. This produced closure of the broncho-pleural leak, complete obliteration of the bulla, and full re-expansion of the underlying lung. There was, however, no appreciable change in lung function studies, either in the contribution by each lung, or in the overall function. Case 151 (see Chapter III, under heading of "Concomitant Cardio-Respiratory Disease"), after being considered unfit for a pneumonectomy to remove a giant bulla occupying most of the right lung, was later judged to be able to withstand a localised pleurodesis and subsequent suction of the bulla through an intercostal tube. This, as in Case 284, was successful in obliterating the bulla.

Cases 284 and 151 were unfit to withstand resection surgery, obviously the more definitive therapy, and pleurodesis with suction was substituted. How permanent this will be, it is impossible to forecast just now. But at present both are well, and their bullae appear obliterated.

III. IMPORTANCE OF LUNG FUNCTION STUDIES IN THORACIC SURGERY.

Gaensler, Cugell, Lindgren, Verstraeten, Smith, and Streider (1955) undertook a most detailed and painstaking study to judge the value of routine pre-operative pulmonary function studies in relation to operative mortality and disability following surgery in a large number of tuberculous patients.

They included fluoroscopy, bronchoscopy, the total vital capacity, maximum ventilatory capacity, and exercise ventilation as routine in all patients before operation. Where any one of these simple tests was at all doubtful, special ancillary investigations were undertaken, such as the intrapulmonary mixing index, arterial blood gas analysis (oxygen and carbon dioxide contents), and differential lung function (broncho-spirometry). Deaths from respiratory insufficiency occurred only when the M.V.C. before operation was 50 per cent. or less of the predicted value.

Baldwin, Cournand, and Richards (1948) predicted normal values for the M.V.C. according to this formula:-

Females = (71.3 - (0.474 x age)) x sq.m.s.a.
Males = (86.5 - (0.522 x age)) x sq.m.s.a.

The deaths which took place in the present series bore out the work referred to above by Gaensler et al., although the critical level of the M.V.C. was well below 50 per cent. of the predicted value. The M.V.C. has been found of far more reliance than the vital capacity reading, which as Comroe (1951) pointed out may be nearly normal even in the presence of advanced pulmonary emphysema. An M.V.C., in absolute values, of less than 40 litres per minute would tend to vitiate major surgery in such a patient.

The M.V.C. has been recorded only in absolute values in the present series, this being regarded of more value than the

CASE 49.

BRONCHIAL CARCINOMA
R.L.L. P.A.FILM.

R.LATERAL FILM OF
CASE 49.

predicted value. Bronchospirometry, on the other hand, portrays nerely the percentage values of each lung, not the absolute value. However, the importance of knowing the percentage contribution of each lung in cases for pneumonectomy, particularly if overall function is impaired, has been discussed adequately previously.

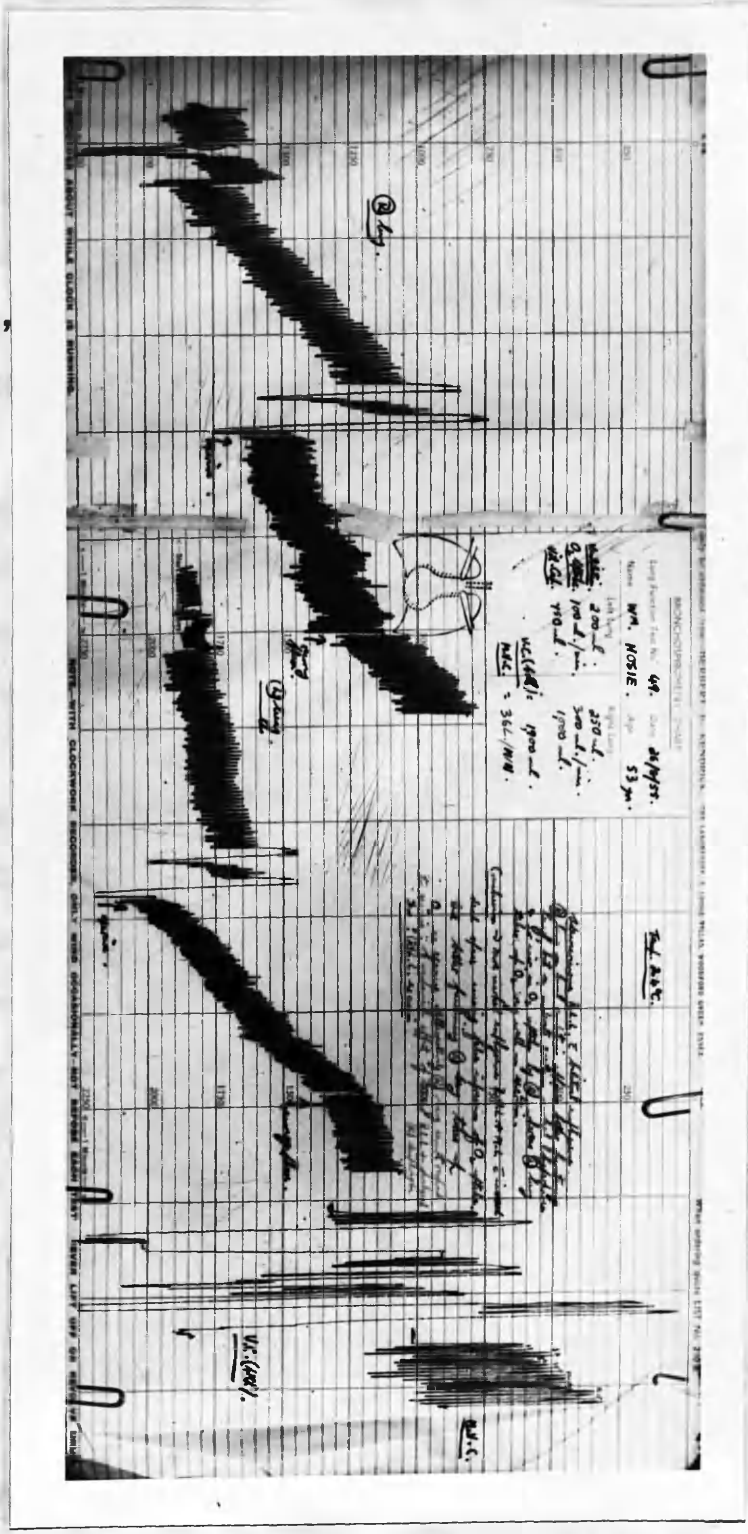
At this point it is perhaps appropriate to consider the total number of operations carried out, the mortality in these cases, and the causes of these deaths. Altogether in the 253 patients who comprised the total of 316 bronchospirometric examinations, 203 cases were operated on. Two cases had bilateral surgery (Cases 6 and 47), constituting thus a total of 205 operations. In these 203 patients, there were seven deaths. An analysis of these is considered in Table XLIII.

TABLE XLIII.

7 DEATHS IN 203 PATIENTS (205 OPERATIONS)

Case.	Age & Sex.	Pre-Op. M.V.C.	Condition.	Operation.	Cause of Death.
49	49.M.	36 L/min.	Br.Ca.	Excision R.M.L. + R.L.L.	Respiratory Insufficiency.
78	60.M.	48 L/min.	Br.Ca.	Rt.pneumonectomy.	Haemorrhage.
85	25.F.	50 L/min.	P.T.B.	Excision L.U.L. + 'plasty.	Respiratory Insufficiency.
156	30.F.	48 L/min.	P.T.B.	Rt. pleuro-pneumonectomy.	Respiratory Insufficiency.
205	42.F.	40 L/min.	P.T.B.	Rt. pneumonectomy.	Respiratory Insufficiency.
240	63.M.	85 L/min.	Br.Ca.	Rt. pneumonectomy.	Respiratory Insufficiency.
264	55.M.	68 L/min.	Br.Ca.	Excision R.U.L.	Haemorrhage.

CASE 49.
PRE-OP. CHART.
IMPAIRED FUNCTION,
FIT FOR LOBECTOMY
ONLY.



Four of the deaths occurred in patients with bronchial carcinoma, the other three in tuberculous subjects. Two of the deaths were from causes other than respiratory insufficiency, Case 78 dying suddenly from haemorrhage due to a ligature slipping from the pulmonary artery on the first post-operative day. Case 264 progressed favourably till the tenth post-operative day, when he developed retention pneumonitis in the remainder of the right lung. Death occurred suddenly and very swiftly two days later following a massive haemoptysis, the bleeding originating from a tear in the right pulmonary artery, presumably due to the surrounding infection causing weakness in the arterial wall.

Of the five deaths from cardio-respiratory insufficiency, four occurred in patients with an M.V.C. of 50 litres per minute or less (Cases 49, 85, 156, and 205). Case 264 became acutely distressed on the first post-operative day, despite a pre-operative M.V.C. of 68 litres per minute. He was broncho-scoped to try and suck out the accumulated secretions, but died during the procedure due possibly to aspiration of vomitus, supervening on his already depleted general and respiratory states.

The importance of a respiratory infection supervening and accelerating, if not actually producing, death from respiratory insufficiency is obvious from Cases 49, 156, and 205. Another important factor that emerges is the inadvisability of undertaking major thoracic surgery in cases with an M.V.C. of 45 litres per minute or less, particularly where pneumonectomy is contemplated. If bronchospirometry demonstrates, in addition, that each lung contributes 50 per cent. of total function, removal of one lung would precipitate death from respiratory insufficiency.

In all, 50 cases had no surgery undertaken (Table XLIV). Twenty-two of these were cases of artificial pneumothorax (successful or otherwise) or pneumoperitoneum and phrenic crush. The remaining 28 cases included five cases in whom the final diagnosis made surgery unnecessary.

TABLE XLIV.

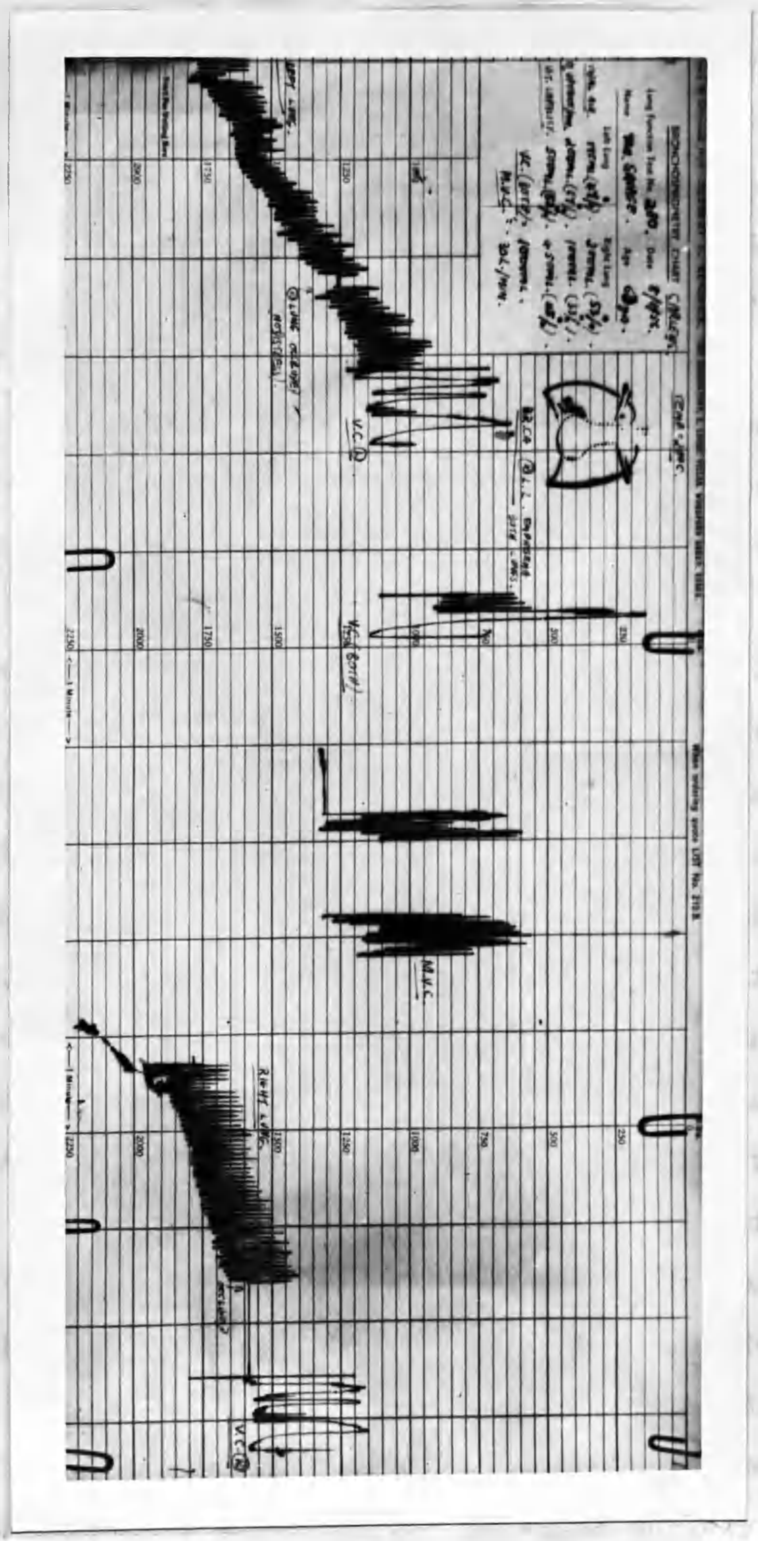
50 CASES NOT SUBJECTED TO SURGERY

Total.	Other forms of Therapy.	No. Rejected.	Other Diagnoses.	No. rejected as result of lung function tests.
50	22 (4 had P.P. + phrenic crush; 3 had successful A.P.S.; 15 had A.P.S. that had to be abandoned.)	28	5 (1 case of chronic bronchitis; 1 of T.B.empyema that healed with aspirations alone; 1 with respiratory infection only; 1 with Bronchial Ca. inoperable bronchoscopically; and 1 with P.T.B. + chronic bronchitis.)	23 Unsuitable for any surgery from data obtained at bronchospirometry and from other lung function tests.

There were 23 cases deemed unfit for any form of surgery as a result of lung function tests. Some of these were rejected

CASE 280. BRONCHIAL CARCINOMA R.L.L.

CASE 280.
LUNG FUNCTION CHART
- UNFIT FOR
OPERATION.



because of poor overall respiratory capacity, others because the supposedly good lung was found to be the poorer functioning of the two, and the third group comprised cases for possible pneumonectomy in whom blockage of the affected lung during bronchospirometry produced quite definite upset or embarrassment.

The value of lung function studies in patients with giant emphysematous bullae has been mentioned. Two cases in the present series (Cases 284 and 151) appeared unfit for resection of the diseased parts, and were subjected to pleurodesis with deflation of the bulla as an alternative.

Finally bronchospirometry proved of inestimable use in deciding the best type of procedure to adopt in many cases of impaired lung function. Thirteen cases for possible pneumonectomy were judged unfit for this procedure, but proved fit enough to withstand more conservative surgery. Four of these were lung cancers, and lobectomy was accomplished uneventfully, whereas excision of the entire lung would have resulted in almost certain death. (However, unfortunately not all cases of lung cancer can be treated by simple lobectomy, pneumonectomy being required in most to remove the tumour and associated lymphatic glands.). The other nine were tubercle patients with widespread disease involving one lung and cavitation in the ipsilateral upper lobe. As the overall function was impaired in these cases and the affected lung still contributed a considerable proportion of that function, conservative collapse surgery was undertaken to preserve as much functioning lung parenchyma as possible; while at the same time control of the cavitated disease was accomplished. Four had plombage operations, and five had five-rib thoracoplasties. All are now well, with cavity closure, and minimal functional loss as a result of conservative surgery.

This study has shown beyond all doubt the fallacy of attempting to assess lung function solely on clinical and radiological findings, which has been noted previously by Maier (1949). By prior knowledge of the probable functional loss resulting from each type of procedure, the surgeon can select the operation he considers most suitable for the individual patient, taking into account the nature and extent of the disease present and the patients' respiratory capacity. Bronchospirometry and other tests of lung function are the only accurate means of obtaining the loss of function that can be expected after each type of procedure, and that only after studying a series of cases in each group as has been described in this chapter.

In cases for bilateral surgery, in those with impaired function from either previous disease or collapse measures (medical or surgical), and in older patients with concomitant pulmonary emphysema, lung function tests are of the greatest value. In this way cases unsuitable for any form of surgery will be rejected, while in others conservative surgery will be substituted in place of more radical measures. Deaths from respiratory insufficiency will occur only rarely, and the danger of producing "respiratory cripples" in other instances will be minimal.

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Summary.

The number of bronchospirometric examinations (316 in all) is divided into their various disease categories. The majority of cases were tuberculous (256), bronchial carcinoma (34) being the next in order of precedence.

The functional loss from each procedure is then dealt with fully. Fifty-six out of the 63 who had both pre- and post-operative lung function studies were tubercle patients. Of these, 27 had a thoracoplasty, 12 resection, 9 plombage, 2 apicolysis with fixation, 3 artificial pneumothorax, and 4 phrenic crush with pneumoperitoneum. The indications for, complications that ensued, and functional loss from each are detailed. In the modern type of thoracoplasty, the operative side loses on the average 12 per cent. of its pre-operative level, while the vital capacity decreases by 10.5 per cent., and the M.V.C. by 3 per cent. only. In resection cases, the corresponding figures are 11 per cent., 20 per cent., and 12 per cent., respectively. (Resection includes here segmentectomy, lobectomy, and bilobectomy.). Fourteen per cent., 4.5 per cent., and 8.5 per cent., respectively are the

corresponding figures in plombage; while in pneumothorax 7 per cent., 25 per cent., and 17 per cent. are the values; and 14 per cent., 20 per cent., and 5 per cent., are those in phrenic crush with pneumoperitoneum.

Figures are also presented for cases after re-expanded E.P.P. and after the old-type of "crash in thoracoplasty". In the former the function is excellent, while in the latter the underlying lung is severely impaired functionally.

The factors influencing impairment of lung function pre-operatively are mentioned.

Thirty-two cases of lung cancer were examined, 2 before and after operation. Six were rejected for surgery because of impaired lung function. Four deaths occurred in the 26 subjected to operation.

Bronchiectasis (15 cases) and miscellaneous (6) comprised the remainder. Three of the latter were emphysematous bullae, one of whom was deemed fit for resection surgery. The other two bullae were unfit for this, and had instead pleurodesis + deflation of the bulla by suction through an intercostal tube.

Seven deaths occurred in 203 patients operated on, five of these being due to cardio-respiratory insufficiency post-operatively. The dire significance of a respiratory infection supervening after operation in poor-risk cases is stressed. The importance of the M.V.C. is emphasized - one lower than 40 litres/minute would tend to preclude pneumonectomy.

Twenty-three cases in the whole series were rejected for operation as a result of lung function studies, and the causes for such rejection are noted.

Bronchospirometry proved of great help in deciding the type of operation in many cases with impaired respiratory capacity. Its importance in cases for bilateral surgery, where there has been previous extensive disease or collapse measures, and in elderly lung cancer patients is underlined.

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CHAPTER VIII.

CONCLUSIONS

CONCLUSIONS.

1. Until recently, bronchospirometry has been very much neglected in this country, though investigators elsewhere, particularly in the United States of America and Sweden, have gained much information from it over the past eleven years.

   Admittedly its scope is somewhat limited, in that its main application is in relation to the pre-operative assessment of cases for thoracic surgery. It should, however, occupy a prominent position in a thoracic surgical unit, concerned as it is with the investigation and assessment for surgery of cases with many varied types of chest diseases.

2. This thesis deals with 316 bronchospirometric examinations, involving 253 patients. The majority of the examinations were carried out in tuberculous cases (256), while bronchial carcinoma was next in precedence (34). The remainder comprised cases of bronchiectasis, emphysematous bullae, and a few miscellaneous groups. The findings and results in each are presented.

3. The literature on the subject is reviewed, and the indications and contra-indications to bronchospirometry are dealt with fully.

4. The technique is described, and the importance of correlating the findings from lung function tests with the clinical, radiological, and bronchoscopic appearances is stressed. The Carlens tube is far superior to all others for bronchospirometry.

5. With very few reservations, bronchospirometry carries little or no discomfort for the patient, and complications are exceptional and never serious. They should never occur if adequate preparation is carried out beforehand, particularly with reference to postural drainage and antispasmodics. No deaths occurred attributable to bronchospirometry.
6. Seven deaths occurred in 203 cases operated on (comprising a total of 205 operations). The causes of these are dealt with. The dire consequences of a respiratory infection occurring in the early post-operative phase are mentioned.
7. A total of 23 cases were rejected as unfit for surgery as a result of lung function studies.
8. In patients for proposed pneumonectomy, temporary blockage of the affected bronchus during bronchospirometry has proved of great value, particularly where the respiratory capacity is impaired. The exercise test (using an ergometer) has also proved useful in these cases in estimating respiratory reserve.
9. The value of the M.V.C. as an estimate of overall ventilatory function is emphasized, an M.V.C. of 40 litres per minute or less tending to preclude pneumonectomy.
10. Bronchospirometry is the only method of measuring in a precise and accurate way the loss of function resulting from the many types of procedures now available for the treatment of pulmonary tuberculosis. These include resection

(including pneumonectomy, lobectomy, segmentectomy, sub-segmentectomy), thoracoplasty, plombage, extra-pleural pneumothorax, and apicolysis with fixation, apart from such medical collapse measures as artificial pneumothorax and pneumoperitoneum with phrenic crush.
The results for these measures as determined in this study are presented in detail.

11. The value of lung function studies, including broncho-spirometry in assessing patients for bilateral surgery (particularly tubercle), and in judging the fitness for operation of emphysematous subjects with bronchial carcinoma, is discussed. Where there has been previous collapse measures or previous extensive parenchymal or pleural disease in tuberculous patients, lung function tests are imperative.

12. Bronchospirometry is also of assistance in determining the type of procedure most suitable for cases with impaired respiratory function. Some of these, while unfit for resection of an entire lung, can often withstand a thoracoplasty or a lobectomy.

13. It is well to recall, nevertheless, the plea made by Comroe (1951), and reiterated by others, that no single test evaluates all aspects of pulmonary function. In all cases the first step is an estimate of overall lung function, reserving measurement of differential lung function by

means of bronchospirometry for patients in whom this is considered necessary. Further information regarding cardio-respiratory function may be required in other instances, and values for the arterial oxygen saturation at rest and on exercise (determined by either the Van Slyke method or oximetry) will indicate the presence or otherwise of any significant degree of emphysema.

14. Finally, in very doubtful cases measurement of pulmonary artery pressure at rest and on exercise, by means of cardiac catheterization, may reveal pulmonary hypertension. (This test was performed in two cases in the present series.) A severe degree of pulmonary hypertension usually indicates incipient cor pulmonale, and as such points to the inadvisability of undertaking major surgery. Simultaneous blockage of the bronchus and pulmonary artery (by using combined bronchospirometry and cardiac catheterization) on the side for proposed pneumonectomy has been performed successfully in Sweden and America, but its use is not yet favoured greatly in this country.

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