BRONCHOSPIROMETRY

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In 1932 Jacobaeus, Frenckner and Bjorkman first described the method of bronchospirigraphy using a double-channelled bronchoscope. Satisfactory respiratory tracings showing the tidal air, ventilatory volumes, vital capacity and oxygen uptake of each lung were obtained. The respiratory level of the subjects was raised (more air in the chest than normally at the end of expiration) and the total vital capacity was reduced (Bjorkman, 1934). These differences were due to the resistance of the instrument to respiration.

In 1939 Gebauer, and Zavod shortly afterwards, designed, quite independently, soft rubber bronchial catheters which rendered the procedure less unpleasant and traumatizing, and gave a maximum respiratory excursion far nearer to the vital capacity as measured by external spirometry. These catheters have two channels, one opening into the lower trachea and the other near the semi-rigid tip, which passes down the left bronchus. The distension of rubber balloons just above each of these openings, segregates the two lungs. The Gebauer catheter has slightly larger airways, is more radio-opaque, and the tip, which passes into the left bronchus, is smaller. However many workers prefer the Zavod catheter. As Procter (1950) has stated, it seems to fit the anatomy better. After suitable local surface anaesthesia the catheter is placed in the correct position under direct fluoroscopic observation. The increased resistance to respiration still causes unpleasant subjective symptoms and the necessity for screening limits the use of the method.

In 1948 Norris and his associates evolved a single-lumen catheter which passes uninterrupted from the left lung, through the mask, to the left lung spirometer. The airway to the right lung is from inside the mask and round the left lung catheter. The resistance of the catheter is about only one-fifth of that encountered in the channels of the double-lumen catheters, and the resistance to the right even less. The catheter is also introduced under fluoroscopic control. There are, however, a number of objections to this technique. The resistance to respiration is not the same for the two lungs, and there is a considerable difference

in the dead space on each side. The vocal cords may contract round the catheter and cause further discomfort and resistance. Lastly, as workers in this field well know, masks leak, no matter what precautions are taken.

Carlens (1949) has evolved a flexible, double-lumen, rubber catheter of about the same rigidity as an ordinary ureteric catheter. It has a small rubber hook which automatically engages the carina. This hook is tied down by a silk thread to allow passage through the larynx. After this, the introducing stylet is removed and the catheter adopts its natural curve. The thread is pulled, releasing the hook and the catheter is turned, so that the curve points the tip towards the left. It is then passed down without fluoroscopy until the hook engages the carina, the tip of the catheter passing into the left bronchus. Subsequently the procedure is the same as with the other types of catheter. The lumen and resistance of each channel is approximately the same as that of the Norris single-lumen catheter. Although the author has not used this catheter yet, it appears, by all reports, to be a considerable advance.*

Procedure

The procedure of bronchospirometry is best studied by watching a team at work. It should be carried out in a special room. The two spirometers and respiratory circuits should be on a trolley, which can be fixed, and all the apparatus should be carefully checked and in perfect working order before the patient comes in. Many workers employ relatively low resistance non-return valves in the spirometric circuit. This, however, means the adding of the resistance of the valves and the absorbent canister to the already uncomfortable resistance of the catheter. The resistance to air flow should be bench tested in all new catheters before they are used. Unpleasant respiratory resistance can be minimized by the use of pumps to circulate the gases through the absorbent canister, as originally described by Knipping. The catheters

* This catheter is now available in the sterling area from A. B. Stille-Werner, Stockholm 4, Sweden.

are connected to a point in each circuit where the negative and positive pressures each side of the pump are balanced, no valves are necessary, and there is practically no added work to be done in breathing, apart from that due to the catheter. The reason that pumps are not universally employed is the considerable difficulty in obtaining and setting up efficient pumps that do not leak or cause unsuspected heating. Such events will falsify the results and, as will be discussed later, this may cause tragically wrong decisions to be made.

It is usual to carry out a preliminary spirometry. In most cases where differential spirometric data is required, the information obtained by bronchoscopy is essential. Ulceration of the trachea and left main bronchus may be found and this is a contraindication to bronchial catheterization. Difficulties due to deformity of the tracheo-bronchial tree may be anticipated and successfully overcome. The finding of bronchial stenosis will greatly help in the interpretation of results and decisions concerning resection. Other contraindications to bronchosprometry are recent spread of tuberculosis, any pulmonary haemorrhage in the previous two weeks, and recent acute laryngitis, tracheitis or bronchitis. Most patients find bronchosprometry 'relatively easy' to tolerate after bronchoscopy. This is rather a Spartan philosophy, but, as bronchoscopy is usually essential, it is fortunate that the more quantitative procedure is the less unpleasant. Routine external spirometry for the determination of lung volumes and ventilatory capacity is best carried out before, as all these procedures are valuable training, apart from the important data they yield. The patient's chest should also be screened and an initial estimation of the relative functions of the two lungs should be made and written down, taking into consideration the history and clinical findings as well as the results of any special investigations. In this way invaluable experience is gained, the value of the more orthodox methods of study enhanced, and errors of judgment long remembered.

If the patient is producing a great deal of sputum, then a preliminary course of postural drainage should be carried out. It is most important to attempt to clear the bronchial tree as not only does the patient tolerate the catheter more easily, but the local anaesthetic is more effective and there is less chance of blockage from secretions.

Sodium amytal (gr. iii), or any appropriate sedative can be given one hour before the examination. A soluble intravenous barbitone preparation should always be immediately available in case of untoward reactions. Half an hour before the commencement, $\frac{1}{4}$ to $\frac{1}{2}$ gr. of morphine sulphate

should be given. Large doses of morphine must be avoided. It is claimed that atropine sulphate (gr. 1/100) reduces the secretions, although many others, the author included, consider that this drug renders the secretion more viscid and troublesome. After the patient has been lying quietly for half an hour, the back of the tongue, the fauces and pharynx are painted with 5 per cent. cocaine hydrochloride, the tongue being held well forward by the patient, who is given a swab for this purpose. The application of the anaesthetic with a camel hair brush keeps the quantity of cocaine solution required to a minimum and also prevents undue amounts being swallowed. The patient should be warned about this and allowed to spit as frequently as possible. There is no doubt that spraying is a far more fortuitous procedure. Next the pyriform fossa is anaesthetized by means of small pledgets on specially curved laryngeal forceps. Counter pressure should be applied below and behind the angle of the jaw. The pledget should be kept in position for at least a minute. This procedure is stated to anaesthetize the superior laryngeal nerve. Others claim that it is unnecessary, but this is not the author's experience.

The larynx is then visualized by means of a mirror and 1 cc. of 5 per cent. cocaine solution is injected between the cords. This results in an explosive cough followed by a deep inspiration which carries the remaining solution downwards thus anaesthetizing the larynx and upper trachea. After a brief period, two further $\frac{1}{2}$ cc. of solution are injected into the trachea, while the patient leans over to the left side. Another $\frac{1}{2}$ cc. is injected while he leans over to his right side. Although anaesthesia of the right bronchus is not essential it certainly appears to reduce irritation and coughing when the catheter is in place. The whole anaesthetization is carried out while the patient is sitting on the edge of the screening table, and it cannot be emphasized too strongly that unless the process is carried out carefully, systematically and satisfactorily, the whole procedure will fail. Not more than 4 cc. of 5 per cent. cocaine hydrochloride solution, or more than 8 cc. of 1 per cent. amethocaine solution, should be used. When anaesthesia is completed the patient is allowed to lie down for the next stage.

There are several methods of introducing the catheter and a metal guide is usually provided. However, in properly trained hands this is not necessary. Nor is it necessary to use a mirror to enter the larynx, as the insertion of the catheter 'blind,' with deep inspirations, soon results in its entry into the trachea. Air can be heard, and felt, passing through the catheter as soon as this occurs. Much depends at this stage upon the con-

fidence of the patient being maintained and a bland and reassuring monologue from the operator will work wonders.

After passing the larynx the final placing of the catheter is carried out under direct fluoroscopic observation. As the catheter tip is semi-rigid and slightly curved, it is not difficult to pass it into the left bronchus. The sudden turn of the catheter will indicate its entry and, if passed further, it will enter the lung field. The catheter should be left just medial to the heart border and about 3 cm. from the carina. At this stage, or when the balloons are inflated, there may be troublesome coughing. The practice of injecting further anaesthetic down the catheter may stop this, but it is an untidy technique and a very poor second best to adequate and careful anaesthetization at the beginning.

When the patient has settled down the balloons should be slowly and carefully inflated by means of an air-filled syringe. As the balloons engage the wall of the respiratory passages they may not only stimulate coughing but the patient will now be subject to the full resistance of the catheter and will no longer be able to breathe around it. This is a very critical juncture and firm reassurance and instruction to breathe deeply and calmly are essential. The author has, at times, invoked the awful lie that 'divers breathe through many feet of tubing and that it is only a matter of confidence.' The integrity of the balloons should have been tested previously in a glass tube of the shape and size of an average trachea and bronchus. Many of the balloons on these catheters are unsatisfactory and it is wise to have a reserve of latex balloons that can be used for replacements. The pressure needed for satisfactory sealing should also have been noted, so that it can be repeated by watching the manometers attached to the appropriate channels. An unduly large trachea may cause some trouble with the upper balloon but examination of the X-ray and bronchoscopy should give adequate warning. Carlens uses a control balloon on the outer end of the channel so that the correct degree of distension can be obtained without a manometer. Before commencing any observations, it is important to listen carefully with a stethoscope to the left upper lobe to check that there are normal breath sounds and good air entry. If the catheter has been inserted just a little too far, the balloon may block the upper lobe bronchus and thus cause low left lung readings. This auscultatory test is most unreliable and the only adequate precaution is to see that the catheter is properly placed when screening. Herein lies another important advantage of the carinal hook on Carlens catheter, as it prevents the catheter slipping before the balloons are distended.

As soon as the observer is satisfied that the catheter is satisfactorily placed, then recordings should be started on the spirometers. There must be no delay, as time is precious. If the lungs are not separated then the whole system is a common chamber and one spirometer will empty into the other, as even the most minute differences of resistance are enough to cause such transference. This will result in the tracings either diverging or converging. Another not uncommon event is due to the upper balloon being too near the carina or distending unequally and downwards. This may result in the right bronchus being blocked. The patient may or may not be distressed but, in any case, the spirometer in the right-sided circuit will show no movement. If the tracings are satisfactory then they should be continued for about five minutes. This will allow a reasonably accurate measurement of the slope of the tracings. It is unwise to assess oxygen uptake from a two minute tracing, particularly as the first minute is frequently unstable. Usually the increased resistance discourages 'temperamental' changes of respiratory level and the slope of the tracing is very definite. Before terminating the test the vital capacity, reserve air and complementary air of each lung should be determined. In some cases mild leg exercise against resistance is carried out, the changes in ventilation and oxygen uptake being noted. Usually the patient will not tolerate a very great increase in activity and ventilation, but Carlens (1950, 1951) reports that, with his new catheter, he is able to exercise patients on a bicycle ergometer attached to the table, and that they will tolerate degrees of exercise involving up to 1.5 l. O₂ consumption per minute. This is a considerable advance and it will be discussed later.

Finally it must be again emphasized that smooth, well-trained teamwork is essential. The procedure is so near to the maximum of discomfort that a patient will reasonably tolerate that there must be no added unpleasant physical or psychological stimuli such as unnecessary noises, coughing, inexperienced or careless manipulation, or inadequate anaesthesia. Wright ('Methods in Medical Research,' 1950) sums up the matter very neatly by stating that the anaesthesia should be carried out at leisure and the intubation and recording in judicious haste. As soon as the requisite information has been obtained the balloons are deflated and the catheter removed. It is usual to measure the vital capacity at once with a mouth-piece, as the comparison of this figure with the added vital capacities of the two lungs is a useful check on the reliability of the recordings. The usual precautions must be taken concerning the patient drinking or eating before the anaesthesia has passed off.

Another important consideration should be mentioned. This is the question of causing re-activation or spread of tuberculous disease by bronchspirometry. Michelson and Wright ('Methods in Medical Research,' 1950) have reviewed a large series of cases most carefully as to this possibility and have found no evidence that bronchspirometry precipitates such an event. Again there is the vexed problem of transmitting the viable tubercle bacilli to another patient from the apparatus. Although some authorities do not think this is important in a group of tuberculous patients, the recent development of streptomycin resistant strains may cause some danger. The author, working entirely empirically, pumps through the apparatus, for several hours, air which has been passed through a strong formalin solution, and the apparatus is then washed out with air for a period. Rubber tubing is boiled and valves are washed with ether. Surprisingly enough there is no unpleasant taste or sensation after this. As a general rule non-tuberculous patients should not be tested on the same circuits as tuberculous patients. This problem is usually evaded and it should be more fully discussed by those whom it concerns.

Other Types of Data in Bronchspirometry

It is of interest to consider other types of data obtained by bronchspirometry. Attempts have been made to measure the ventilatory capacity of each lung by voluntary hyperventilation while the catheter is still in place (Leiner *et al.*, 1940). This is a most unsatisfactory procedure as the stenotic breathing renders such an effort most unpleasant and the figures obtained are far below the true figures. Further, the catheter may be displaced or blocked during such an attempt. Others have measured the residual volume of each lung by the oxygen washout method or by the dilution of an inert gas. Such data is difficult to interpret. Fibrosis, collapse or infiltration of one lung may cause a small residual volume, and the total capacity of the lung may similarly be so altered that the relation of the residual volume to this figure will be of little value in assessing the possibility of emphysema. In the same way, a relatively normal lung may be increased in size by mediastinal shift. It has been shown that even healthy lungs under such conditions will have an increased total and residual capacity. Further, the residual volume may be an abnormally high percentage of the total capacity, without any impairment of the ventilatory capacity or any true evidence of emphysema (Gaensler and Cugell, 1951; Cournand *et al.*, 1950). On the whole the value of such lung volume data does not appear to warrant the considerable trouble of collecting it.

Another method of investigation is to cause the lung which is to be removed or resected to breathe pure nitrogen (Wright and Woodruff, 1942), or to rebreathe into a small bag. There are a number of ways of interpreting the results obtained, but if there is but little disturbance or cyanosis (arterial saturation may be measured), then this is considered as good evidence of lack of function of the lung. Such a finding would certainly suggest considerable reduction of blood flow through the lung, but this can be demonstrated more precisely by the more orthodox procedure of measuring oxygen uptake. Others block the bronchus of the lung or lobe to be resected (Jacobaeus and Bruce, 1940) and, if this causes no disturbance, it is considered good evidence that resection will cause little alteration in the patient's respiratory function. Accurate arterial blood studies are rarely used during this procedure. All these various tests are only carried out in near-basal conditions and inferences concerning ordinary activities and moderate exercise after operation are unwarranted. Further the breathing of low percentages of oxygen or bronchial blockage almost certainly causes marked vasoconstriction in even a healthy lung (Wright and Woodruff, 1942; v. Euler and Liljestrand, 1946; Dirken and Heemstra, 1948; Rahn, 1950), and therefore conclusions concerning the amount of blood flow while breathing air are not justified.

Attempts have been made (Whitehead *et al.*, 1942) to measure the 'reserve' of the 'good lung,' which will remain after resection, by submitting it to what is termed the 'stress' of breathing low percentages of oxygen. The ability of this lung to continue carrying out a large proportion of the oxygen uptake under these conditions is mainly a function of the lack of circulation through the other lung and is in no way related to its ability to ventilate adequately and accept and oxygenate the cardiac output during reasonable exertion. Such procedures produce extremely complicated physiological situations on a background of disease and, although perhaps of fundamental interest, they have no place or value as a routine investigation.

Meaning and Value of Results Obtained

Having considered the details of technique and procedure, let us now turn to the meaning and value of the data obtained by this method. The ventilation, vital capacity and oxygen uptake of each lung can be expressed as a percentage of the total under these conditions. The ratio of oxygen uptake of the two lungs is an accurate measure of the relative blood flow through them. As the patient is breathing high percentages of oxygen, no matter how poor the distribution of inspired

gas (i.e. the ventilation of all air spaces), a high tension of oxygen will soon result throughout each lung. Thus, providing there is no pulmonary circulation unrelated to air spaces, and this is unlikely, then all blood passing through the lung will be fully oxygenated. Each unit volume of blood passing through the lung will take up an equal amount of oxygen. Therefore, although the absolute values of blood flow are not known, as the oxygen content of the blood entering and leaving the lungs is not measured, the comparative oxygen uptake of each lung is a precise quantitative measure of the relative blood flow. In normal subjects the right lung usually has a ventilation, oxygen uptake and vital capacity which is about 55 per cent. of the total. Occasionally this figure is even higher and in some cases the left lung may show about 55 per cent. of the total function as measured by these findings. Thus only figures below 40 per cent. on either side can be considered really significant.

If a non-return respiratory circuit is employed on each side and air is breathed, the expired gases being collected in a Douglas bag, then the application of Fick's principle is no longer valid, as it cannot be assumed that all alveoli, through which blood flows, are adequately ventilated and that all the blood is fully oxygenated. Thus the oxygen uptake during air breathing, although more accurate than that obtained by a tracing, is not a true measurement of the comparative blood flow through the lungs. Although two lungs may have an equal blood flow and oxygen uptake while breathing oxygen, if one of these lungs has some alveolar underventilation due to emphysema or bronchial obstruction, then this lung may show a considerable fall of the percentage oxygen uptake when both lungs are breathing air. Further, under these more natural gaseous conditions, there may be vasoconstriction and decreased blood flow in the underventilated lung. There is a real possibility that the administration of oxygen may artificially increase the percentage of blood flow through an underventilated lung by eliminating such vasoconstriction. In cases where there is a considerably greater percentage of oxygen uptake than of ventilation it may be wise to carry out air studies as well. These considerations are mainly theoretical although Carlens (1950) has recently reported some work showing significant changes in the oxygen uptake of emphysematous lungs when breathing oxygen and when breathing air. Gaensler and Cugell (1951), using the box-bag spirometric technique (Donald and Christie, 1949), have also shown a remarkable decrease in the oxygen uptake of diseased lungs when air is substituted for oxygen. It must be emphasized that the standard procedure at present involves breath-

ing oxygen and it is always assumed, unless stated otherwise, that this is the case.

When bronchspirometry is performed it is usually in order to determine, firstly, the function of the diseased lung which is to be collapsed or resected and, secondly, if possible, the function of the lung that will remain after operation. The latter is, of course, the more important as the safety and the comfort of the patient will depend upon this. Before considering how the findings in bronchspirometry will help to answer these problems, it must be emphasized that such studies only measure the relative function of the two lungs and in no way indicate the functional capacity and reserves of either lung. For example, if a person with crippling bilateral emphysema were tested by this technique, the oxygen uptake and ventilation of each lung would be within normal limits and the vital capacity of the two lungs would be approximately equal. Yet removal of either lung would probably cause death from acute respiratory insufficiency. To carry this illustration further, if severe bulla formation began to occur in one lung in such a person, the percentage ventilation and oxygen uptake of the other lung would increase well above the usual percentage and yet the lung would be grossly diseased and incapable of sustaining life.

Let us return to the consideration of the function of the more markedly diseased lung, which is, if possible, to be collapsed or resected. In a number of cases (severe tuberculosis, bronchiectasis, etc.) the ventilation, oxygen uptake and vital capacity are negligible. Only a small amount of air and blood enter the lung and it can be safely assumed that it is virtually functionless, and that little alteration in the patient's status will result from its removal. Again, the fact that nearly 100 per cent. of ventilation and oxygenation is carried out by the other lung does not prove that it is a healthy lung. However, its true functional capacity can be assessed fairly well by studying the patient's exercise tolerance and ventilatory capacity. The assumption that the remaining lung will function as well after resection as before is only valid if the operation does not injure or deform this lung.

Unfortunately many cases under consideration are not so clear cut as this. The patient may have severe tuberculosis in one lung and the other lung may be apparently normal or healed as judged by clinical and radiological data. Resection or extreme collapse of the diseased lung may be envisaged. Yet if this lung shows 30 to 50 per cent. of total function the observer may find it difficult to decide whether this is due to a considerable amount of functioning lung tissue remaining, despite the disease, or whether this is due to the

inability of the other lung to carry out more function. This type of argument is quite illogical, as if the diseased lung is taking up a significant portion of oxygen then there must be considerable functioning lung tissue present. Resection or irreversible collapse of such a lung should only be carried out if such a procedure is considered absolutely necessary to control the disease, and if the clinician is satisfied that the other lung has almost normal functional capacity. Again, in this type of case, it is sometimes found that the more diseased lung (shall we say with fibrocaceous disease and cavitation) is carrying out more ventilation and oxygen uptake than the lung which now appears healed or is even radiologically clear of disease. In such cases, there is almost invariably a history of pleural disease. Healed bronchial stenosis may give rise to a similar situation (Jacobaeus, 1938). It has been shown by many investigators (Jacobaeus, 1938; Pinner *et al.*, 1942) that so-called parenchymal disease, which may be quite extensive and give marked radiological changes, frequently interferes but little with ventilation and oxygen uptake, whereas old pleural disease (i.e. pneumothorax with fluid and long delay in re-expansion), although showing little radiological abnormality, often causes gross impairment of ventilation and oxygen uptake. It is in this type of patient, where one lung has had pleural involvement and appears healthy and the other lung requires collapse at a later date, that bronchspirometry is so valuable. This finding that old pleural involvement can cause severe and hitherto unsuspected impairment of lung function should be remembered when the advantages and disadvantages of therapeutic pneumothorax are being considered, particularly as it has been shown by bronchspirometry that thoracoplasty, if not too extensive, and in the absence of diaphragmatic paralysis, leaves the lower portion of the lung with a considerable (up to 40 per cent.) amount of function (Pinner *et al.*, 1942). As already mentioned, if there is but little ventilation and considerable oxygen uptake in a diseased lung, then a differential study while breathing air should be done, as it is possible that the blood flow and function are far less under these more natural conditions. A number of workers have suggested the possibility of a considerable 'shunt' of poorly ventilated and oxygenated blood through diseased lungs, but it is only recently that attempts have been made to support this unlikely thesis by arterial blood studies before and after resection.

With regard to the problem of prognosticating the function of the remaining lung after resection, it must be realized that bronchspirometry can only give very limited information in most cases. There has been a great deal of loose thinking about

this subject. What precisely is meant by the functional capacity of a lung after pneumonectomy? It is reasonable to employ the physiological capacity of a normal lung, after removal of the other lung, as a standard. Cournand *et al.* (1950) have shown that one normal lung (defined as such only after detailed and demanding tests) will allow the patient to live a normal life and even carry out moderately severe exercise without any respiratory or cardiac disability. Considering this in more detail, such patients could undertake moderately severe exercise without ventilatory discomfort (dyspnoea), the flow of the total cardiac output through the remaining lung did not cause an undue rise of pulmonary artery pressure, or embarrassment or hypertrophy of the right ventricle, and finally, despite the increased flow through one lung, the blood was normally oxygenated.

Unless one is dealing with a functionless lung as previously discussed, then the assessment of the risk involved and the prognostication of the maximum function of the remaining lung is most difficult. In the case of the diseased lung, which is to be collapsed or resected, showing, shall we say, 40 per cent. of function at comparative rest, it is often suggested that, on more marked exertion, the affected lung will not be able to continue to carry out such a high proportion of ventilation and oxygen uptake. Such an attitude, and it is quite a reasonable one, may lead to resection in 'border line' cases. It is very human to want the organ which is to be removed to be relatively functionless, and this is therefore a tempting hypothesis. However, Carlens (1950, 1951) using his new type of catheter, has been able to exercise patients up to an oxygen consumption of 1,500 cc. per minute and obtain satisfactory differential studies. These experiments have shown a remarkable constancy of the ratio of ventilation and oxygen uptake in all degrees of activity. This is a very important observation and demands more realistic thinking. It means that, despite the disease present, collapse or resection often demand a high price in terms of function, and care must be taken that this price can be paid and that the remaining lung will have adequate function, as defined above, to make life tolerable. It is important to note that Carlens' observations were made while using oxygen enriched mixtures and these exercise studies should be repeated while breathing air.

In the case of patients with relatively recent but severe unilateral disease and no previous history of asthma, bronchitis or any other respiratory disability, it is reasonable to assume that the remaining lung tissue is healthy and that resection or collapse of a whole lung would not cause any great disability. However, if the patient is older, the history and clinical findings suggest emphysema

sema or fibrosis, or if the other lung has been diseased or collapsed, then great care must be taken. The present exercise tolerance should be determined. Exercise tests may not be feasible if the patient has been strictly at rest in bed for a considerable period. The ventilatory capacity (maximum breathing capacity) can be measured and the capacity of the lung that is to remain can be approximately calculated. It should be remembered that after resection the ventilatory capacity will be considerably more than the demonstrated percentage of total ventilation, as the single lung compensates by more rapid but smaller respirations. A normal lung under these conditions can sometimes give a maximum breathing capacity as great as that obtained with two healthy lungs (Cournaud *et al.*, 1950). There is a great deal more work to be done on this problem. Warring (1949) prognosticates the ventilatory capacity of the lung before resection by determining the maximum breathing capacity and then watching the ventilatory movements during screening. Another most important observation is the minute ventilation of the patient during moderate exercise (walking, etc.). This can be measured by collecting the expired air in a Douglas bag over a reasonable period. It has been shown by Warring (1949) that these ventilatory demands alter but little, no matter what surgical procedures are carried out. The relation of these figures, which vary enormously, to the prognosticated ventilatory capacity will give some idea of the degree of exercise that will be tolerated without dyspnoea after operation.

As the majority of cases in whom collapse and resection are carried out are relatively young people with tuberculosis, or quite young people with localized bronchiectasis, and these people do not have marked emphysema or generalized lung disease, the main problem is a ventilatory one and the possibility of right heart embarrassment and inability to oxygenate the arterial blood are remote. Careful ventilatory studies and consideration of the possibility of ventilatory insufficiency and dyspnoea are therefore most important and rewarding. In patients with considerable lung damage, such as pulmonary emphysema or fibrosis, pleural fibrosis, or massive healing, resection or collapse may be most hazardous. Ventilatory problems can be studied as already outlined. Circulatory considerations are more difficult and can only be investigated by highly specialized procedures such as by cardiac catheterization with pressure recording during rest and exercise. Carlens' observation that differential blood flow remains constant should be a great help in such studies. Electrocardiographic studies and screening will give further evidence of the state of the right heart. Arterial

blood studies with exercise are also of value.

These brief observations emphasize that although bronchspirometry is a valuable procedure in assessing differential lung functions it cannot by itself enable the investigator to foretell function after operation. More general studies and considerations are necessary for such prognostication, and there is a great deal of work still to be done in this field.

Future Possibilities

It is of interest to consider what procedures would make it possible, in difficult cases, to assess the functional capacity of a single lung more precisely before operation, so that it could be definitely stated whether or not this single lung will be able to support reasonable activity after resection or collapse of the other.

Let us first consider the ventilatory capacity. The techniques and difficulties of this assessment have already been discussed. Although the contribution of each lung to the total ventilatory capacity can be fairly well determined by bronchspirometry or screening, it is difficult to determine precisely what the performance of this lung will be when functioning alone. A feasible method would be to pass a thin catheter, with a balloon attached, down the bronchus of the lung that is to be resected. This bronchus could then be occluded with a minimum of interference with the air way to the other lung. Ventilatory tests (maximum breathing capacity) could be carried out in this state and the figures obtained related to the patient's ventilation during moderate exercise. Such data would enable the observer to give an almost precise estimation of the degree of activity that will be possible without dyspnoea or ventilatory embarrassment. There is a theoretical objection to this simple procedure. It is possible that the increase of blood flow through the lung after operation may alter its ventilatory capacity. The complete and final test would be the occlusion, not only of the bronchus as described, but also of the appropriate branch of the pulmonary artery by a saline or diodrast filled balloon on a cardiac catheter. If, under these conditions the supine patient could exercise on an ergometer, up to a reasonably high oxygen uptake, without ventilatory distress, or a significant rise of pulmonary artery pressure, or arterial desaturation, then it would be possible to state that the lung was relatively normal and that function would be adequate after operation. This procedure would ensure virtual physiological amputation of the lung and this is probably the only way of assessing the patient's function after its resection. There is always, of course, the proviso that the operation will not injure or deform the remaining lung.

The temporary occlusion of the pulmonary artery has been shown by Hansan (1951), after many animal experiments, to be safe in the human subject, at least, at rest. The simultaneous blockage of bronchus and artery has not yet been reported, but it is probably only a matter of time before it is done. The original concepts of many chest and heart operations, which are now a routine procedure, were far more dramatic and apparently dangerous than that of simultaneous bronchial and pulmonary artery blockage. It is an odd comment on human nature that a considerable number of patients have died after ill-judged resections, with little more than a transient regret by those involved that the best judges can make mistakes, but the suggestion that simultaneous bronchial and pulmonary artery blockage be carried out, will cause many to rise up and protest against unjustifiable experimentation. Yet a 'doubtful resection' is, of all things, an unjustifiable experiment, no matter by what standards it is judged. Further, unsuccessful operations are inclined to be forgotten or lead to all border-line cases being rejected, when operation may be feasible and life-saving (i.e. bronchial carcinoma with generalized pulmonary emphysema).

Final Comment

Bronchospirrometry is not a difficult investigation and yet it is but little used in this country.

Although it was described nearly 20 years ago and year after year, both chest surgeons and physicians state how invaluable such data would be, the method does not come into general use. What are the reasons for this odd state of affairs? Many physicians and surgeons, who practice the most difficult procedure of bronchoscopy, consider that bronchospirrometry requires a considerable knowledge of respiratory physiology and its experimental methods. This is quite untrue and any competent medical man could be adequately trained in a few months. Others hope, usually in vain, that such a service will be provided by another department. However, the few people who have trained with highly-skilled groups usually wish to devote their time, outside their direct clinical activities, to more fundamental work and do not wish to become involved in a routine investigation, which could be adequately performed by an efficient registrar.

It is true that the results can be misinterpreted and that faulty technique may cause incorrect and perhaps, dangerous decisions to be made, but such criticisms apply to many other special tests which are in daily use.

Finally, if the physicians and surgeons, who wish to avail themselves of this technique, really insist that those who are training in thoracic medicine and surgery should devote a few months to mastering it, then the method would be widely used in a year or two.

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