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April 1951

THE SEMON LECTURE

THE DEVELOPMENT AND THE PRESENT USE OF BRONCHO-SPIROMETRY

By Dr. PAUL FRENCKNER (Stockholm)

IN 1929, I started my first experiments with what, from the very beginning and also later, I have called bronchial catheterization. The purpose was to work out a method of clinical examination with which it would be possible to judge the function of each lung individually in the same manner that it is possible to form an opinion of each kidney with ureteral catheterization.

The definition of bronchial catheterization given at that time was as follows: (*Acta Oto-Laryngologica*, Suppl. 20, 1934, page 26) "By bronchial catheterization I mean the procedure of passing a flexible or rigid tubular instrument down into a certain predetermined bronchus and of obtaining an air-tight closure between the bronchial wall and the instrument by means of a special fixture on its distal end so that it is possible to transmit to or from the area of distribution of the air-way in question a gaseous or fluid substance for diagnostic or therapeutic purposes."

In 1932, exceptional opportunities were offered for the application of bronchial catheterization on humans when Professor Jacobaeus requested collaboration and placed all his wealth of ideas as well as all of his clinical material with diseases of the lungs at my disposal for investigation. Jacobaeus' assistant at that time, Dr. Björkman, was just then occupied with spirometric studies in lung diseases. Through application of bronchial catheterization in connection with spirometry, we created the method of examination and the concept of bronchospirometry. The physiologist Prof. Liljestrand gave me very valuable advice in the solution of certain physiological problems.

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My first experiments were carried out with double rubber catheters on dogs. At subsequent investigations on humans, this proved to be unsuitable with the rubber manufacturing possibilities available at that time and, therefore, the double bronchoscope of metal was constructed, which was later used in our experiments during a number of years (*Acta Oto-Laryngologica*, Suppl. 20, page 42): "This instrument was intended to allow a simultaneous flow of all the respiratory air of both lungs through separate tubes under as physiological conditions as possible, that is to say, with normal speed and with the usual difference between intrapulmonary and atmospheric pressure."

The many experiments with different instruments and techniques that Dr. Björkman and I carried out during the following years are found in earlier publications. Many interesting observations were made at bronchospirometric examinations in different body positions, in unilateral and bilateral pneumothorax during actual filling of pneumothorax, on inhalation of different gas mixtures into both lungs, etc.

Figures 3 and 4 call attention to how bronchospirometric curves appear in normal cases and in unilateral pneumothorax.

Because of changed working conditions, I was personally unable to continue with bronchospirometry during a ten-year period after 1938. However, during that time, it was developed by a number of other authors, the most important of whom will be quoted here.

It was already obvious during my earlier work with bronchospirometry that the rigid double bronchoscope had many disadvantages. Attempts to replace it with soft or semi-firm rubber catheters reached no conclusion then but that idea has since been an objective for all who have built new devices.

In 1937, Dr. Paul W. Gebauer, of Cleveland, Ohio, constructed a latex rubber tube in which a coiled steel spring was embedded which gave the tube a desirable semi-rigidity. The tube was introduced under fluoroscopy. Instead of a spirometer, an ordinary metabolism apparatus was used, which was regarded as giving sufficiently exact values for clinical cases but not for physiological research investigations.

At the same time and independent of Gebauer, Zavod constructed an almost identical double catheter.

Pinner, Leiner and Zavod have published several bronchospirometric works, *inter alia*, an extensive investigation of 270 cases. They point out that bronchospirometry is indicated when an irreversible operation to one lung is planned "but it is also indicated to study various physiopathological problems of respiration following disease or operative procedures on one lung".

The same authors have reached the conclusion that pleural involvement causes great functional disturbance in the lung while parenchymal involvement is considerably less noticeable. Concerning lungs injured

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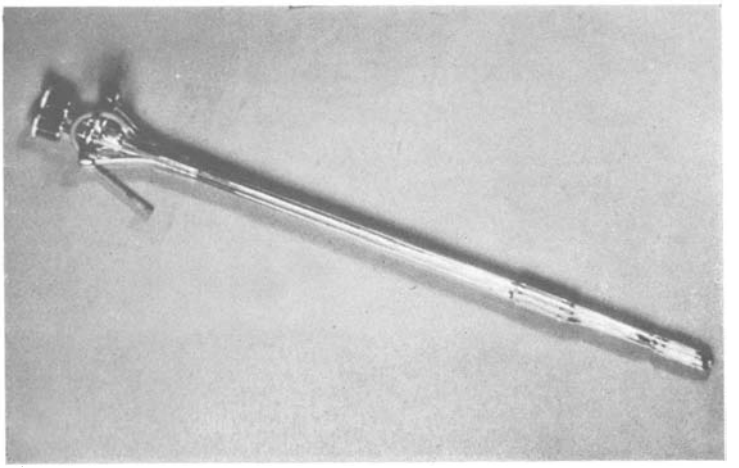


FIG. 1(*a*).
Double Bronchoscope.

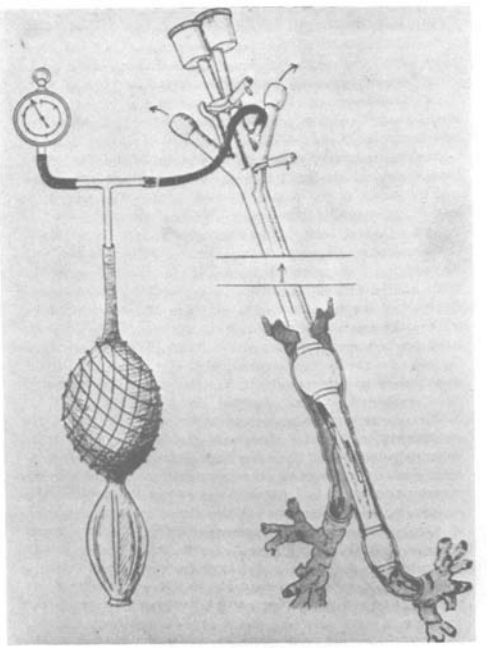


FIG. 1(*b*).
Double Bronchoscope in Position.

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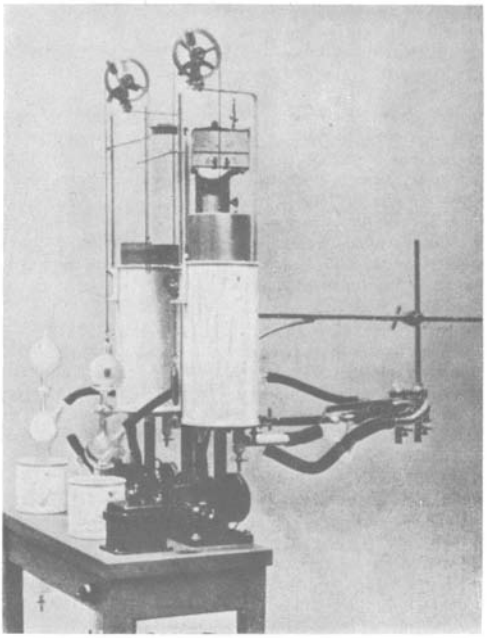


FIG. 2.
Björkman's double spirometer.

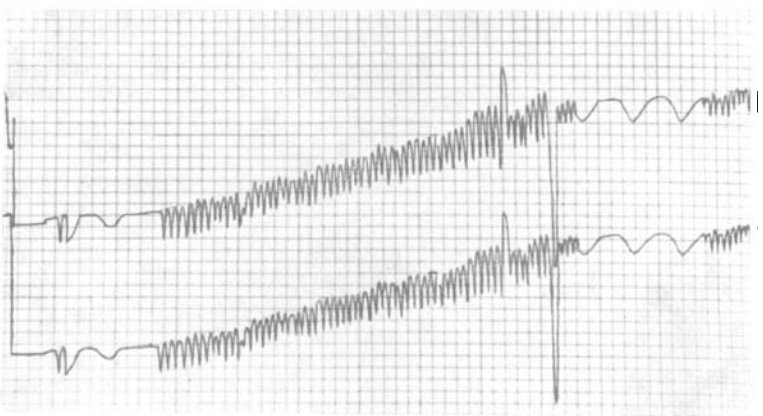


FIG. 3.
Bronchospirometric curve from normal case.

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through illness or treatment, it is pointed out that the respiratory gas exchange is usually much more limited than the ventilation and therefore it is misleading to judge their function by their vital capacity alone.

For several years Charles M. Norris of Philadelphia has used an instrument constructed by himself. It consists of a simple rubber catheter, 55 cm. long, containing a metal spiral with its distal end somewhat bent in order that it may be introduced into the left main bronchus, while the proximal end will pass through an ordinary tightly fitting mouth mask through which the air from the right lung is allowed to escape by means of a Y-shaped outlet from the mask. The catheter is introduced under fluoroscopy. Norris considers this instrument to be superior as it may be constructed wide enough to prevent stenotic breathing. He concedes that a great difference exists between the current conditions of the two sides, wherefore the instrument is not suitable for experimental physiological research investigations.

Norris and his collaborators at the Jackson clinic have made many physiologically and clinically important observations. For example, it has been shown that unilateral pneumonectomy produces insignificant change in the total respiration volume, and the oxygen consumption showed how well one healthy lung can assume the previously bilateral lung function.

The aforementioned instruments have many and large disadvantages. The double bronchoscope causes the patient great subjective discomfort through its rigidity. Gebauer's and Zavod's catheters are very distinctive in their rubber achievement but are all too restricted and uneven in their lumen width. Norris' instrument has altogether too great difference in the current conditions.

Carlens' recently constructed double catheter means a long step forward. It is described in the *Journal of Thoracic Surgery* as follows: "The catheter is made of rubber of approximately the same rigidity as an ordinary urethral catheter and provided with a small hook that is automatically engaged by the carina. The inner diameter of each lumen is 7 mm. for men and 6 mm. for women. The catheter is introduced without fluoroscopy under mirror guidance over a curved metal stylet. The rubber hook is tied down to the catheter with a silk thread until it has been passed through the larynx, when the slipknot is untied. The catheter enters automatically the left main bronchus. The hook is engaged by the carina and the catheter will remain in position of itself."

The ingenious shape facilitates the introduction which takes place without fluoroscopy and guarantees a correct position during the course of the examination. The disadvantage of the instrument is its relatively large outer diameter.

During recent years, together with Björkman, Carlens has made a number of investigations under physiologic and pathologic conditions

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which have given interesting results. *Inter alia*, attempts have been made to ascertain how each lung functions during exertion, and thereby it was possible to determine that even in diseases with pronounced pathologic alteration to one lung, both lungs participate without change in the respiration during moderate exertion.

For the last few years the double catheter has been used routinely for another purpose, namely, for the administration of narcotic gas in lung operations in order to prevent the spreading of infectious material from one lung to the other during the operation. The narcotic medium may be supplied to the healthy lung while the other lung may be completely blocked off and sucked clean during the course of the operation. In addition, it is possible to collapse and inflate this lung as desired and thus facilitate the operation. The accompanying figures which are taken from Björk and Carlens, "The prevention of spread during pulmonary resection by the use of a double-lumen catheter," *The Journal of Thoracic Surgery*, July 1950, for the most part speak for themselves.

This work and a large part of Björkman-Carlens' bronchospirometry have been carried out at Crafoord's thoracic surgery clinic. Professor Crafoord's personal opinion is that bronchospirometry is of great importance to lung surgery. He says that this method of examination is the most certain in the determination as to whether a surgical operation upon one lung is or is not possible from the functional point of view. This is just as true in the case of plastic operations in tuberculosis as in operations of tumours, bronchiectases and other conditions. Crafoord considers the intra-*bronchial* narcosis to be a great advance especially with suppurative lung diseases, and surely a procedure which will be predominate in the future.

My own bronchospirometry, which has been carried out during recent years in collaboration with my closest associate, Dr. Nils G. Richtnér, has in part concerned an occupational medical investigation and in part ordinary routine examinations.

The occupational medical investigation is a series of examinations of 150-200 labourers at Boliden's gold and copper mines. These workers are much exposed to arsenic fumes and sulphur dioxide gases. In earlier investigations, Richtnér found that to a very large extent, despite protective arrangements, the labourers showed pronounced mucous membrane atrophies in the entire respiratory tract from nose to bronchi. Large dry septum perforations occurred in more than 10 per cent. The current series of examinations includes careful X-ray and clinical control of the physical condition carried out by an internist. At the same time we have performed bronchoscopy and bronchospirometry and also ordinary spirometry in a number of cases. The object is to ascertain whether the aforementioned occupational work, in addition to mucous

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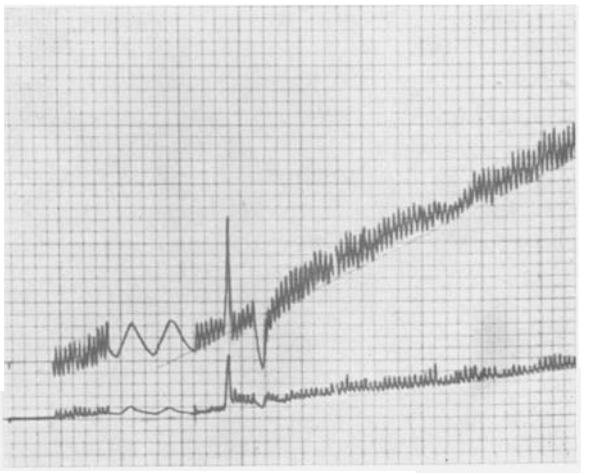


FIG. 4.
Bronchospirometric curve in unilateral pneumothorax.

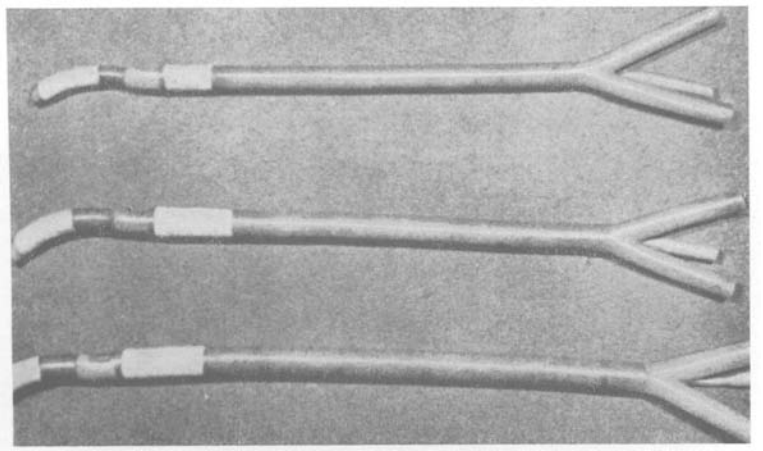


FIG. 5.
Gebauer's double catheter.

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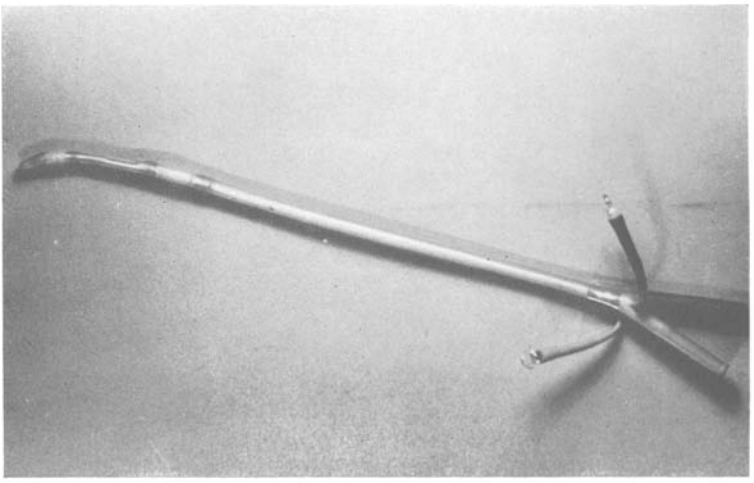


FIG. 6.
Zavod's double catheter.

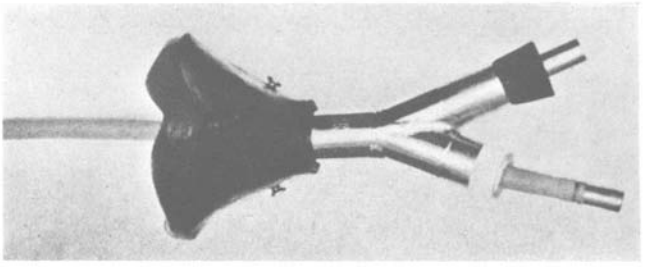


FIG. 7(*a*).
Norris' double catheter.

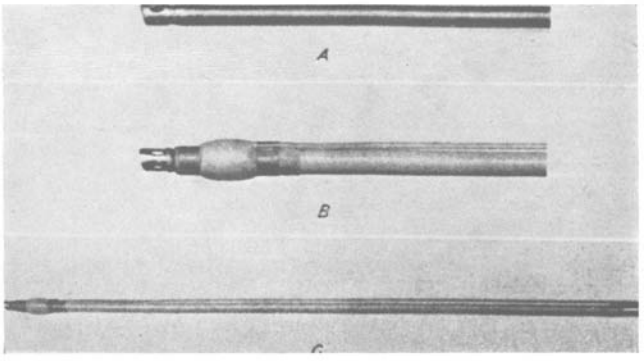


FIG. 7(*b*).
Norris' double catheter.

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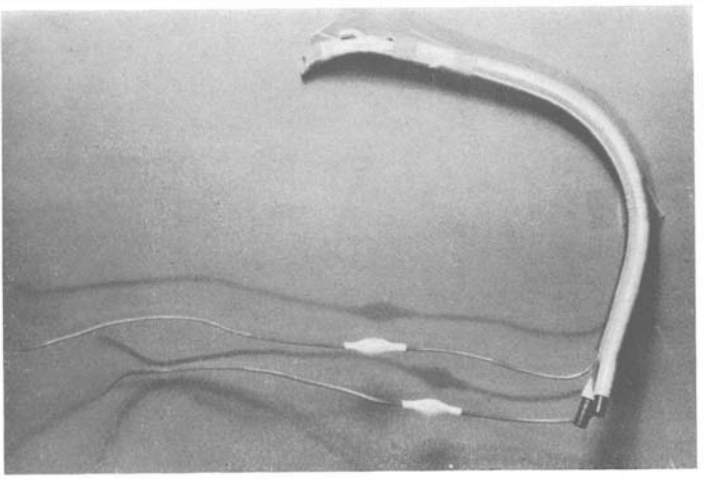
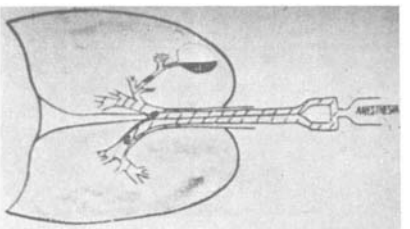


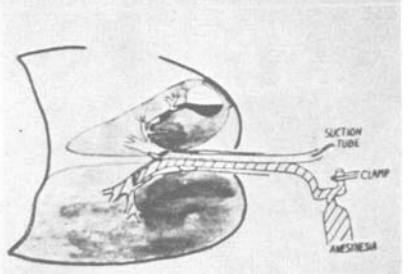
FIG. 8.
Carlens' double catheter.

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9-2



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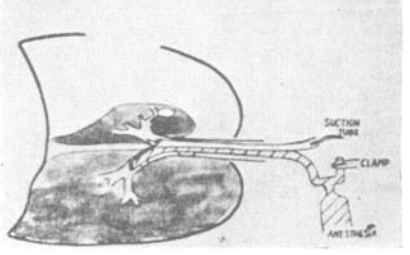


FIG. 9-1.

In the beginning both lungs are connected with the anæsthesia machine.

FIG. 9-2.

When the chest is opened anæsthesia is given to the unoperated lung only. The other lung is atelectatic and immobile, increasing the operation space and facilitating the separation of the lung from the chest wall. Continuous suction is applied in the bronchi of this side.

FIG. 9-3.

After separation of the lung from the chest wall the dissection of an incomplete fissure was found difficult on an atelectatic lung.

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membrane atrophy, causes disturbances of pulmonary function which could be ascribed to emphysema, epithelial damage or such, and if both lungs show equal or unequal percentage impairment of function.

When the entire investigation is completed, the material will be carefully studied by Dr. Richtnér. In the following, I shall summarize the conclusions that might be drawn from the 75 cases so far examined.

Technique: local anæsthesia in the usual manner with 2 per cent. pantocain solution is applied with spray + aerosol + instillation into the larynx.

During all of last year Carlens' rubber catheter has been used. This is introduced after local anæsthesia in either direct or indirect laryngoscopy. The patient is placed in recumbent position and the catheter is attached to the oxygen-filled double spirometer. The spirometer is connected after one to two minutes' quiet breathing. The recording continues eight minutes during which the patient shall also breathe with maximal inspiration and expiration. Thereafter, forced breathing follows for $\frac{1}{4}$ to $\frac{1}{2}$ minute, and finally determination of the residual air, according to Birath. In a number of cases, the examination is continued with ordinary spirometry including forced breathing during $\frac{1}{2}$ minute.

In order to estimate the function of the lung, the volumetric conditions as well as the respiratory gas exchange is of significance. Here only the volumetric values which are of particular interest in this connection will be given, namely, the total capacity, the vital capacity and the oxygen consumption. The proportions of reserve air and residual air are evident from the residual quotient and the equilibrium quotient.

For certain practical reasons, hydrogen has been used in place of helium in the determination of residual air. Possibly this may cause a very slight difference in the values, which however, is entirely without significance from a practical point of view.

The total capacity shows entirely normal average values for right and left lungs, respectively, 2,600 and 2,400 ml., according to Table A. The

TABLE A.

Total Capacity Volume in ml. in 75 Cases.

	Max.	Min.	Average	Differences between right and left
Dt.	3,685	1,460	2,600	in 37% of the cases <200
Sin.	3,850	910	2,400	in 30% „ „ „ 200-400
				in 13% „ „ „ 400-600
				in 9% „ „ „ 600-800
				in 7% „ „ „ 800-1,000
				in 4% „ „ „ >1,000

variations for each lung, 3,685-1,460 and 3,850-910 for right and left lungs respectively, are large, in some cases more than occur with healthy individuals. The difference between right and left lungs remains less than 400 ml. in 67 per cent. Greater differences in 20 per cent.

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It is apparent from Table B that the average value, approximately

TABLE B.
TOTAL CAPACITY, HIGHER OR LOWER THAN AVERAGE VALUE, IN 75 CASES.

Difference	<100	100-300	300-500	>500
Dt. (≷2,600)	in 17% of the cases	in 33%	in 17%	in 33%
Sin. (≷2,400)	in 14% ,, ,, ,,	in 29%	in 17%	in 40%

2,600 and 2,400 respectively, occurs only in a small percentage of the cases. Deviations of 500 ml. above or below the average occur for each lung in about 40 per cent.

Thus the total capacity values show impaired function of one or both lungs in a certain number of cases.

The vital capacity should normally be 2,100 and 1,900 for right and left lungs respectively. In the present material, the values, as presented in Table C, average respectively 1,700 and 1,500. The variations are

TABLE C.
VITAL CAPACITY VOLUME IN ML. IN 75 CASES.

	Max.	Min.	Average	Differences between right and left
Dt.	2,650	720	1,700	in 36% of the cases <200
Sin.	2,480	610	1,500	in 45% ,, ,, ,, 200-400
				in 14% ,, ,, ,, 400-600
				in 5% ,, ,, ,, 600-800

very great : for right and left lungs respectively, 2,650-720 and 2,480-610. According to this table, both lungs are equally affected in the majority of cases. The differences in (36 + 45 per cent. =) 81 per cent. of the cases is less than 400 ml. In 14 per cent. the difference between right and left vital capacity was 400-600 ml., and in 5 per cent more than 600 ml. As regards these latter cases, it is conceivable that there is a markedly unilateral lung damage.

As is the case with the total capacity, the vital capacity also closely approximates the average values in only a small number of cases, respectively 15 per cent. and 21 per cent., according to Table D. In 35 per cent.

TABLE D.
VITAL CAPACITY, HIGHER OR LOWER THAN AVERAGE VALUE, IN 75 CASES.

Difference	<100	100-300	300-500	>500
Dt. (≷1,700)	in 15% of the cases	in 35%	in 25%	in 25%
Sin. (≷1,500)	in 21% ,, ,, ,,	in 36%	in 26%	in 17%

and 36 per cent. respectively, the value obtained has been 100-300 ml. higher or lower than the average, and in about 50 per cent. the vital capacity for each lung has been more than 300 ml. greater or less than ordinarily. These values prove nothing definite, but in a number of cases with very low volumes, the atrophy has been obviously pronounced, which might indicate impaired function.

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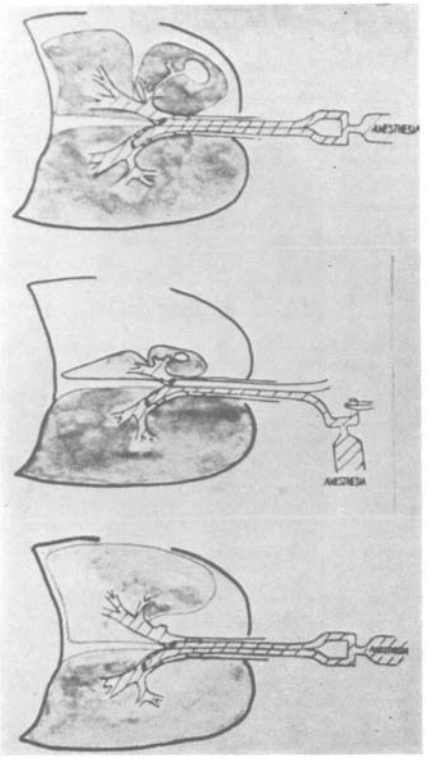


FIG. 9-4.

Both lungs are connected with the anæsthesia machine. The separation of lobes in the fissure was facilitated by the inflation of the lung.

FIG. 9-5.

The non-operated lung only is connected with the anæsthesia machine when dissection of hilum is carried out.

FIG. 9-6.

After completion of the upper lobectomy the anæsthesia is continued on both lungs.

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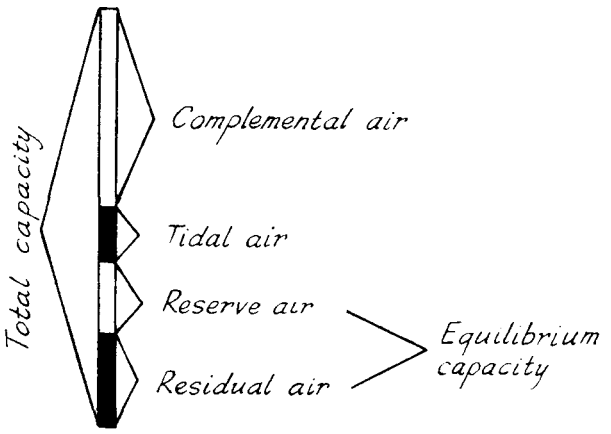


FIG. 10.

Schedule of names of certain respiratory volumes and the reciprocal relationship of their values.

	Dx.	Sin.	Total
Oxygen absorption ml/min.	125 ml.	100 ml.	225 ml.
Total capacity	2,750 ml.	2,450 ml.	5,200 ml.
Vital capacity	2,100 ml.	1,900 ml.	4,000 ml.
Minute volume	c : a 3,000 ml.	c : a 3,000 ml.	6,000 ml.
Complemental air	1,380 ml.	1,220 ml.	2,600 ml.
Tidal air	270 ml.	230 ml.	500 ml.
Reserve air	480 ml.	430 ml.	900 ml.
Residual air	640 ml.	560 ml.	1,200 ml.

Equilibrium capacity = reserve air + residual air.

$$\text{Equilibrium quotient} = \frac{\text{Equilibrium capacity}}{\text{Total capacity}} = 40\%(38\% - 75\%).$$

$$\text{Residual quotient} = \frac{\text{Residual air}}{\text{Total capacity}} = 23\%(15\% - 26\%).$$

$$\text{Ventilation equivalent} = \frac{\text{Minute volume}}{\text{Oxygen absorption ml./min.} \times 10} = 2\tfrac{2}{3}(1\tfrac{1}{2} - 4).$$

FIG. 11

ORDINARY AVERAGE VALUES.

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Even the vital capacity values, on comparison with bronchoscopic findings, may possibly indicate that the function of one or both lungs is somewhat damaged.

The oxygen consumption shows average values within physiologic limits of 180 ml. per minute for the right lung and 160 ml. per minute for the left. The difference between the lungs remains, in (44 + 31 per cent. =) 75 per cent. of the cases, less than 50 ml. per minute and in another 15 per cent., less than 75 ml. per minute, all values being within physiologic limits. The inequality has been significant in only 10 per cent. of the cases, as is evident from Table E. The same table also shows

TABLE E.

OXYGEN CONSUMPTION, ML./MIN., IN 75 CASES.

	Max.	Min.	Average	Differences between right and left
Dt.	304	78	180	in 44% of the cases <25
Sin.	270	31	160	in 31% „ „ „ 25-50
				in 15% „ „ „ 50-75
				in 5% „ „ „ 75-100
				in 5% „ „ „ >100

the extreme values to be of interest, especially the minimum values of 78 ml. per minute and 31 ml. per minute for right and left lungs respectively.

It is evident from Table F, however, that oxygen absorption remained

TABLE F.

OXYGEN CONSUMPTION ML./MIN., HIGHER OR LOWER THAN AVERAGE VALUE, IN 75 CASES.

Difference	<25	25-50	50-75	75-100	>100
Dt. (≷180)	in 44% of the cases	in 42%	in 8%	in 3%	in 3%
Sin. (≷160)	in 45% „ „ „	in 35%	in 11%	in 6%	in 3%

near the average, that is to say, not more than 50 ml. per minute over or under the average of 180 ml. for the right and 160 ml. for the left in 80-85 per cent. of the cases. In only 5-10 per cent. of all cases has the oxygen consumption exceeded or fallen under the average value by approximately 100 ml. per minute.

In the cases in which the oxygen absorption has been low, bronchoscopy showed the mucous membrane to be extremely atrophic, but as a similar condition has been seen in most of the other cases also, no positive conclusions may be drawn concerning a connection between atrophy and poor oxygen consumption, even if such a connection may be suspected. In some cases such a great difference between the oxygen absorption capacity of the two lungs was found that a markedly unilateral damage may be probable.

Thus the values recorded for oxygen consumption may possibly indicate a decreased function which is considerably more pronounced in one lung in

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certain cases. It is not improbable that this decreased oxygen absorption may be caused by an epithelial damage.

Estimation of the respiratory gas exchange has been made with the help of the residual quotient, the equilibrium quotient and the ventilation equivalent at rest and on forced breathing, in addition to oxygen consumption.

The residual quotient $\left(= \frac{\text{residual air}}{\text{total capacity}} \right)$ is said to be normal at 15-26 per cent. in recumbent position (Birath). As is evident from Table G, the values vary about a mean of 35 per cent. to a maximum of

TABLE G.

RATIO OF RESIDUAL QUOTIENT IN 75 CASES.

	Max.	Min.	Average	Variations: Differences between right and left	Differences between right and left: Max.	Min.
Dt.	65%	19·8%	35%	in 68% of the cases <5%	19·7%	0%
Sin.	59·7%	18·7%	35%	in 27% ,, ,, ,, 5-10%		
				in 2% ,, ,, ,, 10-15%		
				in 3% ,, ,, ,, >15%		

65 per cent. on the right and 59·7 per cent. on the left, and a minimum of 19·8 per cent. right and 18·7 per cent. left. The quotient is almost equal on right and left sides in (68 + 27 per cent. =) 95 per cent. of the cases. The difference is significant in only a few cases.

The residual quotient shows high values throughout because of considerably higher residual air values than ordinarily, which indicates a decreased lung function with poor emptying ability. In some few cases, the difference between right and left lungs is obvious, which may well indicate a unilateral damage. The most probable cause of the impaired function appears to be emphysema, but an epithelial damage caused by the poisonous gases cannot be excluded from consideration.

The equilibrium quotient $\left(= \frac{\text{reserve air} + \text{residual air}}{\text{total capacity}} \right)$ is normally 38-45 per cent. In the majority of cases, the quotient in this material is about 45 per cent., according to Table H. Only occasional variations

TABLE H.

RATIO OF EQUILIBRIUM QUOTIENT IN 75 CASES.

	Max.	Min.	Average	Variations: Differences between right and left	Differences between right and left: Max.	Min.
Dt.	74·8%	36·0%	45%	in 63% of the cases <5%	21%	0%
Sin.	66·8%	27·0%	45%	in 23% ,, ,, ,, 5-10%		
				in 13% ,, ,, ,, 10-15%		
				in 1% ,, ,, ,, >20%		

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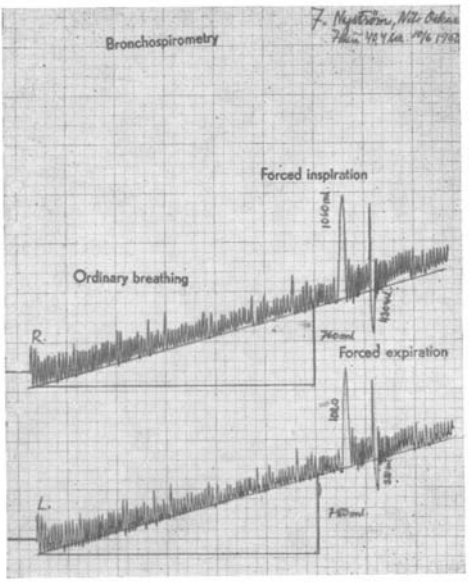


FIG. 12.
Curve, Case 7/1950.

Ordinary breathing :	Right	Left
Oxygen consumption ml./min.	150	156
Tidal air	210	190
Minute volume	3,580	3,240
Reserve air	430	320
Vital capacity	1,490	1,340
Ventilation equivalent	2·4	2·1

FIG. 13.
Values, Case 7/1950.

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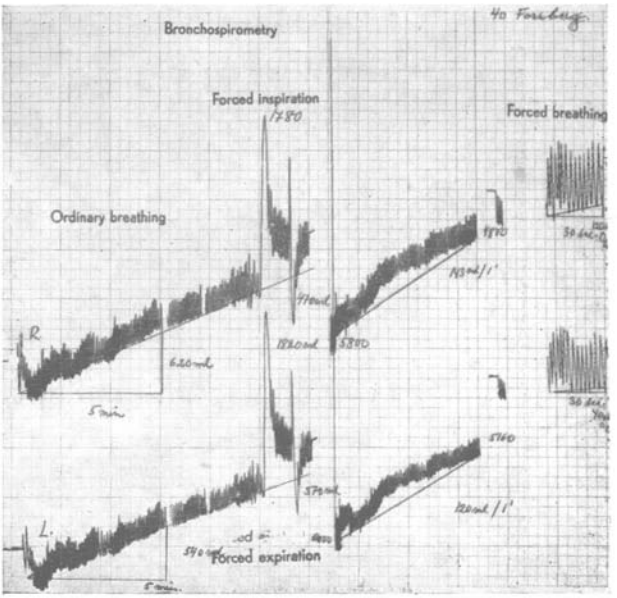


FIG. 14.
Curve, Case 40/1950.

Ordinary breathing :	Right	Left
Oxygen consumption ml./min.	124	108
Tidal air	230	180
Minute volume	4,370	3,420
Total capacity	3,232	3,201
Ventilation equivalent	3·52	3·16
Equilibrium quotient	44·9%	43·1%
Residual quotient	30·4%	31·5%
Forced breathing :		
Oxygen consumption ml./min.	240	80
Minute volume	16,760	14,260
Ventilation equivalent	6·98	17·9

FIG. 15.
Values, Case 40/1950.

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occur, with a maximum of 74·8 per cent. for right and 66·8 per cent. for left, and a minimum of 36·0 per cent. for right and 27·0 per cent. for left lungs. In a few cases (13 + 1 per cent. =) 14 per cent. a considerable difference of up to 20 per cent. between right and left lungs exists. In (63 + 23 per cent. =) 86 per cent. the values for both lungs differ insignificantly.

The equilibrium quotient in the majority of cases presents the physiologic value. The increased residual air value is compensated by the very low reserve air value throughout. Consequently, the patient has difficulty in emptying the lungs. Otherwise the conclusions are the same as with the residual quotient.

In an industrial medical investigation such as this, the estimation of the respiratory gas exchange and the oxygen absorption is of special interest as that function can or should be dependent upon the condition of the alveolar epithelium. If the epithelium is damaged by gas inhalation, its function should be impaired. Such changes as well as other functional disturbances with emphysema, etc., should appear earlier than damage demonstrable by X-ray. It is in just such cases that it would be desirable to perform a more detailed test of Brauer's so-called pneumosis-theory ; that is the theory of decreased ability of the alveolar epithelium to transmit gases, above all oxygen, depending upon local or general damage to the alveolar epithelium.

A measurement of the gas exchange with special regard to the oxygen absorption has been obtained through calculation of the ventilation equivalent. In the present investigation this has been calculated according to the formula : $\frac{\text{Minute ventilation}}{\text{oxygen consumption/min.} \times 10}$ and is therefore $2\frac{2}{3}$ if the minute volume is figured for both lungs together at 6,000-8,000 ml. and oxygen consumption at 225-300 ml. per minute. Consequently, with obstructed oxygen consumption, the ventilation equivalent rises ; with increased oxygen exchange, it falls. The equivalent value must, therefore, be seen in comparison with that of the minute ventilation. If the minute ventilation is very small, even a low equivalent value may indicate poor oxygen consumption.

Taking this into consideration, it appears that the ventilation equivalent should be the most important factor in the estimation of the condition of the alveolar epithelium. An increased residual quotient may certainly also indicate epithelial damage, but its more usual cause is emphysema.

As Norris pointed out, great care should be taken in the interpretation of the ventilation equivalent, " since it represents an attempt to correlate a physio-chemical process (oxygen absorption) with one which is controlled by nervous and humoral mechanisms which are variable (ventilation) ".

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As appears in Table I, the ventilation equivalent values have varied for the right lung *at rest* between a maximum of 3·76 and a minimum of

TABLE I

VENTILATION EQUIVALENT IN ORDINARY BREATHING IN 75 CASES.

	Max.	Min.	Average	Variations: Differences between right and left	Differences between right and left: Max.	Min.
Dt.	3·76	1·08	1·8	in 34% of the cases <0·25	1·61	0
Sin.	3·01	1·17	1·8	in 33% „ „ „ 0·25-0·50		
				in 15% „ „ „ 0·50-0·75		
				in 12% „ „ „ 0·75-1·0		
				in 6% „ „ „ >1·0		

1·08, and for the left lung at rest between a maximum of 3·01 and a minimum of 1·17 with the average of 1·8 for each lung, consequently entirely normal. The difference between the ventilation equivalent values of the two lungs has been less than 0·5 in (34 + 35 per cent. =) 69 per cent. of the cases, while the difference in a smaller number of cases has been above 1·0 with 1·61 as maximum. This variation is of a certain importance and may well mean that the epithelial damage to one lung is more pronounced than to the other.

In *quiet* breathing the ventilation equivalent indicates that the oxygen absorption is rather good even if the mechanism of respiratory gas exchange is damaged; in *forced* breathing is shown much more the ability or not of the epithelium to transmit gases. With *forced* breathing the values are high throughout, in some cases exceptionally high with a maximum of 21·68 for the right and 18·2 for the left. The minimum values are normal with 1·17 and 1·25 respectively, while the average is 7·0 for the right and 5·6 for the left lung. The differences between right and left lungs, as may be seen from Table K, are considerable in

TABLE K.

VENTILATION EQUIVALENT IN FORCED BREATHING IN 75 CASES.

	Max.	Min.	Average	Variations: Differences between right and left	Differences between right and left: Max.	Min.
Dt.	21·68	1·17	7·0	in 33% of the cases <1	9·67	0
Sin.	18·2	1·25	5·6	in 25% „ „ „ 1-2		
				in 15% „ „ „ 2-4		
				in 22% „ „ „ 4-6		
				in 5% „ „ „ 6-10		

nearly half of the cases with 9·67 as maximum. Therefore, all the values obtained with forced breathing seems to be very important when judging the function of each lung.

At ordinary spirometry, which was carried out immediately following the bronchospirometry in some cases, the ventilation equivalent with

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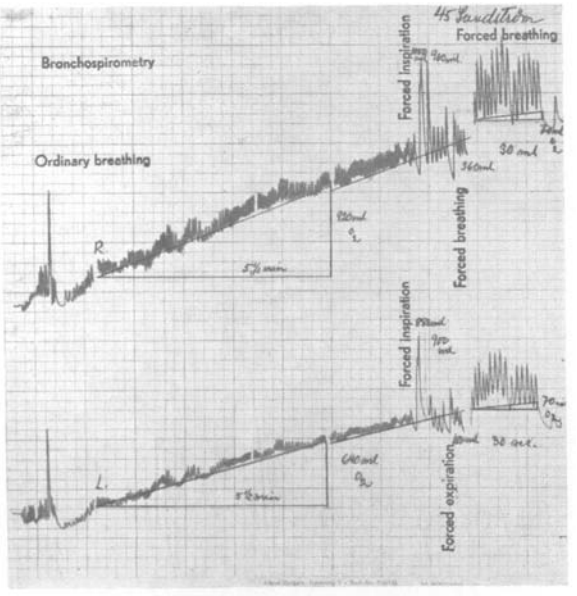


FIG. 16.
Curve, Case 45/1950.

Ordinary breathing :	Right	Left
Oxygen consumption ml./min.	167	116
Tidal air	170	70
Reserve air	360	180
Total capacity	2,750	1,540
Ventilation equivalent	2·09	1·18
Equilibrium quotient	63·6%	42·6%
Residual quotient	50%	31·2%
Forced breathing :		
Oxygen consumption ml./min.	140	140
Minute volume	8,490	5,840
Ventilation equivalent	12·1	8·3

FIG. 17.
Values, Case 45/1950.

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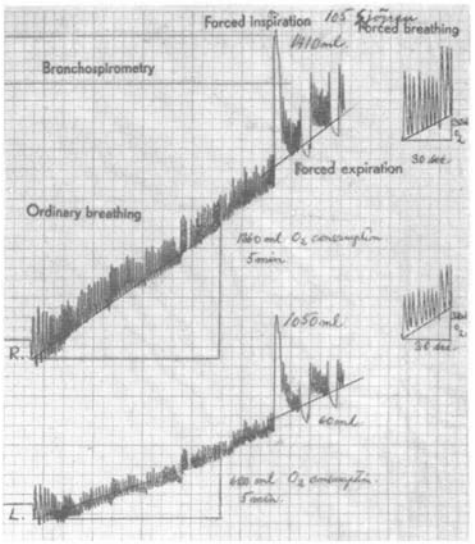


FIG. 18.

Curve, Case 105/1950.

	Right	Left
Ordinary breathing :		
Oxygen consumption ml./min.	272	124
Tidal air	285	155
Minute volume	4,810	2,660
Reserve air	200	200
Total capacity	3,145	2,150
Ventilation equivalent	1·76	2·14
Equilibrium quotient	48·8%	44·6%
Residual quotient	42%	35·3%
Forced breathing :		
Oxygen consumption ml./min.	500	640
Minute volume	12,880	8,040
Ventilation equivalent	2·57	1·25

FIG. 19.

Values, Case 105/1950.

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forced breathing proved to be a maximum of 14·8, a minimum of 2·89 and an average of 9·5 according to Table L.

TABLE L.

VENTILATION EQUIVALENT IN FORCED BREATHING. ORDINARY BILATERAL SPIROMETRY IN 13 CASES.

Max.	Min.	Average
14·8	2·89	9·5

The values, which were obtained from the ventilation equivalent, should thus indicate both that the gases inhaled under occupational conditions have injured the alveolar epithelium of the lungs and also that this damage affected the right and left lungs unequally.

As examples of the widely varying results obtained with the broncho-spirometric examination of the patients occupationally injured through arsenic and sulphur-dioxide fumes, I shall briefly report on some cases which, to a certain extent, represent somewhat different types.

CASE 7/1950. Exposed to arsenic fumes for many years. Bronchitic symptoms and dyspnœa. Pronounced atrophic mucous membrane alterations observed at examination including bronchoscopy 1946 and 1950. Bronchospirometry, see curve.

This is the type for a number of cases with similar changes in both lungs. Relatively small volumes, which are often more pronounced as regards reserve air than in this case. Relatively good oxygen consumption and normal ventilation equivalent.

CASE 40/1950. Worked in arsenic fumes for many years. Dry cough, shortness of breath, palpitation on movement. Atrophic mucous membrane demonstrated at examinations including bronchoscopy in 1946 and 1950. Bronchospirometry in 1950, see curve.

The curves appear relatively normal but the oxygen consumption is low despite the high ventilation values. At rest the respiratory gas exchange is fairly good with the ventilation equivalent within normal values. On forced breathing, good volumes but poorer oxygen absorption by the left lung. That one lung should work more poorly than the other under forced breathing is surprising, as neither bronchoscopy nor other investigations revealed inequalities. Technical defects and failings in the apparatus were suspected but none could be discovered and several cases have shown the same result without any other explanation having been found than more pronounced damage of one lung which can be seen only with forced breathing.

CASE 45/1950. Gas exposed, 1928-1943. Since then has had other work. Pharyngo-tracheobronchitic symptoms and shortness of breath

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with movement. Pronounced atrophy of the mucous membrane was demonstrated at examinations including bronchoscopy in 1946 and 1950. Changes in the bronchi of the right side, rather less pronounced than in 1946, were observed at bronchoscopy in 1950, while the mucous membrane on the left side was obviously atrophic with alternating hyperplastic spots. Bronchospirometry in 1950, see curve.

All ventilation values are very low, especially for the left lung. The respiratory gas exchange, because of these low values, is less in the left than in the right lung, but the oxygen consumption is quite as good on the left side, which is shown in the lower ventilation equivalent in ordinary as well as in forced breathing.

CASE 105/1950. Periodically gas exposed for many years. Catches cold easily, irritating cough, shortness of breath with exertion. Swollen, reddened, hyperplastic mucous membrane with abundant secretion, in part purulent, bilateral, was observed at bronchoscopy in 1946. In 1950, bronchoscopy showed the same appearance on the right side but pronounced atrophy on the left. Bronchospirometry in 1950, see curve.

The ventilation volumes are considerably lower on the left side ; the reserve air is obviously low bilaterally. Oxygen absorption is relatively good. The good respiratory exchange with forced breathing is surprising. Thanks to the significantly smaller minute volume on the left side combined with a good oxygen consumption, the ventilation equivalent for the left lung is very low.

CASE 270/1950. Gas exposed, 1932-40. Nosebleeds, dry cough, bronchitic symptoms. The mucous membrane in the trachea and bronchi were found to be atrophic on the right as well as the left side at bronchoscopy in 1946 and 1950. Bronchospirometry in 1950, see curve.

Small ventilatory volumes on both sides, especially for reserve air. The respiratory gas exchange very good despite the atrophy seen at bronchoscopy, with low ventilation equivalents at quiet as well as forced breathing.

CASE 1,362/1950. Gas exposed since 1940. Hoarseness, cough, shortness of breath. Tracheobronchitis picture with alternating atrophy and hyperplasia at bronchoscopy in 1950. Large spots with extreme mucous membrane atrophy in the main bronchi on both sides. Bronchospirometry, see curve.

The ventilation volumes small, especially on right side. Oxygen consumption poor for right lung but because of small volumes, the ventilation equivalents are low. The right lung functions better with forced breathing but, nevertheless, has obviously smaller minute volume than the left.

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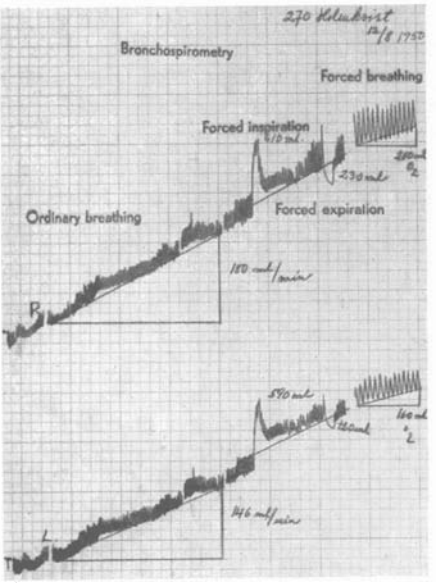


FIG. 20.
Curve, Case 270/1950.

Ordinary breathing :	Right	Left
Oxygen consumption ml./min.	180	146
Tidal air	170	160
Minute volume	3,590	3,330
Reserve air	230	120
Total capacity	1,780	1,240
Ventilation equivalent	1·99	2·28
Equilibrium quotient	61·2%	50%
Residual quotient	48·3%	40·3%
Forced breathing :		
Oxygen consumption ml./min.	400	320
Minute volume	9,160	6,240
Ventilation equivalent	2·29	1·95

FIG. 21.
Values, Case 270/1950.

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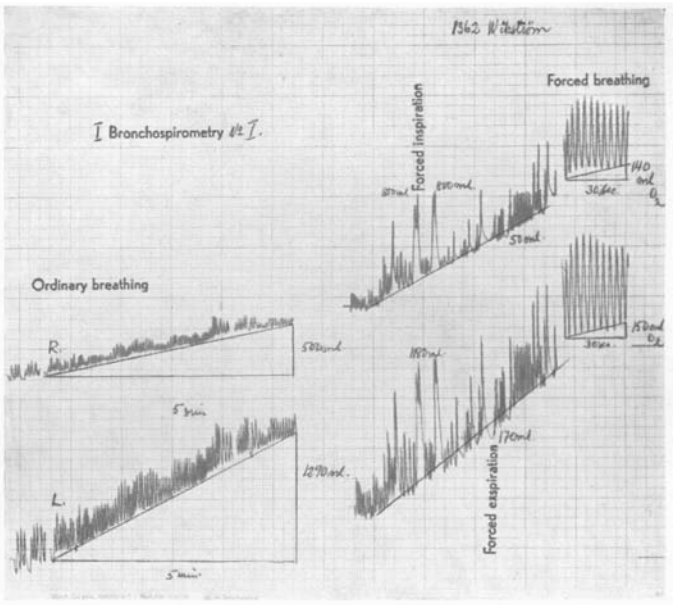


FIG. 22.
Curve, Case 1,362/1950.

Ordinary breathing :	Right	Left
Oxygen consumption ml./min.	100	258
Tidal air	85	228
Minute volume	1,790	4,800
Reserve air	50	170
Total capacity	1,460	2,070
Ventilation equivalent	1·79	1·86
Equilibrium quotient	41·7%	42·9%
Residual quotient	38·3%	34%
Forced breathing :		
Oxygen consumption ml./min.	280	300
Minute volume	7,420	10,330
Ventilation equivalent	5·30	6·88

FIG. 23.
Values, Case 1,362/1950.

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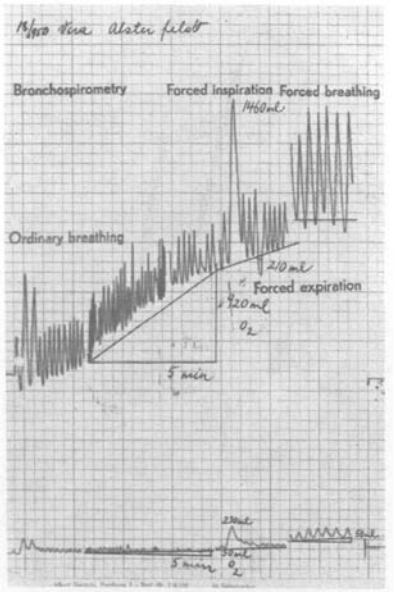


FIG. 24.
Curve, Case 18/1950.

Ordinary breathing :	Right	Left
Oxygen consumption ml./min.	10	184
Tidal air	23	407
Minute volume	210	3,660
Ventilation equivalent	2·1	1·98

FIG. 25.
Values, Case 18/1950.

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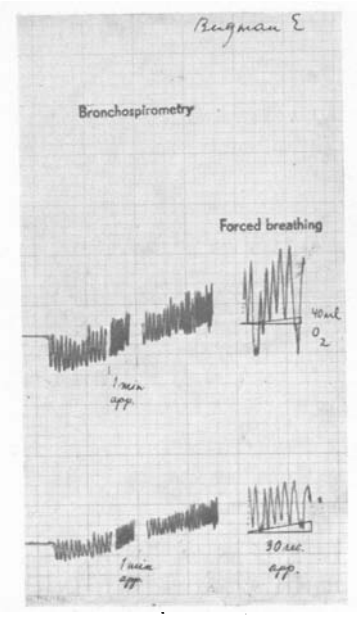


FIG. 26.
Curve, Case 403/1950.

Ordinary breathing :	Right	Left
Oxygen consumption ml./min.	220	144
Tidal air	320	180
Minute volume	4,480	2,560
Ventilation equivalent	2·03	1·77
Forced breathing :		
Oxygen consumption ml./min.	40	110
Minute volume	5,510	3,390
Ventilation equivalent	13·7	3·08

FIG. 27.
Values, Case 403/1950.

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Bronchospirometry has been done routinely in a large number of cases with different lung diseases. From the practical clinical point of view it is still most important to estimate the oxygen consumption and function otherwise, including the determination of the residual quotient and the ventilation equivalent of each lung, in order to be able to give the tuberculosis specialist and the lung surgeon dependable prognostic information concerning operative indications and contra-indications in pulmonary tuberculosis, bronchiectases, local emphysema and such conditions in which irreversible collapse therapy is desirable. There have been so many contributions from other sources regarding these problems that I shall restrict myself to reporting a few cases of different types.

Case 18/1950. 1946, dextral pulmonary tuberculosis with cavern. Pneumothorax November, 1946, cauterization, good collapse. Subsequent exudation, less effective collapse. Pneumothorax terminated, August, 1948. Signs of cirrhosis and bronchostenosis suspected on right side. Plastic operation on the right side was planned in 1950 but it was considered that if the function of the right lung were good it would possibly be unnecessary and less favourable for the patient, to shunt this lung, as the general condition was still so good that surgery was not entirely necessary. Therefore, it was desirable to control the function. Bronchoscopy showed scarred strictures both in the orifice of the bronchus to the right upper lobe and also in the main bronchus immediately below where the upper lobe bronchus branches off. The lumen of the main bronchus was the width of a goose quill. It was impossible to inspect the deeper portions even by telescope.

Bronchospirometry in 1950 showed almost no function on the right side, see curve.

The bronchospirometry shows that the right lung is practically useless from a functional viewpoint notwithstanding that the X-ray and physical examinations cannot demonstrate the parenchyma to be damaged. The extreme stenosis impedes ventilation and gas exchange. The lung may be treated by collapse therapy without hesitation, and entirely removed from function.

Case 403/1950. Fresh sinistral pulmonary tuberculosis with cavern, 1940. Left side pneumothorax with cautery. Sinistral pleurisy, 1943. Pneumothorax terminated, 1944. Good expansion of the lung. 1947, dextral pulmonary tuberculosis, progress, 1950, therefore possible dextral pneumothorax of immediate interest. Bronchoscopy in August, 1950, showed diffuse bronchitis but no specific changes. Bronchospirometry, August, 1950, see curve.

Volumes for the healed tuberculous-pleuritic lung were less than for the newly affected right lung but, nevertheless, were sufficient and with excellent gas exchange. At forced breathing it may be observed that by

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far the greater part of the function was assumed by the healed lung, notwithstanding that its minute volume was considerably lower than that of the right lung. The ventilation equivalent for the left side was normal, 3·08; for the right it was very poor, 13·7. This case is an example of a phenomenon which seems to be comparatively common, namely, that the healed lung, if it is not greatly damaged from pleuritis, may very well assume the function of both lungs. Even here may be emphasized the importance of testing the function in forced breathing.

Case 11,225/1950. 1925, sinistral pleuritis; 1935, dextral pulmonary tuberculosis, no pneumothorax treatment. 1940, slight progress. 1949-50, more progress with cavern. Dextral pneumothorax desirable and planned. In addition to lung changes on the right side, X-ray showed traces after the sinistral pleuritis but otherwise nothing significant. Bronchoscopy showed nothing remarkable on the left side, on the right, intensive bronchitis with abundant purulent hæmorrhagic secretion, especially from the bronchus to the upper lobe. Bronchospirometry, see curve.

The surprising result of this investigation is that practically the entire lung function is carried on by the parenchyma-sick right lung while the parenchyma-healthy, healed-pleuritic left lung does nothing. Certainly the left lung is ventilated by large volumes, but no oxygen consumption takes place. This is as clearly apparent from the slope of the curve as it is from the exceptionally high ventilation equivalent on the left side.

Since technical failure could be suspected as the cause of these peculiar values, the examination was repeated three times and curves with exactly the same appearance were obtained each time. When the tube to the right lung was shut off during the course of the examination, the patient suffered extreme shortness of breath.

This case is a distinct example of how misleading X-ray and physical examinations alone may be in the estimation of the function of the lungs. Without the help of bronchospirometry, undoubtedly a dextral pneumothorax would have been induced, but in all probability with an unhappy ending.

Even if such exceptional cases belong to the unusual, there are, none the less, similar occasions when the lung which has not been treated by collapse therapy certainly is capable of taking care of the respiratory gas exchange in rest and under normal conditions, but when it is not sufficient in forced breathing or if it should be the seat of a chance infectious process, for example, in connection with an ordinary cold.

In order to expand the field of bronchospirometry in the examination of varied conditions, I have tried to improve and change the apparatus.

Attempts to construct a new double catheter which could afford greater advantages and less disadvantages than those we have had until

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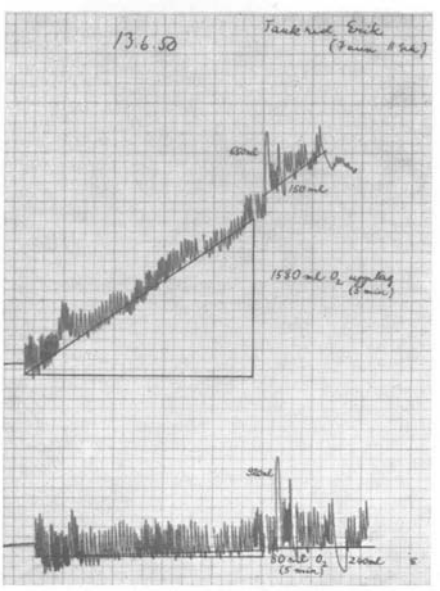


FIG. 28.
Curve, Case 11,225/1950.

Ordinary breathing :	Right	Left
Oxygen consumption ml./min.	316	16
Tidal air	205	300
Minute volume	3,920	4,800
Ventilation equivalent	1·24	30

FIG. 29.
Values, Case 11,225/1950.

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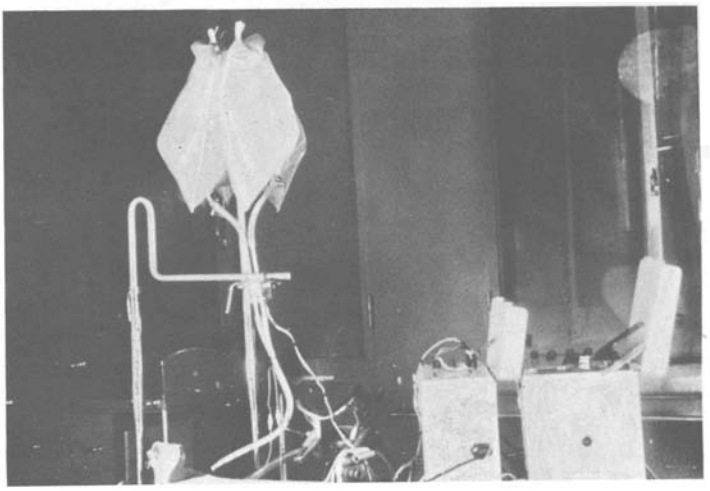


FIG. 30.
The new recording apparatus.

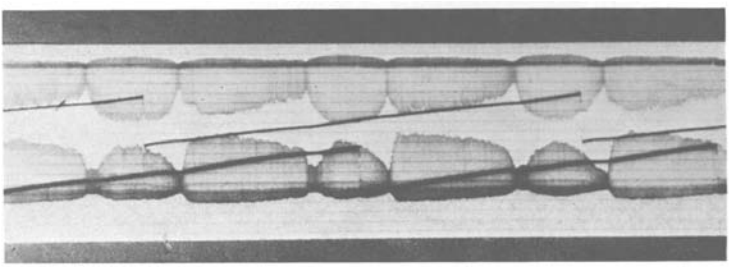


FIG. 31.
Curve recorded by electrocardiograph.

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now have been going on for several years but have not yet been completed.

An entirely new method of recording, which, at least from certain angles, should permit a more careful analysis of the breathing phases, is under development. The in-going and out-going air from each lung passes a small sensitive antenna consisting of the finest of platinum wire. This wire is located in a current-carrying electric circuit and upon its being cooled by the passage of air, variations in voltage occur, which are registered by an oscillograph, that is to say, in practice, by an ordinary electrocardiograph. The patient will breathe in and out in two plastic containers which are filled at the start with oxygen or the desired gas mixture. Or, if a spirometer is available, the electric recording apparatus is connected between the bronchoscope and the spirometer.

From what it has been possible to interpret so far, it appears as if interesting details should be brought out from the curves obtained. For example, the delay of one lung may be recorded with precision to one-tenth second. The speed of the air current is recorded every instant; with 50 cycles alternating current, 50 times per second. Inhalation and exhalation give typical curve pictures, and certain diseases, for example asthma, appear to give such typical curves that they make the diagnosis positive. As the recording of the curves has not yet been entirely perfected, only one example of how, in principle, the curves will be registered is shown.

With our present technique, naturally many experimental failures must be expected and the results must be judged with strong criticism and reservation. It is clear, however, that with lungs which are damaged through disease or treatment, the respiratory gas exchange is far from always equal to the ventilation. Therefore, their function cannot be estimated on the vital capacity alone, for example, and a decision cannot be reached as to the functional ability of one lung through spirometric examination of both together, and neither do X-ray and ordinary clinical examinations give a dependable picture of the functional capacity of each lung.

I am not a lung physiologist and therefore do not intend to present any results which are noteworthy from a physiologic viewpoint. My intention is now as from the very beginning, to search for a clinical examination method, which will make possible the exposition of the individual functional capacity of the lungs under normal and pathologic conditions. I hope the account of the occupational medical investigation will serve as an example of the many problems which could be attacked. Instrumentarium and apparatus, which are still far from perfect, need to be critically tested and improved.

Demonstration of a coloured film showing the whole procedure of bronchospirometry, the old and the new apparatus and the curves obtained.

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