

46 (Case B). As the majority of the patients were in an old age group it is not surprising that three more have died, 15 years, 4 years, and 2 years respectively after the operation, apparently from conditions unassociated with it.

There were no particular complications in the post-operative period. In four of the cases there was some infection of the abdominal wound. In one the organism was a clostridium: the patient was not ill with it, but it delayed healing of the wound by about 10 days.

In none of the cases was there any apparent leakage at the anastomosis.

I have been a little surprised at the freedom from symptoms shown by these patients since operation. None has had jaundice or chills. A few have had some abdominal discomfort occasionally, and one man who had had four operations in all had a severe pain lasting three to four hours ("just like my old pain") 16 months after his choledochoduodenostomy. Three patients noticed a slight dragging feeling in the right hypochondrium after a big meal: whether this was due to distension of the common duct, to a pull on the anchored duodenum, or to adhesions it is impossible to say.

There are no apparent digestive or duodenal symptoms following this operation. Three patients said their motions were looser than previously.

In a number of cases, post-operatively, air can be seen in a large part of the biliary passages. A barium meal can be seen to go into the ducts for a considerable distance, but it soon comes out again. In one of the patients, who had a barium-meal examination post-operatively, the radiologist made the interesting observation: "Barium meal: in the erect film the biliary tract is outlined by air. As soon as the patient was placed in the supine position, the barium refluxed up the bile duct, which is rather dilated." One wonders whether this observation by the radiologist should prompt us to advise patients who have had a choledochoduodenostomy not to lie down after a meal until sufficient time has elapsed to allow the stomach to empty. I have not done so. Another thought that has passed through my mind is whether mud or stone forms in the duct distal to the anastomosis or whether food collects there. I do not know the answer to this; but trouble, so far as fresh symptoms are concerned, does not seem to arise.

Conclusions and Summary

A vertical, supraduodenal choledochoduodenostomy is an operation which gives good results with a surprising freedom from symptoms afterwards.

It is very valuable in cases in which there are recurrent stones or biliary mud in a thickened, dilated common bile duct when previous operations have been done.

It is also probably sound practice to do the operation in any patient in whom the duct, in addition to being dilated from obstruction by stones, is thickened and rigid from chronic inflammation, even though no previous operation has been done. It is not advised when the duct appears healthy, even though it contains stones.

Twenty-one cases in which this operation has been performed for stone are referred to.

Some points in the technique of the operation are mentioned.

The results and post-operative radiographic appearances are discussed.

The 113th annual issue of the *Medical Directory* is now available from Messrs. J. & A. Churchill Ltd., 104, Gloucester Place, London, W.1 (2 parts, 84s.). It contains 87,122 names, nearly 2,000 more than last year.

MASS SPECTROMETRY APPLIED TO CLINICAL PRACTICE AND RESEARCH

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Defects in the function of many organs in the body may be detected by chemical analysis of blood or of secretions, such as gastric or intestinal contents, faeces, or urine. The collection of specimens for such analyses can be done by nurses or technicians, and their analysis is usually accepted as a routine by departments of clinical chemistry.

The situation is quite different in testing lung function. Impairment of the lungs' action as a bellows can be assessed from study of their ventilatory reserve by measuring the maximum breathing capacity either directly, by asking the patient to hyperventilate maximally for a given period of time, or indirectly from a spirometric tracing of a single forced expiration. This measurement is relatively simple and is becoming an accepted clinical investigation; nevertheless it requires trained observers. But the study of defects in pulmonary gas exchange usually demands analysis of expired gases. The taking of gas samples for such analysis, either at a specific time in the breathing cycle or from a collection of gas expired over even a short period of time, requires intricate or bulky apparatus, while the established methods of chemical analysis of the gases so collected are tedious, time-consuming, and beyond the routine capacity of many laboratories. Before most of the tests of defects in gas exchange can be accepted as part of routine clinical study simpler and more rapid techniques of gas sampling and analysis are needed.

Automatic gas-analysers such as the infra-red analyser for carbon dioxide or carbon monoxide, the spectrophotometric nitrogen analyser, the para-magnetic oxygen analyser, the katharometer for helium or nitrous oxide, etc., have simplified some of these tests sufficiently for them to be performed routinely in specialized laboratories. But advances have been limited, and the problems of gas sampling have remained because none of these instruments, except the nitrogen meter and some forms of infra-red carbon dioxide analyser, can continuously record the changes in gas concentration occurring within the breathing cycle. Their response time is too slow and the gas flow required for their operation is too large a fraction of the total breath expired. Moreover, each instrument can estimate only one gas, whereas simultaneous analyses of several gases is required for many purposes.

It has long been realized by workers seeking new methods of gas analysis that the mass spectrometer is a versatile instrument, theoretically capable of overcoming

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all these difficulties, but machines commercially available are designed mainly for isotope separation or for hydrocarbon analysis in the oil industry, and even if modified for respiratory use, as some have been in the U.S.A., they are not entirely satisfactory. Some have been designed for continuous analysis for one or for two gases (Hitchcock and Stacy, 1948; Miller *et al.*, 1950), but none has fulfilled the requirements of respiratory work. A new type of instrument was required for this purpose which was also reliable enough for daily routine use, and one has been designed by one of us (K. T. F.). We propose to describe it briefly and to show some of its potentialities in clinical investigation and physiological research. A full technical description will be published elsewhere.

The Respiratory Mass Spectrometer

Specifications.—The instrument was designed to fulfil the following requirements: (1) It should provide a continuous analysis of inspired and expired gases drawn either from a mouthpiece or from within the bronchial tree at bronchoscopy. (2) It should simultaneously record concentrations of at least four gases, including oxygen, nitrogen, and carbon dioxide, and some other foreign gases of physiological interest. (3) It should present the analysis both as meter deflections and continuous traces on a direct-writing recorder. (4) It should require a sample not greater than 15 ml. per minute, which is a negligible fraction of the respiratory minute-volume. (5) It should have a response-time short enough to follow accurately changes in gas concentrations throughout the respiratory cycle. Full deflection in 0.1 second was required. (6) It should be stable and accurate enough to detect 1% change of concentration. (7) It should be readily transportable from the laboratory to ward, theatre, clinic, or field survey. This meant dispensing with the running water and dry ice required to maintain the vacuum system of existing machines.

Principles of Operation.—Analysis in a mass spectrometer is performed by separation of the molecules in the gas sample according to their molecular weight. This separation is achieved by bombarding the gas molecules entering the machine with a beam of electrons so that the molecules are ionized, and then deflecting the ions with a magnetic field. This field is at right angles to the direction of travel of the ions, so that they are deflected into circular paths. The deflection is greater for light than for heavy ions, so the stream splits up into beams of different molecular weight, any of which can be caught on a suitably placed collecting electrode. As each ion carries a positive charge, the number in any beam can be found by measuring the minute electric current which it carries to the collector. The proportion of molecules of different weights in the gas sample can thus be found, and a complete analysis of the gas sample can be made provided that all the constituent gases have different molecular weights, which is usually the case in respiratory work. These processes are conducted in a high vacuum, normally produced by water-cooled pumps and vapour-traps cooled by liquid air or dry ice.

Description

In this instrument (see Fig. 1) a small fraction (0.1%) of the patient's exhaled breath is drawn continuously and at high velocity through a length of hypodermic tubing into the spectrometer by a sampling pump. An even smaller fraction (0.01%) of this sample passes through a molecular "leak"

into an ionization chamber where the gas molecules are charged (ionized) by bombardment with a transverse stream of electrons. The charged molecules (ions) diffuse out of a slit in the chamber wall and are accelerated by being attracted towards a plate (P_2) to which a negative accelerating voltage is applied. A similar slit in this plate permits

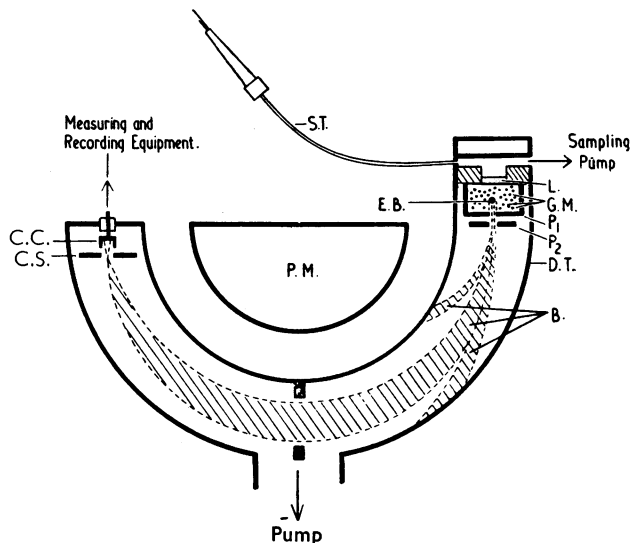


FIG. 1.—Diagram of the mass spectrometer. (B.=ion beams of different mass; C.C.=collector cup; C.S.=collector slit; D.T.=dispersion tube; E.B.=electron beam, at right angles to plane of diagram; G.M.=gas molecules within ionization chamber; L.=molecular leak; P_1 and P_2 =accelerator plates; P.M.=permanent magnet; S.T.=sampling tube.)

many of the accelerated ions to stream as a narrow pencil into a magnetic field at right angles to their course so that they are deflected and separated into a fan-like pattern of beams of different molecular weight.

The position of this pattern of ion beams may be altered by changing the velocity with which all the ions enter the magnetic field. This velocity is controlled by the voltage which accelerates them from the ionization chamber; by variation of this voltage it is possible to move the "fan" and so direct a beam of ions of a given mass on to one collector. An analysis can thus be performed by varying the accelerating voltage from its maximum to its minimum value, thus "scanning" all the ion beams across the collector. The collector current therefore rises to a series of peak values representing the abundance of ions in each beam in turn, and falls to zero between them.

The scanning process is in practice made repetitive at 25 cycles per second. The pulses of current thus brought to the collector, as the array of ion beams swings across it, are amplified and displayed on a cathode-ray oscilloscope running synchronously with the scanning accelerating voltage. The current pulses are thus spread out as a series of peaks in an apparently stationary "mass spectrum" (see Fig. 2). The horizontal position of a peak identifies the molecular weight of a gas in the sample, and the vertical height of a given peak is proportional to the abundance of molecules

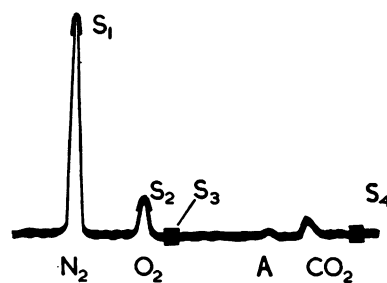


FIG. 2.—Drawing of mass spectrum as seen on the oscilloscope screen with the instrument sampling expired air. (N_2 , O_2 , A, CO_2 =peaks of nitrogen, oxygen, argon, carbon dioxide, respectively. S_1 , S_2 , S_3 , S_4 =light spots for "tuning" pen-recorder to following variations in height of any peak.)

of that gas at a given instant, and hence its partial pressure. Thus, when air is being drawn down the sample tube the nitrogen (mass 28) is represented by a tall peak on the left, next the oxygen (32), then the argon (39), and finally the carbon dioxide (44). On exhaling over the end of the sampling tube the oxygen peak will fall and the carbon dioxide peak will rise immediately the expired gas from the lungs enters the instrument. During breathing the heights of the peaks

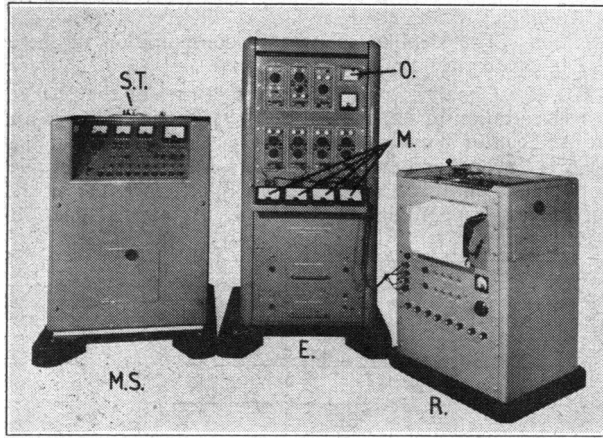


FIG. 3.—Photograph of mass spectrometer (M.S.), electronic measuring equipment (E.), and four-channel pen-recorder (R.). (S.T.=entrance for sampling tube; M.=monitoring meters; O=oscilloscope displaying mass spectrum.)

fluctuate as inspirate or expirate passes the sampling point. The height of one or more of the displayed peaks can be automatically reproduced on a multichannel pen-recorder, so giving a continuous trace of the variations in partial pressure of a gas against time.

The selection of the peak or peaks to be recorded is done with the aid of a number of brightened spots (Fig. 2) which may be moved along the baseline of the oscilloscope trace by their respective control knobs on the electronic selector cabinet (Fig. 3, E) so that they climb the required peak. When the spot is tuned to the apex of a peak, as determined by the monitoring meters (Fig. 3, M.), one of the pens will automatically follow the variations in height of that peak. For instance, to measure oxygen concentration the operator positions one spot on the top of the peak corresponding to mass 32, and one pen of the recorder will then continuously record the changing partial pressure of this gas. As many

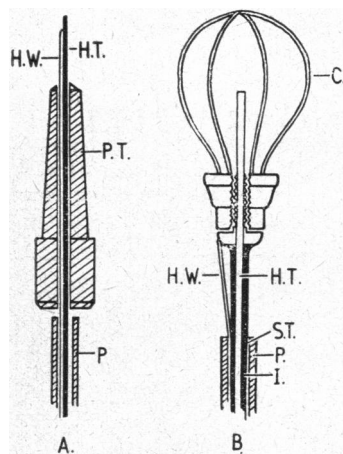


FIG. 4.—Diagrams of ends of sampling tubes: A, with taper plug (P.T.) for routine use in a mouthpiece; B, with protecting interchangeable cages (C.), sizes from 5 to 14 mm., for use at bronchoscopy. (H.W.=wire carrying heater current; H.T.=0.5-mm. bore hypodermic steel sampling tube; S.T.=outer steel tube for rigidity; I=electrical insulating coating; P=plastic covering.)

about 3 feet (91 cm.) of fine (0.5 mm. outside diameter) hypodermic stainless-steel tubing. This is heated electrically to 70° C., to prevent condensation of water vapour, and covered with a protective, thermal insulating cover. The end of the tube goes into a taper plug so that it can be sited accurately at the centre of a gas stream, usually in a mouthpiece, as a push-fit (Fig. 4, A.).

For use regionally within the lungs at bronchoscopy an alternative 4½-ft. (137-cm.) sampling tube is used, on the end of which different sizes of "cage" (Fig. 4, B.) can be screwed so that the end of the sampling tube can lie centrally within the lumen of the chosen segmental bronchus. Three cages (of 5, 9, and 13 mm. diameter, respectively) have been made for us by Dr. B. M. Wright so that they fit different parts of the bronchial tree as determined initially from a precision cast of the tree made in plastic (Tompsett, 1952). The wire to carry the heating current is replaced by wider-bore hypodermic tubing (electrically insulated from the sample tube itself). This wider tubing makes the whole sample tube more rigid for manipulation down the bronchoscope, a short flexible end being left, as shown in the diagram, for bending as required. The outer hypodermic tube is finally covered with heat-insulating plastic. Sampling tubes can be changed for sterility between cases or in the event of blockage during sampling, and the instrument brought back into operation within two minutes.

Dimensions and Performance Data

The general appearance of the instrument is shown in Fig. 3. It consists of three mobile cabinets: the spectrometer itself (2 ft. 6 in. by 2 ft. 6 in. by 3 ft.—76 by 76 by 91 cm.), the electronic measuring equipment (2 ft. 6 in. by 2 ft. 6 in. by 4 ft. 6 in.—76 by 76 by 137 cm.), and finally the four-channel "Sanborn" pen-recorder (2 by 2 by 3 ft.—61 by 61 by 91 cm.). Each selector channel of the electronic equipment is on a plug-in separate chassis allowing immediate replacement. The case of the spectrometer is rapidly removable for servicing.

The instrument is designed so that potentially any stable gas of molecular weight between 18 (water vapour) and 80 (krypton) can be analysed. In practice the instrument is normally set for the mass range 25 to 50, thus including most gases of physiological importance, except helium (mass 4) which, because of its insolubility, has often been used for measuring the lung volume and distribution of ventilation within the lungs (Meneely and Kaltreider, 1949; Gilson and Hugh-Jones, 1949, 1955; Bates and Christie, 1950; Briscoe *et al.*, 1951). To have included helium would have meant more complex design and cost, using high-potential electrical components; moreover, neon (mass 20) is an almost equally insoluble inert gas available in substitute.

If the gas concentration at the tip of the sampling tube changes abruptly there is a constant "delay time" before the pens start to respond to the change, of 0.10 to 0.15 second, depending on the length and bore of the sampling tube in use. The pens then rise to the new level, 95% of the movement being completed in 0.10 second. It is this latter "response time" which is important in following fast gas-concentration changes. The delay time which is small may usually be ignored; it simply means that events are recorded slightly later than they occurred. If precise time relationship with other events is required the gas concentration tracing may be moved back by the required time interval.

The machine is normally left in a "stand-by" condition, with only the vacuum pumps running. To put it into operation the ionizing electron beam is turned on, the sample pump is started, and the electronic valves are warmed up. An air sample flow is then admitted and sufficient time allowed to elapse for the temperature and pressure conditions in the ionization chamber to stabilize. Our experience has been that one hour is sufficient time to prepare the machine for use. The various selector spots on the oscilloscope trace are positioned on the relevant peaks and the

Sampling Tubes

The sampling tube for general use consists of

sensitivity of each channel is adjusted to give a known and convenient full-scale deflection, by using standard mixtures of the gases to be included in the analysis. Stability is affected by conditions in the ionization chamber, which are changed slightly if widely different gas mixtures are used. An overall control of the sensitivity of all channels together is therefore provided to make any minor corrections necessary during operation, using room air or a known mixture as standard.

At any time the trace has an absolute accuracy within 3%, though relative variations can be determined within 1%, of the full-scale deflection selected. Exact full-scale deflection is selected for convenience to the work in hand, and may be given by gases whose partial pressure is anything from 3% to 100% of the total.

Clinical Use of the Spectrometer

The instrument's ability to provide a continuous analysis for several gases should remove the difficult problem of gas sampling for routine clinical tests, and facilitate advances in research on the mechanism of gas exchange in the lungs.

Lung-function tests are rapidly proving their value in clinical medicine. With their help the mechanism of a patient's signs and symptoms, such as breathlessness or cyanosis, can often be understood from a quantitative measure of such factors as the relation between the distribution of gas and blood in the lungs, or of any barrier to the normal diffusion of gas between the alveoli and the blood. Such an assessment not only provides a basis for logical therapy, but repeated tests enable the physician to follow the efficacy of treatment. Measurement of all the different aspects of lung function aids the surgeon in gauging the likely functional effects of proposed operation. But lung-function tests are of no value in making a diagnosis of chest disease in terms of morbid anatomy or histology, with the notable exception of making a positive diagnosis of the presence and degree of emphysema.

The likely uses of the spectrometer in lung-function testing can best be considered under two headings: (1) studies of expired gases sampled at the lips; and (2) regional analysis within the bronchial tree.

Analysis of Expired Gases at the Lips

Multiple Breath "Wash-out" Data

The well-established procedure for determining the degree of inequality of gas distribution in the lungs by "washing-out" the nitrogen in them with successive breaths of oxygen or, alternatively, "washing in" a foreign inert and insoluble gas can readily be done. Part of a typical tracing taken from the spectrometer is shown in Fig. 5. Nitrogen is being washed out of the lungs by the inhalation of a mixture of argon and oxygen, the spectrometer being set to record the concentration of argon and nitrogen at the lips. Before the point marked S in Fig. 5 the subject is sitting breathing air, fluctuations in the nitrogen concentration between inspiration

and expiration being caused by the effect of the respiratory quotient and of the different moisture content of inhaled and exhaled air. During the expiration after S, a tap is turned so that the subject will breathe the argon-oxygen mixture in the next inspiration, the brief spike of the records at P being caused by a puff of argon-oxygen mixture used to flush the dead space in the tap. In each subsequent breath as nitrogen is washed out argon is washed in, so that finally the exhaled argon is at the same concentration as that inhaled, while nitrogen almost disappears from the expirate. The steplike changes in concentration of these two gases are virtual mirror images.

The usual analysis of these curves is to plot the change in concentration of either gas on a logarithmic scale against the number of breaths. When the gas distribution in the lungs is "even," as in normal subjects, a nearly straight line is obtained on this semilogarithmic plot, since the wash-out process is approximately a simple exponential one. If

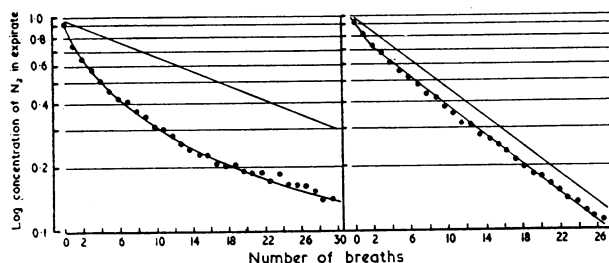


FIG. 6.—Nitrogen concentration in each successive expiration during a period of breathing a nitrogen-free gas mixture of a patient with emphysema (left) compared with a normal subject (right), plotted on a logarithmic scale against the number of breaths on a linear scale.

ventilatory inequality exists, as in emphysema, a biphasic exponential process becomes more obvious, and the semi-logarithmic plot is curved (Fig. 6). The procedure is simple and rapid with the spectrometer. The continuous analysis throughout each breath will make it possible to find the effect of sampling at different times during the expirate and hence assess the results that were obtained when using some of the older methods of gas analysis; while the effect of using gases of different solubility or of nitrogen excretion from the blood to the lungs during the process can be determined.

Single-breath Data

Useful as the spectrometer is for "wash-out" tests, the information it will provide from analysis of a single breath is much more useful. By analysis of a single expiration with this instrument it should be possible not only to elucidate the unevenness of gas distribution but also to determine the way in which blood is distributed in the lungs in relation to gas distribution, and to estimate the diffusion barrier between blood and alveolar gas. This multiple information from analyses of single expirations is obtainable in no other way.

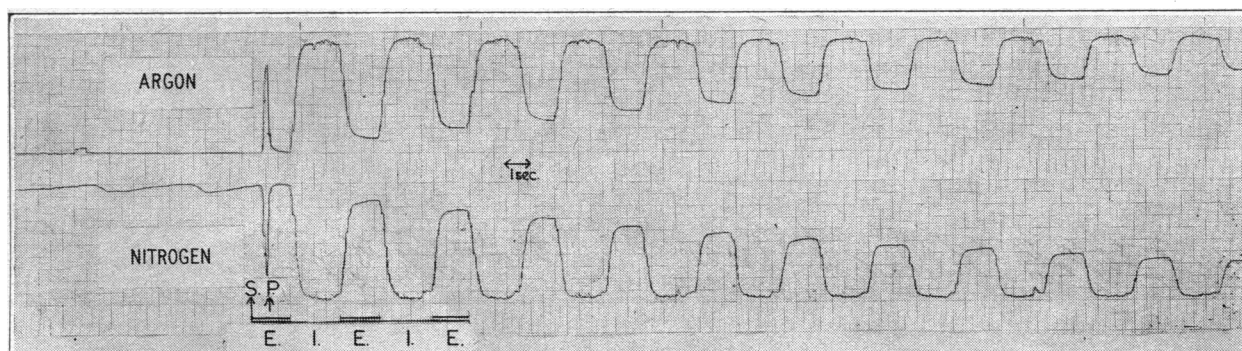


FIG. 5.—Assessment of uneven ventilation in the lungs by the "gas wash-out" technique. (Part of a record in a normal subject showing the nitrogen in the lungs being washed out by a mixture of argon and oxygen, as described in text. Tap turned in expiration following point S; puff of gas to clear apparatus dead space at P. E and I=expiration and inspiration, respectively. Ordinates, relative gas concentrations. Paper speed 10 mm. per second.)

Nitrogen Analysis

Nitrogen analysis in a single expirate following an inspirate of oxygen (Fig. 7, bottom tracing) gives information similar but supplementary to that obtained from the "wash-out" data. Initially, oxygen from the upper respiratory dead space is exhaled so that there is a negligible amount of nitrogen in the record (phase 1), then an S-shaped portion (phase 2) appears which represents dead-space oxygen dilut-

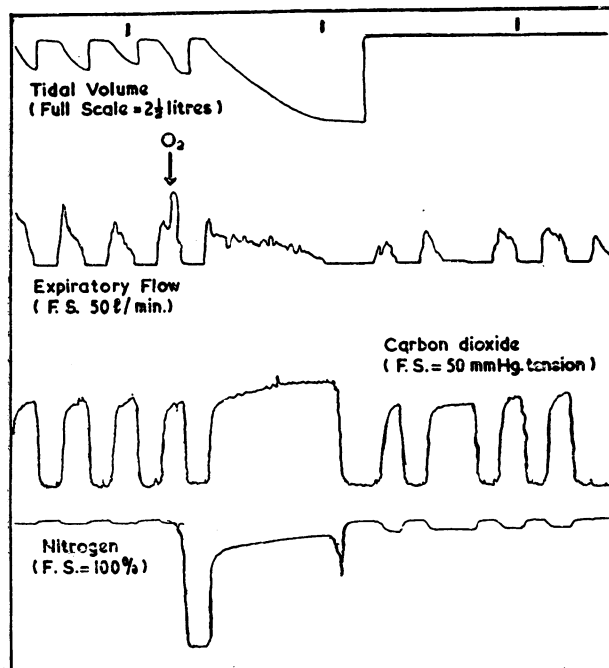


FIG. 7.—Analysis of a long expiration following a single breath of oxygen. Tap turned from air inspiration to oxygen at point marked O_2 . Lower two tracings: concentration of CO_2 and N_2 sampled at the lips. Upper two tracings: concurrent rate of flow of expired gases from pneumotachygraph, and gas volume, from electrical integration of flow. Paper speed 5 mm. per second.

ing alveolar nitrogen, and finally a plateau of alveolar nitrogen (phase 3). The slope of the alveolar plateau gives a measure of the inequality of gas distribution, for a difference in concentration at the beginning and end of the alveolar plateau results from nitrogen being preferentially diluted by the breath of oxygen in some parts of the lung at the expense of others (Fowler, 1948). But this slope must depend not only on the uneven distribution of gas to the different parts of the lung but also on the timing of emptying of these parts. If all the regions, with different dilutions of nitrogen in them, emptied together, the alveolar plateau would be horizontal. By combining data from the nitrogen wash-out and single-breath experiments it may be possible to obtain measure both of inequality of gas distribution and of the relative timing of emptying of the different parts.

Carbon Dioxide and Oxygen Analysis

Carbon-dioxide and oxygen analysis will provide even more important data. Although inequality of gas distribution is important in itself (for example, in diagnosis and assessment of emphysema), from the functional point of view the significance of this factor depends on the relative distribution of blood to the well and badly ventilated parts of the lungs. If air is sent to parts of the lung which are poorly perfused with blood there is wasted ventilation, while blood flow through poorly ventilated parts causes "venous admixture" in the arterial blood. In fact, the distribution of ventilation-perfusion ratios in the lung determines the gas tensions which can be maintained in the blood, and likewise those appearing in the exhaled breath. Since there is practically no carbon dioxide in the inspired air, that exhaled

must come from the blood, and the concentration of this gas in the alveolar phase of the expiration is an indication of the uniformity of the ventilation-perfusion ratio (Comroe *et al.*, 1955). Unfortunately, other factors besides the ventilation-perfusion ratios affect the carbon-dioxide curves. However, the respiratory quotient is also a function of the ventilation-perfusion ratio, and a simultaneous record of oxygen and carbon dioxide in a long exhalation following an ordinary inspiration of air can readily be got from the spectrometer, on a tracing similar to that in Fig. 7, and hence the variation in respiratory quotient during expiration can be measured.

Calculations from the respiratory quotient with the aid of the oxygen-carbon-dioxide diagram (West *et al.*, 1957) will enable an estimate of the variation in the ventilation-perfusion relationships throughout the lungs to be made, and provide a simple test of this factor for routine clinical use. This measure, not hitherto available in a form simple enough for clinical use, may be of great help in understanding the behaviour of the lung in such conditions as asthma and emphysema, besides being an important measure for determination of the cause in patients who exhibit cyanosis or carbon-dioxide retention.

Carbon Monoxide

Carbon monoxide has recently been used increasingly for studying the readiness with which gases diffuse between gas in the alveoli and the blood. It has such a high affinity for haemoglobin that its rate of uptake is primarily a function of this diffusion. This test of carbon-monoxide uptake readily permits the detection of a barrier to diffusion caused by pathological change in the alveolar wall ("alveolar-capillary block" of Cournand, 1952) in diseases such as sarcoidosis, scleroderma, etc., or from any reduction in the effective surface area of the lung. It can be performed by either the multiple-breath (Filley *et al.*, 1954; Bates *et al.*, 1955; Gilson and Hugh-Jones, 1955) or the single-breath (Forster *et al.*, 1954) technique. Infra-red gas analysis has made it a clinically practicable procedure, but the infra-red analyser has a response time too slow and needs a gas sample too big to observe accurately the "alveolar plateau" for carbon monoxide. The new spectrometer would be ideal for the analysis, especially as for many calculations it is really necessary to know the distribution of an inert insoluble gas given concurrently with the carbon monoxide, were it not that nitrogen has the same molecular mass (28) as carbon monoxide, hence they both contribute to an identical peak in the mass spectrum. However, it may be possible to wash out the nitrogen in the lungs with, say, argon-oxygen mixtures and then record a single breath of carbon monoxide together with another inert gas, say, neon, as a tracer for gas distribution.

Since this spectrometer can record the analysis of a gas mixture for four gases concurrently there seems no reason why, ultimately, the degree of inequality of ventilation, of ventilation-perfusion ratios, and of perfusion (the latter from the relation between the first two) should not be measured at the same time as the diffusing capacity from single expiration measurements following the inhalation of a suitable mixture of gases.

Regional Analysis at Bronchoscopy

Gas analysis, similar to that of the expirate sampled at the lips, can be used to determine ventilation and perfusion relationships in individual lobes and segments. A special sampling tube (Fig. 4, B.) is introduced at routine bronchoscopy so that the appropriate cage holds the tip of the sampling tube itself centrally within the required branch of the bronchial tree. The small (0.5 mm.) tube causes little obstruction to the air flow from lobar or even segmental bronchi. When the sampling tube has thus been sited under direct vision, the bronchoscope (redesigned with a side arm proximally and an inflatable cuff near the distal end) can be withdrawn just above the main carina, and its cuff inflated.

By closing the usual inlet of the bronchoscope round the sampling tube, gas is washed out through the side arm, while a record is taken on the pen-recorder of the changes in gas concentration from the lung segment under exploration. We have not yet done detailed investigations within the bronchial tree, though tracings from the main bronchi show the procedure to be quite practicable.

From such tracings it should be possible to calculate the ventilation, ventilation-perfusion relationships, relative blood flow, and gas uptake of any portion of the lung which can be individually probed. Even a knowledge of the respiratory quotient, which can be measured from a continuous tracing of oxygen and carbon dioxide taken with an unmodified bronchoscope at routine diagnostic bronchoscopy (Fig. 8), will provide a measure of differential lung

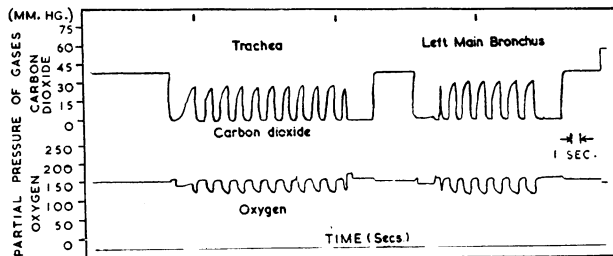


FIG. 8.—Continuous gas analysis within the bronchial tree at diagnostic bronchoscopy. Upper tracing, carbon dioxide (5-cm. full-scale deflection \equiv 75 mm. p.p. CO_2); lower tracing, oxygen (F.S.D. \equiv 250 mm. p.p. O_2). Paper speed 5 mm. per second.

function without bronchspirometry (Armitage and Taylor, 1956), and since this can be done segmentally with the mass spectrometer it should provide useful information for the surgeon before local resection is contemplated. For example, if the respiratory quotient of a part of the lung is unchanged by a pathological process there may be no functional indication for resection of this part, since there would be no venous admixture or wasted ventilation caused by it.

Applications in Medicine and Surgery

The procedures which we have described would be quite impracticable without the mass spectrometer. With its help they may well become practicable as routine diagnostic procedures. They demand but little effort and co-operation from the subject, and neither the complex apparatus for "snap" gas samples nor the bulky apparatus for gas collection are necessary.

Both prognosis and treatment of the large group of chronic chest diseases at present lumped together within the general terms of asthma or bronchitis and emphysema are unsatisfactory and empirical. The mass spectrometer should enable large series of such cases to be submitted to frequent functional testing, which by clarifying the functional disturbance should place prognosis and treatment on a more rational basis. Moreover, since the instrument is transportable, it could be used in field survey work, such as that designed to enlarge our knowledge of the evolution of chronic chest diseases.

The regional assessment at diagnostic bronchoscopy will be of obvious value to the surgeon as an indication of the advantages or danger of subsequent lobectomy or pneumonectomy. Perhaps in this field the *ad hoc* advances with the instrument will be greater than in any other. Regional continuous gas analysis within the lungs should also open up wide research possibilities in the elucidation of the changes in pulmonary blood flow associated with heart disease, such as mitral stenosis, and congenital abnormalities, and help in the study of the mechanism of pulmonary hypertension.

By contrast the use of the spectrometer in anaesthesiology will be limited, since the complex organic gases employed in modern anaesthetics are not readily analysed by this type of machine. It could be used for such simple purposes as

checking the level of carbon dioxide in the patient's breath during an operation, but there are other much simpler and less expensive instruments available for doing this. On the other hand, the spectrometer can prove very useful in checking the efficiency of oxygen masks, detecting leaks in equipment, rapidly checking the calibration of gas-delivering equipment, and so on.

Finally, the spectrometer can provide the most elegant and convincing demonstrations, for teaching purposes, of many classical experiments in physiology. The effects of breath-holding, hyperventilation, carbon dioxide narcosis in emphysema from oxygen inhalation, and many other phenomena can be beautifully demonstrated.

Summary

A mass spectrometer has been made, specifically for clinical practice and research, which will continuously and automatically analyse a gas mixture containing components of molecular weight in the range 18–80; this includes the majority of gases of physiological importance. It requires only electricity for operation, is transportable, and draws its gas sample (at a rate of 15 ml. per minute) through about 4 feet (122 cm.) of fine (0.5 mm.) hypodermic steel tubing.

The uses of this instrument are described. It will make the study of the gas exchange of the lungs as simple as measuring their ventilation for many clinical purposes. Analysis of single expirates and "wash-out" curves will enable measurements to be made of the inequality of gas distribution in the lungs, of the relation between distribution of gas and blood, and of the efficiency of gas transfer between alveoli and blood. These measurements are of value in making a positive diagnosis of emphysema, in elucidating the nature of the functional changes in chronic lung disease, in determining factors causing effects such as breathlessness, cyanosis, and carbon dioxide retention, and in following the efficacy of treatment in lung disease.

By passing the fine sampling tube into the bronchial tree, at diagnostic bronchoscopy, individual lobes and segments of the lung can be explored and local function examined; this should open new possibilities in cardio-respiratory research, and should be of considerable help to the thoracic surgeon.

The instrument provides a continuous record of the constituents of the gas sample as a series of peaks on an oscilloscope screen; the horizontal position of the peaks represents their identity as nitrogen, oxygen, carbon dioxide, etc., and their vertical height is directly proportional to their partial pressure in the mixture. Up to four components can be selected independently and simultaneously from this display, which represents their varying partial pressures, and these are recorded continuously on a direct-writing multi-channel pen-recorder. Pneumotachygraphic, electrocardiographic, or other information can be recorded simultaneously.

The response time when one gas is changed to another is such that 95% of full-scale deflection with the new gas is given in less than one-tenth of a second. The sensitivity is such that full-scale deflection may be obtained for partial pressures of anything between 3% and 100% of the total. The absolute accuracy is within 3%, though incremental changes can be measured within 1%, of the full-scale deflection selected.

The cost of construction and work with the spectrometer has been borne by the Medical Research Council, to whom we are most grateful. We would also like to record our thanks for the help and encouragement given by Dr. D. K. Hill, Director of

Bio-Physics Laboratory, and by Professor John McMichael and Dr. C. M. Fletcher, of the Department of Medicine of the Postgraduate Medical School. Dr. J. West, of the Medical Research Council's staff, has made valuable contributions in the initial use of the instrument. Mr. C. Lawden and Mr. T. Neal were responsible for construction of the instrument in the Postgraduate Medical School workshop.

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COMPARISON OF SIDE-EFFECTS AFTER PARTIAL GASTRECTOMY AND VAGO- TOMY AND GASTRO-ENTEROSTOMY*

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Partial gastrectomy is a well-established procedure with a low mortality rate and a low incidence of anastomotic ulcers. Dissatisfaction with it correctly centres in its side-effects—that is, those symptoms not due to ulceration. The figures for mortality rates and anastomotic ulcers are easily definable, but the side-effects prove a difficult field to chart. Numerous surgical procedures have been devised with the object of reducing or eliminating them: fixing the gastric stump, changing the position of the stoma, the combination of vagotomy with practically every known variant of partial gastrectomy, and, more recently, Billroth I for duodenal ulcer. If gastric operations, in an attempt to reduce side-effects, are not to show a discouraging tendency to rot in popularity, the results of different procedures must be compared with a fixed standard.

This fixed standard should be a simple clinical yardstick which illustrates principles rather than catalogues symptoms and which omits comparative terms as a basis or aid to comparison.

This paper compares the side-effects in 100 patients who have had partial gastrectomy for duodenal or anastomotic ulcer with the side-effects in 100 cases of duodenal ulcer treated by vagotomy and posterior

gastro-enterostomy. Each type of operation was carried out in comparable and unselected cases.

No case included in this report has been operated on during the past 12 months. As long-term results of vagotomy and posterior gastro-enterostomy are still unknown, it was decided to limit to 100 the number of cases in which this operation was carried out as a routine.

Facts have been collected in respect of the following points; (1) biliary regurgitation; (2) ability to take a normal-size mixed meal; (3) ability to take a one- or two-course meal; (4) the presence of selective impairment of digestion; (5) the incidence of dumping; and (6) the existence of any interrelation between the above.

All 200 patients have been personally interviewed on more than one occasion. The above questions were evolved with the object of demonstrating underlying principles.

PARTIAL GASTRECTOMY FOR DUODENAL ULCER

This operation was carried out for duodenal ulcer in 83 cases and for anastomotic ulcer in 17 cases (after posterior gastro-enterostomy 16, after pyloroplasty 1). Gastric section in all cases was carried out after division of the left gastric artery at the point at which it gives off the descending branch and after division of the lower two vasa brevia. Reconstruction was as follows: antecolic with spur, 85 cases; Polya, 8; Moynihan 1; Schoemaker 5; and Finsterer, 1. The afferent loop was made as short as possible consistent with the avoidance of tension.

Follow-up—Ninety-eight cases were operated on between 1947 and 1953, inclusive, and two in 1954. The average time between the date of operation and the date of this follow-up was four years five months. Eleven patients did not attend for review; the next 11 were therefore reviewed.

Biliary Regurgitation

Investigation into the incidence of biliary regurgitation in 100 patients gave the following results:

Nil	74 patients
Definite	5 "
(1) $\frac{1}{2}$ pint (285 ml.) once a day	1 patient
(2) $\frac{1}{2}$ " (285 ") " week	1 "
(3) $\frac{1}{2}$ " (285 ") " in two months	1 "
(4) Half a cupful (85 ml.) three times a week	1 "
(5) " " (85 ") once a month	1 "
Negligible (less than a mouthful once a week)	21 patients

Regurgitation of bile was therefore nil or negligible in 95 patients. Of the five patients with definite biliary regurgitation four had an antecolic partial gastrectomy with a spur and one had a Polya gastrectomy; four were females and one was a male.

Ability to take a Normal-size Mixed Meal

By this is meant the ability to take the normal-size two-course meal, whether in the evening or midday, composed of meat or fish and potatoes as the first course, and milk puddings, steamed puddings, etc., as the second course. The patient was asked to compare the size of the meal with the size of the corresponding meal prior to the development of the ulcer. No account has been taken of any patient's inability to take a large meal.

Group A: 55 patients were able to take a normal-size mixed meal.

Group B: 45 patients were unable to take a normal-size mixed meal.

In just under 50% of patients, therefore, there is a quantitative reduction in the food taken in this meal. An inability to take a normal-size meal may be a major handicap. The underlying problem has, we believe, not been pursued to its logical conclusion. A patient who is unable

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