THE MECHANICAL CONTROL OF PNEUMOTHORAX DURING OPERATIONS ON THE CHEST,

WITH A DESCRIPTION OF A NEW APPARATUS.*

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THE unexampled increase in the possibilities of surgical treatment which followed upon an understanding of the causes of wound infection has been of universal applicability to all regions of the body, with one notorious exception—the thorax. The surgery of the nervous system, the bones, the joints, has grown more and more elaborate and enterprising and been able to set before itself higher and higher standards of efficiency, while the surgery of the thorax has until quite recently remained almost as primitive and timid as it had been before Pasteur and Lister. The reason is obvious enough. The principles of asepsis gave to the abdominal surgeon freedom of access to the diseased parts and allowed him to elaborate his measures against the actual disease, secure in the knowledge that the primary intervention was in itself practically free from risk. The possibility of carrying out a safe exploratory laparotomy once established, the development of abdominal surgery was assured. To the surgeon of the thorax, however, no such freedom of access was given. The execution of a safe and thorough exploratory thoracotomy was barred by an unsolved physiological problem of quite another sort.

A free opening of the abdomen in itself produces no disturbance in the functioning of the contained organs, whereas a free opening of the chest under ordinary conditions produces, by causing a complete collapse of the lung, an immediate and dangerous interference with the vital mechanisms which depend directly upon the integrity of the pleural cavities. Until the disturbance consequent upon a pneumothorax could be prevented, it was impossible for the surgery of the thorax fully to share in the general progress of the art.

As a preliminary to the consideration of this problem, an understanding of the elementary facts of the mechanism of respiration is essential. The respiratory movements are not concerned merely with the single function of the aëration of the lungs, but contribute a factor essential to the normal maintenance of the pulmonary circulation and of considerable importance to that of the systemic. There are certain pronounced differences in the mechanics of the pulmonary and systemic circulations. The latter consists essentially of a pump driving blood under high pressure into an elastic reservoir, the arteries; and the current of blood is mainly influenced by variations in the elasticity of the latter affected through the vasomotor apparatus. The pulmonary circulation, on the other hand, consists of a pump driving blood under comparatively low pressure into a reservoir, the lungs, which is constantly varying in size with respiratory movements. This variation, moreover, in its effects on the circulation is an active one, drawing blood into the lungs during inspiration and expelling it during expiration. Thus the pulmonary circulation may be regarded as made up of two parts, each of which is in active pulsation, the ventricle impelling the blood onward with the rapid pulsations of the cardiac rhythm, while the lungs contribute the slower but more voluminous impulses of the respiratory cycle. It should be clear from the foregoing that interference with the pulmonary circulation will be produced by collapse of one lung,† and that although this lung might have its aërating capacity restored by mechanical inflation, the embarrassment of the pulmonary circulation would still remain unless the normal respiratory movements of the lung were re-established.

In this connexion it is appropriate to refer to the most obvious of the expedients that have been devised to maintain the function of the lungs after the chest has been opened. As long ago as the middle of the sixteenth

century Vesalius¹ recognized the possibility of aërating the blood after the chest had been opened, by passing a continuous current of air through the lungs, whilst in 1667 Hook read before the Royal Society a paper entitled, "An Account of an Experiment made by Mr. Hook of Preserving Animals Alive by Blowing through their Lungs with Bellows,"‡ of which the following is an abstract:

I did heretofore give this Illustrious Society an account of an Experiment I formerly tried of keeping a Dog alive after his Thorax was all display'd by the cutting away of the Ribs & Diaphragme; & after the Pericardium of the Heart also was taken off. But divers persons seeming to doubt of the certainty of the Experiment (by reason that some Tryals of this matter made by some other hands, failed of success) I caus'd at the last Meeting the same Experiment to be shewn in the presence of this Noble Company, & that with the same success, as it had been made by me at first; the Dog being kept alive by the Reciprocal blowing up of his Lungs with Bellows, & they suffered to subside, for the space of an hour or more, after his Thorax had been so display'd, & his Aspera Arteria cut off just below the Epigolotis, & bound in upon the nose of the Bellows.

And because some Eminent Physicians had affirm'd, that the Motion of the Lungs was necessary to Life upon the account of promoting the Circulation of the Blood, & that it was conceiv'd, the Animal would immediately be suffocated as soon as the Lungs should cease to be moved, I did (the better to fortify my own Hypothesis of this matter, & to be the better able to Judge of several others) make the following additional experiment; . . . [Hook fixed another bellows unto the first so as to be able to keep up a constant blast of air.] This being continued for a pretty while, the dog, as I expected, lay still, his eyes being all the time very quick, & his heart beating very regularly. But upon ceasing this blast, & suffering the Lungs to fall & lie still, the Dog would immediately fall into Dying convulsive fits; but be as soon reviv'd again by the renewing the fullness of his Lungs with the constant blast of fresh Air. . . . [At the end of the operation Hook cuts off a piece of the lung and finding that the blood is still circulating in it says:] Which seem to be Arguments, that as the bare Motion of the lungs without fresh Air contributes nothing to the life of the animal, he being found to survive as well when they were not mov'd, as when they were; so it was not the subsiding or movelessness of the Lungs that was the immediate cause of Death, or the stopping the circulation of the Blood through the Lungs, but the want of a sufficient supply of fresh Air.

I shall shortly further try, whether the suffering the Blood to circulate through a vessel, so as it may be openly exposed to the fresh Air, will not suffice for the Life of an Animal; & make some other Experiments, which, I hope, will thoroughly discover the Genuine use of Respiration; & afterwards consider of what benefit this may be to Mankind.

Mechanical respiration, as is of course well known, has been used for a long time, and extensively in experimenting on animals for the inflation of the lungs when it is required to open the chest. It has proved of great value by lowering the high mortality that must necessarily result if the operations are carried out with the lungs collapsed and an uncompensated pneumothorax present. That the method is in itself the cause of a small percentage of the deaths that result from the experiments, is not a sufficiently great objection to outweigh its advantages. But in human beings such a danger must necessarily be an absolute contraindication.§

By means of mechanical respiration the lungs are rhythmically inflated by a current of air blown into the trachea and respiratory undulations in the arterial pressure are still produced. But the effect of the inpumping of the air in mechanical respiration (the substitute for inspiration) is exactly the reverse of that of a normal inspiration. In the latter, after the initial fall of blood pressure, there is a steady rise during the rest of inspiration, and continued into the beginning of expiration, and this is succeeded by a fall which continues until the next inspiration has begun. When the lungs are inflated mechanically, the intrathoracic pressure is increased instead of decreased, and the arterial pressure, after the initial rise, falls. Thus mechanical respiration reverses the normal influence of the respiratory movements on the pulmonary circulation. Such a reversal of the normal process is at least undesirable, seeing how delicate the respiratory mechanism is known to be in many during anaesthesia. Mechanical respiration produces a condition of apnoea, and it is conceivable that the additional effect of the toxic influence of chloroform might prevent the centres from resuming their normal activities.

† Read before the Royal Society, October 24th, 1667. Published in the *Philosophical Transactions*, 1667, page 539.

§ Tuffier and Hallion speaking, however, of mechanical respiration, say: "The success of this method on animals justifies its use in man."

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† We are here considering collapse of the lungs as such without reference to dislocation of the mediastinum or other possible factors.

Further, interstitial emphysema is a not infrequent sequela of mechanical respiration.

The grave symptoms which follow when a large opening is made in the chest wall are not, however, entirely due to the loss of the physiological function of the lung: they are in part the result of the pathological complication of an open pneumothorax.

Garré² has shown that an opening in the chest wall produces no serious consequence in itself so long as the size of that opening is less than the size of the glottis.

Air enters the pleural cavity with each inspiration and the lung collapses gradually, but this collapse is neither complete nor maintained. The lung by virtue of its elasticity is greatly reduced in size, yet with each inspiration and expiration there is some slight alteration in volume, and during forced expiratory efforts—for example, coughing—some of the air from the sound lung is forced over into and expands the collapsed lung. The amount of movement in the lung, though not great, assists in the maintenance of the pulmonary circulation and in the aëration of the blood passing through the collapsed lung, and further, the size of the thoracic opening is not sufficient to allow the mediastinum to flap to and fro. But when a large opening is made through the chest wall

Fig. 1.—Front view of author's hyperatmospheric apparatus. Air chamber empty.

the lung at once collapses and the alarming symptoms of an uncompensated pneumothorax at once appear and progress to a fatal termination. Garré attributes the symptoms of an uncompensated pneumothorax—cyanosis, dyspnoea, and rapid irregular beating of the heart—to the flapping to and fro of the mediastinum and its contents, the heart, and large vessels, etc., with each inspiration and expiration. This to-and-fro flapping occurs as the result of the negative pressure between the pleural surfaces of the unaffected lung and the atmospheric pressure on the mediastinum, which is not a rigid body. During inspiration, therefore, since the pressure in the sound lung is less than atmospheric, the mediastinum is pushed across to that side, but during expiration the intrapulmonary pressure is greater than atmospheric, and so the mediastinum is pushed back towards the affected side.

Sauerbruch,³ on the other hand, considers that this is not the most important cause of the cyanosis and dyspnoea of an uncompensated pneumothorax, and attributes these phenomena to the alterations in the pulmonary circulation produced by collapse and loss of movement of the lung.

The pulmonary circulation differs very considerably from the systemic, and is dependent on: (1) The force of the right heart. (2) The difference of the pressure in the pulmonary veins and arteries; this increases with the increase in negative pressure during inspiration and decreases during expiration. (3) The diameter of the vessels. (4) The pressure in the lung.

During expiration the difference in pressure between

artery and vein is lessened, and associated with the increase of pressure in the lung the diameter of the vessels is diminished. But if the lung is collapsed as the result of an uncompensated pneumothorax there is loss of the most important influences controlling the pulmonary circulation on that side, and the forces which now act on the vessels are directly antagonistic to the proper aëration of the blood. Thus the absence of the intrathoracic variation of pressure on the affected side prevents the constant alteration in the difference in pressure in the pulmonary veins and arteries, and in the alveoli and alveolar vessels, while the alveolar vessels dilate, as they are no longer compressed by the difference between the intrabronchial and pleural pressure, and are easily distensible by virtue of their elasticity. These changes result in a considerable increase in the capacity in the blood vessels of the collapsed lung, the presence of which increase has been also demonstrated by injections and by the estimation of oxygen in cases of unilateral lung collapse due to an open pneumothorax.

It is to this hyperaemia of the collapsed lung that Sauerbruch attributes the dyspnoea of an uncompensated pneumothorax. The lung on the unaffected side is still able efficiently to aërate all the blood that passes through it, but as the result of the collapse of the other lung, and the associated increase of the size of the vessels, more than half the blood in the pulmonary system circulates

through that lung and returns to the heart unoxygenated; there is a rapid increase of the carbonic oxide in the blood which, stimulating the respiratory centres, produces the dyspnoea.

It is to the genius of Mikulicz that we owe the first systematic attack on the physiological difficulty which beset the surgery of the thorax. At his suggestion Sauerbruch began in 1903 a series of experimental researches which have amplified our know-

ledge of the physiological problems concerned, and have given us a practical solution of them which has already enlarged the possibilities of surgery. The apparatus he set himself to design must, if it was to satisfy the requirements of the problem, provide not only for the prevention of collapse of the lung, but also for the continuance of active respiration and for the prevention of any serious displacement of the mediastinum upon one pleural cavity being freely opened. These conditions are satisfiable only if there is maintained a difference between the pressure of the air entering the trachea and the pressure on the surface of the lung, the latter being always negative in relation to the former.

Fig. 2.—Side view of author's hyperatmospheric apparatus. Air chamber full.

Fig. 6.—Author's intubation tube.

Such difference need never be great—approximately that of the elastic recoil of the lung, $7\frac{1}{2}$ to 9 mm. Hg—and it must be capable of being continuously and steadily maintained throughout the period during which the chest is open. It is obvious that these requirements can be fulfilled in two ways: First, the patient may be caused to breathe air of a tension greater than that of the atmosphere, so that when the chest is opened and the lung exposed to atmospheric pressure, this is less than that of the air the patient is breathing by an amount greater than the elastic recoil of the lung; and, secondly, while the patient is breathing air at atmospheric pressure, his body is exposed to air of pressure less than atmospheric, so that when the chest is opened there is no increase of pressure on the lung but the normal respiratory difference is maintained. It must be clearly understood that in the first-mentioned method (hyperatmospheric or *ueberdruck*) the increased pressure of the respired air is slight and is constant, there being no intention of inflating the lungs as in mechanical respiration, but rather the reverse of this,

A very brief description of the working principles of the Sauerbruch chamber and the Brauer machine must be given.

The hypotatmospheric chamber of Sauerbruch is an airtight room with an air lock for entrance and exit. The ventilation is regulated by a pump, but the air in the chamber is always maintained at a negative pressure equal to 7 to 9 mm. Hg below atmospheric. The operator and his assistants work in the chamber. The operating table is fixed against one wall, and opposite the head end there is an opening in the wall partially closed by a rubber sleeve. When the patient is placed on the table his head is passed out through the sleeve, which is then adjusted round the neck so as to be airtight. Thus the body of the patient is inside and is exposed to a negative pressure, while the head is outside in the normal atmosphere; the anaesthetist is also outside, and communication between those outside and those inside can be carried on by telephone. The legs and lower part of the patient's body are further enclosed in a rubber sack which communicates with the outer air, so as to exclude the greater part of the systemic circulation from the influence of the diminished atmospheric pressure. When the thorax is opened under such conditions the movements of inspiration and expiration continue, and the lung on the ex-

Fig. 3.—Scale drawing of front view of author's apparatus.

Fig. 4.—Scale drawing of sagittal section of author's apparatus.

the object being simply to maintain the normal respiratory difference, so that normal active respiration may continue undisturbed. Sauerbruch experimented with both of these systems, and in 1904 completed a hypotatmospheric as well as a hyperatmospheric apparatus, with both of which he was able to carry out much successful experimental work. The former apparatus (*unterdruck Kammer*) is designed so that while the patient breathes air at atmospheric pressure, his chest, and after thoracotomy the surface of his lung, is exposed to a pressure less than that of the air. The latter apparatus (*ueberdruck Apparat*) allows of the patient breathing air greater than that of atmospheric pressure, while his body is exposed to normal atmospheric pressure.

While, however, Sauerbruch soon gave up his hyperatmospheric apparatus from preference of his hypotatmospheric chamber, Brauer⁴ also in 1904, and working independently of Sauerbruch, produced his model of a machine working on the hyperatmospheric system. This *ueberdruck Apparat* of Brauer was thus the first based on this system to come into general use.

posed side remains in apposition to the chest wall. None of the phenomena of an uncompensated pneumothorax appear.

The Brauer hyperatmospheric apparatus works on the reverse principle—that is to say, that instead of a negative pressure of about 8 mm. Hg formed outside the exposed lung the lungs are kept charged with a positive pressure of the same amount. The apparatus consists of a motor (or pump worked by hand) which forces air into a large bellows-like chamber expanding against springs; from this the air, at a pressure above that of the atmosphere, passes into a casket in which the head of the patient is enclosed. The casket has a glass top and two side openings fitted with rubber sleeves into which the anaesthetist inserts his hands and arms for the manipulation of the anaesthetic. The anaesthetic enters by a separate tube from a Roth-Dräger apparatus, and the pressure in the Roth-Dräger system and in the casket are equalized by a special device. The expired air passes out through a tube fitted with a lever valve. This valve controls the pressure in the casket by permitting of escape of air when it exceeds the required pressure.

Since the introduction of these two types of differential pressure mechanisms there have been other various forms invented about which a few words must be said before a comparison of their merits can be made. The apparatus devised by Karewski⁵ resembles closely the Brauer *ueber-*

druck and needs, therefore, no further mention. Willy Meyer⁶ has had constructed a big chamber whereby he can operate either with a positive or negative pressure. Two other types of hyperatmospheric apparatus, the Tiegel-Henle⁷ and the Lötsch,⁸ must be noticed because both have been brought forward with a view to putting on the market a simple, cheap, and portable mechanism* for the prevention of uncompensated pneumothorax in intrathoracic surgery. The former of these introduces the air by means of a tightly-fitting mask, the latter by mask or intubation tube. In both the expired air passes out through a column of water, and the pressure is regulated by the height of this column. There are thus two distinct types of differential pressure apparatus the hypoatmospheric (*unterdruck*) and hyperatmospheric (*überdruck*). In the latter the compressed air reaches the lungs either by a casket, mask, or intubation tube.

COMPARISON OF THE HYPOATMOSPHERIC AND HYPERATMOSPHERIC SYSTEMS.

There is no doubt that the hypoatmospheric chamber reproduces the physiological state, when the chest wall is opened, more nearly than the hyperatmospheric apparatus, and Sauerbruch and Robinson⁹ and Haecker have demonstrated in their experimental pneumectomies on animals that there is less danger of the animal dying from effusion of serous fluid into the pleural cavity on the side of the

COMPARISON OF THE CASKET, THE MASK, AND THE INTUBATION TUBE.

It may at once be said that the mask is highly unsatisfactory, even when that form is used which has a vomit bag connected with it. It is difficult to make a mask to fit so well as to be airtight. It is most uncertain that all the vomit, should vomiting occur during the anaesthesia, will go into the special bag attached to the mask, and if

some of the vomit is inhaled, or if the tongue falls back, it is quite impossible to remedy these serious complications without removing the mask, and with it the increased pressure, whereas a constant maintenance of pressure is obviously essential.

The casket and the intubation tube are both satisfactory. In the casket, however, which must necessarily be large, the anaesthetic has to be introduced from a separate apparatus; the patient's neck

is surrounded by a rubber band firmly applied to ensure against escape of air, and the anaesthetist must carry out all the necessary manoeuvres inside the casket with his hand surrounded by rubber; if he withdraws a hand to attend to the apparatus, the rubber sleeve is at once turned inside out by the pressure of the air in the casket, and has to be reinvaginized before he can again attend to the patient's head with that hand.

The objections raised against the intubation tube are that it may produce oedema of the glottis, is difficult to insert and restricts the air-way; unless considerable

Fig. 5.—Scale drawing of author's apparatus, viewed from above.

Fig. 7.—Scale diagrammatic drawing of author's apparatus.

operation when the experiment has been done in a hypoatmospheric chamber than when the hyperatmospheric system has been used. But on the other hand it has been shown from a series of experiments with the two types of apparatus¹⁰ that there is no material difference in the effect on the blood pressure or on the respirations during the operation. The great disadvantage of the hypoatmospheric apparatus is its size.

* The Brauer with motor costs ... about £90
The Tiegel-Henle with 1 cylinder costs about £21
" with 2 cylinders costs ... £26
The Lötsch costs ... about £18

irritation of the larynx is produced by careless intubation, there need be no fear of this complication, as has been shown by the extensive use of intubation by O'Dwyer and Kuhn, and the possibility of the use of the large instruments required for bronchoscopy and intrabronchial operations. With the finger on the glottis as a guide, the tube is easily inserted, and the constant stream of air amply compensates for the slight restriction of the air-way. The advantages of the intubation tube are considerable; the head is freed of all cumbersome enclosures with guarded apertures through which all the attention necessary for the administration of the anaesthetic, the holding

up of the jaw, keeping forward of the tongue, removal of saliva and vomit from the mouth and pharynx, must be done; there is no danger of vomit entering the trachea, and once the tube is in position only one hand is required to keep it there. There is no constriction of the neck, which must tend to produce venous congestion of the brain and stormy respiration.

Before describing my own hyperatmospheric apparatus mention must be made of Meltzer's insufflation method.¹¹

Meltzer uses a long tube of about two-thirds the diameter of the trachea, which is passed down through the larynx to just above the bifurcation of the trachea. Air is pumped through this by bellows, and the returning air escapes between the tube and trachea. The method is said by those who have used it to answer its purpose, but Meltzer himself admits ignorance of the pressure of the air in the tube, and that, owing to the cyanosis and change in pulse-rate which develops, the lungs have to be allowed to collapse, and be then re-expanded once every few minutes. The method, then, would seem to be rather like mechanical respiration done with an irregular pump and a leaky apparatus.

My reasons for designing a new type of hyperatmospheric apparatus are as follows. The recognition of the necessity of being able to do intrathoracic operations without the constant anxiety of the risks of an uncompensated pneumothorax made me investigate the existing machines very fully. The *unterdruck* chamber of Sauerbruch needed so much space as to make it impracticable. Of the existing hyperatmospheric machines there were three different types to choose from—the Brauer; Tiegel-Henle; or Lötsch. Neither of these latter two suited my requirements, as in both of them, in my opinion, too great sacrifices have been made in order to secure cheapness and portability, and neither of them can be relied on for giving accurate working and a constant pressure throughout a long operation; in neither of them, therefore, can the maximum degree of security be said to be obtained. This does not imply that they cannot be used with considerable success, but it does suggest that by the inaccuracy and inconstancy of the pressure there is danger of increasing the shock of the operation. That the patient has often sufficient reserve to enable him to overcome remediable deficiencies of the instrument in no way justifies his being loaded with them in addition to the unavoidable necessities of the operation. In a department of surgery such as this, where so much as to the conditions of successful treatment is as yet unknown, it seems to me most important that the highest standard of accuracy should be insisted upon with mere mechanical apparatus, and that no elaboration should be grudged which gives any possibility of increased safety.

Compared with these the Brauer machine is vastly superior; but there are certain objections to it. I have already suggested that the employment of a casket for the conveyance of the air at a positive pressure is not altogether satisfactory. The whole Brauer apparatus consists not of one but of two pieces of machinery, the Roth-Dräger chloroform machine with the intercommunicating pressure equilibrator, and the hyper-pressure part with its motor, air chamber, casket, and exit air valve, etc. As the air chamber is a large bellows working against the resistance of springs, the pressure of the air entering the casket must constantly vary, and the whole responsibility for maintaining uniformity of pressure in the casket rests on the respiratory valves. Lastly, the apparatus is very costly.

It seemed to me to be possible, working on a principle quite different from any of those already in use, to produce an apparatus by which absolute constancy in the flow and pressure of air could be combined with simplicity of working at a cost considerably lower at any rate than that of the Brauer type.

In designing such a machine, the following were the essentials which had to be determined on: the method of obtaining the air, the method of obtaining the pressure, the control of the pressure, the manner of conveying the air to the lungs, the administration of the anaesthetic.

For the reasons above given I decided on using an intubation tube in preference to the casket or mask, but the use of the intubation necessitates the exclusion of the mouth, nose, and pharynx from the air circulation, and it is therefore necessary that the air shall be moistened and warmed before passing into the trachea. Further, intubation necessitates an expiratory and inspiratory circuit, both

under accurate and easily regulated pressure control. Neither rubber bags nor bellows expanding against the resistance of springs give constancy of pressure; the greater the distension of the rubber or the compression of the springs the greater the pressure, but an air chamber made on the principle of a gasholder with a suitably weighted inner cylinder will give an equal pressure, whatever the height of the cylinder. But the pressure of the air in the cylinder must always be as great as, and preferably greater than, the maximum pressure ever required, and some mechanism, therefore, is required to cut down the pressure to a constant quantity, yet allow of variation if required. This want is supplied by the Stott gas governor, which gives a constant pressure independently of the rate of flow; the pressure can be increased or decreased according as certain weights are increased or decreased. The supply of air is easily obtained from compressed-air cylinders, and either air or oxygen, or a mixture of the two, can be given as required. As Alcock's chloroform apparatus is worked normally by driving air through it with bellows, and as it permits of accurate reading of the percentage of chloroform given according to the temperature of that fluid, it was possible, after a few minor alterations, to connect it up in the inspiratory circuit of my machine, and it has proved itself to be most satisfactory. Lastly, it was necessary that the various parts should be readily accessible for cleaning purposes, and so assembled that everything is within view and reach of the anaesthetist.

AUTHOR'S HYPERATMOSPHERIC APPARATUS.

The main features of the machine are an air chamber working on the principles of a gasholder and fed from compressed air and oxygen cylinders; the air in this chamber is at a greater pressure than that required in the bronchial tubes, but after it leaves the chamber passes through a governor and the pressure is there regulated to the required amount; it then passes through Alcock's chloroform box, then through a heating chamber, and so into the trachea by an intubation tube. The expired air leaves the trachea again by the exit pipe of the intubation tube and enters the expiratory chamber, where the pressure is again regulated by a weight valve.

Figs. 1 and 2 are woodcuts from photographs of the machine. Figs. 3, 4, 5 are scale drawings showing the various details. Fig. 6 is a woodcut of the intubation tube. And Fig. 7 illustrates the apparatus in diagrammatic form.

The whole apparatus rests on a steel triangular base with three wheels; the front wheel has a pivot action, and a handle is fixed to it by which the machine is moved about. The main air chamber consists of an inner and outer cylinder made of copper, tin lined. The outer cylinder or water tank is filled with water up to a mark shown on the water gauge, and the water serves both to control the air within the air chamber and to moisten the air as it enters the chamber. Attached to the base is the air inlet shaft, the lower part formed of tinned copper and perforated by holes round the bottom to admit free circulation of the water; the upper part consists of wire gauze; the top is closed by a cap, which is just below the surface of the water when the chamber contains air under pressure. Within this shaft open the three pipes from the compressed air and oxygen cylinders and the air as it escapes from these has to pass through the water and through the wire gauze.

The inner or air chamber rises and falls according to the volume of air inside it, and is kept steady by runners working on guides. The weight of this cylinder together with an extra weight of 65 lb. on the top of it keeps the air in the chamber at a pressure equal to 10 in. of water (approximately 20 mm. Hg). This cylinder is prevented from being lifted beyond a certain height by means of a valve which is opened automatically by a lever and allows the excess of air to escape. This valve can also be opened by hand when, should the chamber be full of air, oxygen is required; the replacement of air by oxygen when the chamber is full takes eight seconds and affects in no way the pressure in the inspiratory circuit. When the air chamber reaches its maximum capacity and before it reaches the minimum an electric contact is formed and a small buzzer rings.

To the back of the air chamber are attached three rings which hold two 40 ft. compressed-air cylinders and one 40 ft. compressed oxygen cylinder, which communicate by way of pressure gauges, needle valves, and flexible metal tubing, with the pipes entering into the bottom of the air chamber.

On the front of the air chamber is a tray which carries the rest of the apparatus. An inch outlet pipe conducts the air from the air chamber into the governor. This pipe is U-shaped, and has a small tap at the bottom to allow the escape of any water which may collect in the pipe and the escape of condensed steam during cleaning. The main tap for connecting the air chamber with the inspiratory circuit is on this outlet pipe just below the governor. The governor is a half-inch Stott; the pressure is regulated by weights, and remains constant independently of the rate of flow. The pressure is shown by a manometer connected with the pipe immediately beyond the governor. The air is then conducted into Alcock's chloroform apparatus, which allows of accurate control of the percentage of chloroform used at various temperatures. The air

charged with the required amount of chloroform passes next through a copper chamber containing six 16-candle power electric bulbs; this chamber is baffled so that the air must circulate round each lamp before it leaves. Each of the lamps has a separate switch; usually two lamps only are sufficient to produce the required temperature of about 85° F., but the additional number allows for the possibility of a fuse blowing or a broken filament. When the air leaves the heating chamber it is conducted past a thermometer, and then by a rubber tube to the intubation tube, which will be described presently.

In the expiratory circuit the air passes from the intubation tube into a metal box connected with a manometer and fitted with an expiratory valve which can be weighted to the required pressure. On the tube leading into this box there is a tap which can be opened if it is required suddenly to reduce the pressure.

The two manometers are arranged so that the ascending limbs are side by side; these and the thermometer are in a row, and the light from the electric lamps of the heating chamber fixed beneath the shelf shining through a talc disc illuminates them.

A movable arm fitted to one of the guides supports the rubber tubing between the apparatus and the patient.

The whole apparatus can be easily taken to pieces for cleaning.

The intubation tube consists of an intratracheal part fitted with a collar which rests on the glottis; a curved intrabuccal and an extrabuccal part. The intratracheal portion is surrounded by an airtight rubber sleeve which communicates with a very small pipe, through which it can be blown up. The intratracheal and buccal sections consist of a single tube ending externally in an open expansion, which is closed with a screw cap. The inlet and exit tubes which are joined up with the inspiratory and expiratory circuits enter the main tube just below the expansion.

Before the patient is intubated, the screw cap is disconnected and the patient breathes, and is given the anaesthetic through the opening of the expansion until the time when the pleura is about to be opened. The air is then turned on from the chamber, and as soon as it is flowing freely the screw cap is fixed, and the hyperatmospheric circuit thereby closed.

A movable gag is attached to the buccal portion of the intubation tube, so that the teeth can be made to hold the tube in position by putting a bandage round the jaw and head.

I have used this hyperatmospheric apparatus both on animals and men with complete success. The lungs are kept properly distended, the movements of inspiration and expiration continue unaltered, the pulse remains good as regards quality and frequency, the blood pressure is maintained, and there has been no trace of dyspnoea, even though the chest has been widely opened for one and a quarter hours in man and two hours in animals. During the operations oxygen has only occasionally been given. The details of the operations I hope to publish later.

My justification for publishing a detailed account of this apparatus is that it offers a certain combination of advantages not possessed by other hyperatmospheric machines. The pressure of the air remains constant, yet can be altered at will; the manometer in the inspiratory circuit shows only the slightest inspiratory and expiratory oscillations when the chest is opened, while the expiratory manometer shows a rise and fall of $\frac{1}{2}$ in. to 1 in. with each expiration and inspiration, according to the depth of the patient's respirations, and thus offers a very satisfactory guide to the condition of the patient and the depth of the anaesthesia. The pressure of air is regulated in both the inspiratory and expiratory circuits. The machine is extremely simple in its working, and the anaesthetist can reach and control every part of the apparatus with his right hand, the left being sufficient to steady the patient's head and the intubation tube. There are no motive forces such as motors, which may fail at any moment. The cost is about two-thirds that of the Brauer *ueberdruck*. It is capable of transport, and can be used in any theatre or operating room. Finally, its efficiency has been demonstrated by use.

I should like to take this opportunity of expressing my thanks to Mr. Rood for the trouble and care he has taken in the administration of anaesthetics for me with this apparatus.

Throughout I have profited greatly by the interest shown and the many valuable suggestions given me by Mr. Wilfred Trotter.

REFERENCES.

- ¹ *De Humani Corporis Fabrica*, Basilee, 1559, p. 824. ² Garré and Quincke, *Grundriss der Lungenchirurgie*, Jena, 1903. ³ Sauerbruch, *Zur Pathologie des offenen Pneumothorax und die Grundlagen meines Verfahrens zu seiner Ausschaltung*, *Mittheilungen aus den Grenzgebieten der Medizin und Chirurgie*, 1904, T. 13, S. 399. ⁴ Brauer, *Die Ausschaltung der Pneumothoraxfolgen mit Hilfe des Ueberdruckverfahrens*, *Mittheilungen aus den Grenzgebieten der Medizin und Chirurgie*, 1904, T. 13, S. 483. ⁵ Karewski, *Ueber den Wert des Druckdifferenzverfahrens für die Lungenpleurachirurgie und über eine neue Ueberdruckkammer*, *Berl. klin. Woch.*, 1909, No. 8. ⁶ Meyer, *Pneumectomy with the Aid of Differential Air Pressure*, *Journ. of the Amer.*

Med. Assoc., December 11th, 1909. ⁷ Tiegel, *Ein einfacher Apparat zur Ueberdrucknarkose*, *Centralblatt für Chirurgie*, 1908, No. 22; *Ueberdrucknarkose*, *Beitr. zur klin. Chirurgie*, 1909, Bd. 64, Heft 2, S. 356. ⁸ Lötsch, *Ein Apparat zur Ueberdrucknarkose*, *Archiv für klin. Chirurgie*, Bd. 93, Heft 1, S. 285. ⁹ Sauerbruch and Robinson, *Investigations Concerning the Technic of Lung Resection, with the Application of Both Forms of Differential Pressure*, *Annals of Surgery*, 1910, vol. li, p. 320. ¹⁰ Lothar Dreyer, *Vergleichende experimentelle Untersuchungen über das Ueber- und Unterdruck-verfahren*, *Verhandlungen der deutschen Gesellschaft für Chirurgie*, 1908, S. 146. ¹¹ Meltzer, *Continuous Respiration without Respiratory Movements*, *Journ. of Experimental Medicine*, 1909, ii, p. 622.

A NOTE CONCERNING THE TREATMENT OF TUBERCULOSIS BY "RADIO-ACTIVE IODINE AND MENTHOL."

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At the last Hungarian National Medical Congress Professor Szendeffy laid before his colleagues the results he had obtained during the two preceding years with a new chemical body with a basis of iodine and radium. He cited a large number of facts tending to prove that it was possible with this chemical product to arrest *in vitro* the development of the most virulent cultures of the bacillus of Koch, and also to stop the progress of tubercle in animals which had been experimentally inoculated with the bacillus.

Professor Szendeffy and Dr. Kertez-Aba, Physician to the Austro-Hungarian Court, together communicated a large number of clinical observations which proved that the hypodermic injection of radio-active iodine and menthol was well tolerated by patients, and also that this compound had a very powerful phagocytic action in patients with tubercle who improved under treatment and made progress towards recovery. Wishing to have his statements controlled by an independent expert, Professor Szendeffy asked the help of Dr. S. Bernheim, of Paris, President of the *Oeuvre de la Tuberculose Humaine*, who had a vast field for testing the new treatment among the numbers of patients who attended the various dispensaries and sanatoriums supported by this charity. During the last twelve months Dr. Bernheim, with the help of Drs. Dieupart, Hervé, Diamantberger, Michalovici, Baud, and others, has applied the treatment to a large number of patients, and clinical reports of the cases were recently communicated to the *Société Internationale de la Tuberculose*, the French Clinical Society, and other scientific bodies.

In the opinion of Dr. Bernheim, the action of this chemical product invented by Professor Szendeffy is due more especially, and almost exclusively, to the volatility of radium, which is eliminated slowly by the lungs. Dr. Bernheim believes that there is a true selective action, a fixing of helium at the site of the tubercles in the lung, and considers it not astonishing that this radio-activity should neutralize the harmful action of the bacilli of Koch and of the associated microbes. According to Dr. Bernheim, this radio-activity also paralyses the harmful influence of the toxins. Considering the rapidity with which Koch's bacilli are destroyed by the sun's rays, and also how easily the development of bacilli is arrested when in contact with radium, a comparison between these two physical phenomena is justifiable.

Dr. Bernheim described to me the three following recent cases, which have a great clinical importance and interest.

CASE I.

A lady in society, aged 24 years, tuberculous herself and having tuberculous parents, during her five years of married life had had three miscarriages. Pregnant for the fourth time, and being in the fifth month of pregnancy, she was given injections of radio-active iodine and menthol, and received two series of injections (eighty in all). Her condition improved, and she was able to carry to term, and was confined of a living child, weighing 3 kilos.

CASE II.

A similar case in a woman of the working classes, aged 44 years, tuberculous, a patient at the Dispensaire Antituberculeux at St. Denis, who had had seven miscarriages, and who had contracted tubercle from her husband. She was treated by injections of radio-active iodine and menthol from the beginning of the third month of pregnancy. It proceeded to term, and she was confined of a living child.