A METHOD OF CLOSED ANAESTHESIA

BY

T. A. B. HARRIS, M.B., B.S.MELB.

ASSISTANT ANAESTHETIST, WEST LONDON HOSPITAL

The method of inhalation anaesthesia which is in almost universal use is termed the "open method," so called because the patient is free to expire into the open air. In contradistinction to this is the "closed method," in which the patient's expirations are collected and breathed again. Clover's inhaler constituted an attempt to utilize the fact that anaesthetic agents are exhaled unchanged. About eighteen years ago D. E. Jackson first made use of the well-known chemical fact that sodium and calcium hydrate (soda-lime) would readily and rapidly absorb carbon dioxide. The application of this principle to anaesthesia makes the closed method a real possibility; for expirations containing anaesthetic agent unchanged plus carbon dioxide can be collected, cleansed of carbon dioxide, and used again.

The apparatus illustrated here was constructed in an endeavour to bring the principle of carbon dioxide absorption by soda-lime into the realm of practical anaesthetics. The reasons which prompted this work were: economy of use, more exact regulation and control, and a greater freedom from the possibility of explosions. It must, of course, be used in a closed system. Its practical application depends on four facts:

1. Anaesthetic agents are excreted by the lungs almost completely and in exactly the same form as that in which they are absorbed.
2. Carbon dioxide is absorbed by soda-lime.
3. Once anaesthetic equilibrium has been reached the patient's metabolic rate remains a practical constant, and consequently his oxygen demand will remain constant.
4. The only remaining variable—the depth of anaesthesia—depends on the partial pressure of the anaesthetic agent in alveolar air.

In a closed method of anaesthesia, if one is feeding into the apparatus just sufficient oxygen to satisfy the demands of the patient's metabolism, then with each unit respiratory effort this oxygen is completely used, and is excreted with each expiratory effort as carbon dioxide, to be completely absorbed by the soda-lime. In effect, the pressures of these two substances balance themselves out. The pressure in the apparatus can therefore be taken as an accurate measure of the pressure of the anaesthetic agent in the system. But in a closed system the pressure is a direct measure of the partial pressure in the alveolar air, so that the pressure as read on the manometer becomes a numerical measure of the depth of anaesthesia. Once anaesthetic equilibrium has been obtained at the depth of anaesthesia required, then, if means can be adopted to maintain this pressure constant, the depth of anaesthesia cannot alter.

THE APPARATUS

A two-phase machine is used. Expiratory gases pass from the mask (or endotracheal tube) through the expiratory valve to the canister, which contains soda-lime, and thence to the upper end of the reservoir, a one-and-a-half-gallon rubber bag. Inspiration is made from the bottom of the bag through the inspiratory valve to the mask. A bypass valve, set on the canister, allows the carbon dioxide of the expirations to be absorbed by soda-lime, or allows the carbon dioxide to be retained in the system should the physiological condition of the patient warrant it. This also allows the canister to be changed during the course of an anaesthetic. Nitrous oxide or ethylene, from a source of supply fitted with a reducing valve, enters the reservoir at the bottom

of the bag. Its rate of flow is regulated by a system of levers on the bag, while a thumb-screw on this lever system allows the pressure to be adjusted to within 1/2 mm. Hg. A manometer provides a means of ascertaining the pressure. The oxygen from a source of

DIAGRAMMATIC REPRESENTATION OF APPARATUS

Apparatus unpacked and ready for use.

supply fitted with a reducing valve is regulated by flow-meter control. It enters the bag at its upper end at such a point as to meet the expiratory flow after this has left the soda-lime canister. An ether reservoir is set between the flow-meter and the bag. The in-coming oxygen can be passed over, or through, ether, which is thus carried

into the apparatus. In a closed system all the ether fed in is retained, and it is essential that none should be inadvertently siphoned into the system. The valve guarding the ether reservoir opens or closes both the entrance and the exit to the reservoir synchronously. With the valve in the position to "bypass" the ether reservoir, no ether can possibly leave this reservoir. A common breathing-tube attaches the machine to the mask: it is as short as is mechanically convenient, in order to reduce dead space to a minimum, and carries a Magill expiratory valve.

METHOD OF USE

With the Magill expiratory valve open and the canister valve bypassing the soda-lime, nitrous oxide and then oxygen is fed in in the manner of an ordinary induction. As soon as is convenient an airway is inserted, and the mask accurately adjusted and fitted in position with Clausen's harness. When all the nitrogen has presumably been eliminated the system is closed by shutting the Magill expiratory valve tightly, and the canister valve is moved across to bring into play the carbon dioxide absorbing properties of the soda-lime. It is of the utmost importance to eliminate the nitrogen before closing the system, and this is usually achieved in about twenty expirations with the Magill expiratory valve open. The oxygen intake is now accurately adjusted to the metabolic rate of the patient. Once adjusted it does not alter, and so needs no further attention. The carbon dioxide is meanwhile being efficiently and completely absorbed by the soda-lime. Nothing now remains but to regulate the depth of anaesthesia. The pressure is gradually increased by means of the thumb-screw until the required depth has been reached. This valve is now noted on the manometer for future reference. The lever system can from this time on be relied upon automatically to maintain the predetermined pressure constant. In this manner—even in the presence of a slight leak, for instance, between the mask and the patient's face—the lever system will accurately maintain the predetermined depth of anaesthesia at a constant. Should relaxation be desired, ether is added until the required degree of relaxation has been reached, when the ether is bypassed. Because this ether is retained in the closed system the degree of relaxation will not alter. To lighten the degree of anaesthesia the Magill expiratory valve is opened and the thumb-screw adjusted to the new reduced pressure. When anaesthetic equilibrium has been reached the machine is absolutely self-regulating for the following reasons:

1. The oxygen supply is a fixed value.
2. The carbon dioxide is all being efficiently excreted.
3. The partial pressure of the anaesthetic agent in the alveolar air is being maintained at a constant pressure.

OBSERVATIONS DURING USE

Cost of Materials

This is reduced to an amazing degree. For induction, and until the nitrogen has been eliminated, about three gallons of nitrous oxide are used; and when the machine has been closed the only fresh nitrous oxide required is that necessary to make up for the slight leakage which may occur. I have used as little as four gallons of nitrous oxide for an anaesthesia lasting for one and a quarter hours. Normal oxygen consumption is 5 to 6 c.cm. per kilo of body weight per minute, which is equivalent to 300 to 500 c.cm. per minute for a man from 10 to 13 stone in weight. Should the metabolic rate be high, more oxygen will be required. With this excessive consumption of oxygen there is a correspondingly excessive excretion of carbon dioxide, and consequently the canister charge of soda-lime is more rapidly depleted. A charge of soda-lime is not used for more than five

anaesthetic hours, although it is capable of lasting for a longer period than this. A depleted canister charge shows itself clinically by cyanosis, hyperpnoea, and a rise of blood pressure, with, finally, a sharp fall of blood pressure and a failing circulation. This can occur insidiously. Should it take place during the course of an anaesthesia with this apparatus, by opening the expiratory valve on the mask and turning the canister valve to rebreathe, the anaesthesia can be completed as an open anaesthesia, or, should one so desire, the canister can be removed and recharged.

A difficulty met with was the presence of soda-lime dust. This dust is slightly alkaline in reaction, and is irritating to the skin and the mucous membrane of the respiratory tract. It presents a difficulty during induction, for it produces a troublesome cough. It was only when Siebe Gorman's soda-lime was used that this difficulty was completely eliminated. This soda-lime is slightly harder than the ordinary trade samples, and so has less tendency to pulverize. To make quite sure that no dust is present a blast of gas is blown through the machine immediately before use. The cost of 1 lb. of Siebe Gorman's soda-lime, which charge will last for five anaesthetic hours, is 1s. 6d.

The amount of ether used, even when a great degree of relaxation is required, is correspondingly small. Five ounces of ether for an anaesthesia lasting for one hour would be a fair estimate.

Pre-heating of Gases

The chemical action of carbon dioxide on soda-lime generates heat. If pure carbon dioxide be run through the canister a temperature of up to 100° C. is generated. Consequently, this is a practice not to be recommended. The maximum temperature which the amount of carbon dioxide in expired air has produced is 40° C. in the canister, 30° C. in the mask, and 32° C. in the bag. This chemical action, then, is of value in pre-heating the gases to be inspired, and it would seem that, except who pure carbon dioxide is used over an excessive period of time, this pre-heating is of value and does not err on the side of being excessive.

ANOXAEMIA AND POSSIBLE EXPLOSIONS

In the event of anoxaemia occurring the canister valve is turned to the position of "rebreath" and the oxygen supply is increased. In this manner the carbon dioxide as well as the oxygen content of the system is built up. A possible danger lies in the production of an anoxaemia of the anoxic type, due to the lack of carbon dioxide. The excessive excretion of carbon dioxide by the soda-lime can, especially in very toxic patients, produce an anoxaemia in the presence of a normal supply of oxygen. This is due to the fact that in the presence of a lowered blood carbon dioxide content, oxyhaemoglobin gives off its oxygen with difficulty. The use of the canister bypass valve will correct an error in this direction.

To investigate the question of smell and combustibility ethylene was used, since, in addition to having a foul and penetrating odour, it is very explosive. After care had been taken to render the circuit airtight the patient was moved to the theatre. With a large bladder syringe samples of the theatre air were collected from round and under the head of the operating table. These were then transferred to small children's rubber balloons. Twenty samples were collected at various times and were fired with a hot electric spark in the open air as soon as possible after collection. None of these samples exploded. It is obvious that the results depend on the airtightness of the mask, but then the success of this form of anaesthesia depends on this same factor, and on these results it must be assumed that the apparatus was as airtight as possible. In the face of this series of experiments it would seem that such a method offers a large measure of protection from explosion.

Bacteriological Contamination

An obvious objection to any closed method of anaesthesia is the possibility of bacterial contamination. In the investigation of this problem the mask and common breathing-tube were not washed or investigated bacteriologically.

In each of the four series of experiments the bag was washed out with 20 c.cm. of sterile broth solution. Then 0.25 to 0.5 c.cm. of this was plated on blood agar and incubated for three days. The broth-washing was also incubated and examined. Five cases taken at random in the out-patient department were anaesthetized in turn with the ordinary mask and bag, with the valve at "rebreathes." The outlet was plugged between cases with sterile cotton-wool. We then had in the bag a perfect mixture of the expirations of these five patients. On examination of the agar plates and broth air-borne organisms were present in both, but no pathological organisms were found.

Next, using the apparatus described above, a case was anaesthetized with the canister in circuit throughout, and no ether was used. The object was to ascertain to what extent the canister acted as a filter. This canister is equivalent to a tube 9 inches long with a calibre of 3 square inches. It is packed with soda-lime granules, which have an alkaline reaction. It was anticipated that all bacteria would be caught or destroyed by such a filter, the more so because the gas flow through the canister is in one direction only. After an anaesthesia of one hour the bag was treated as above. On examination of the agar plates and broth, air-borne organisms were present in both, but no pathological organisms were found.

The above experiment was then repeated, using the bypass valve at frequent intervals. This had the effect of abolishing at frequent intervals the filtering action of the canister. Again the same results were obtained.

These two experiments were repeated, and, during the anaesthetic, ether was used with similar results.

Dr. Elworthy reports on the series as follows:

The total number of organisms found was very small. pathological organisms from the mouth, throat, etc., were not seen. Organisms normally found in dust were alone noted. (These may have been in the bag previous to the anaesthetic.) The broth washings gave similar results.

This series of findings suggests that pathological organisms, if present, do not reach the bag, and, as the apparatus is a two-phase machine, cannot therefore be inspired. It would, in fact, indicate the safety of the apparatus from a bacteriological point of view. The possible source of infection lies in the common breathing-tube and mask, which, as in ordinary routine, can be removed easily and washed with an antiseptic solution. It would thus seem that this system of anaesthesia is, from the point of view of bacterial contamination, as safe as any other method now in use.

CONCLUSIONS

I have used this apparatus in its various modifications for a period of two years at the West London Hospital. It can be used for all closed methods of anaesthesia, including closed ether. With the canister valve bypassing the soda-lime and the Magill expiratory valve open, it can be used for all open methods of anaesthesia. It can also be employed in the manner of a Shipway apparatus.

To summarize briefly, the features of this apparatus are:

1. The bypass valve on the canister system, which allows carbon dioxide to be retained when the physiological condition of the patient warrants it. (This also allows the canister to be charged during the course of anaesthesia.)

2. The cost and weight of anaesthetic agents are reduced to very small proportions, as are also the odour of anaesthetic agents and possibility of explosions.

3. Bacterial contamination from patient to patient is not a real danger.

4. As a method of anaesthesia it is physiologically correct in principle and flexible of adjustment.

5. The apparatus enables one to use that very excellent anaesthetic agent ethylene, with a minimum of discomfort, whether this be due to anxiety on the score of explosion or on account of the delicate and susceptible olfactory organs of the normal theatre and surgical staff.

I wish to express my keen appreciation of the willing assistance afforded to me by Dr. R. R. Elworthy, O.B.E., and the staff of the pathological laboratory of the West London Hospital. This apparatus was assembled in its present form by A. Charles King, Ltd., 34, Devonshire Street, W.C.

PROTECTIVE GOGGLES FOR MOUNTAINEERING AND INDUSTRY*

BY

J. D. MAGOR CARDELL, F.R.C.S.

SURGEON TO THE CENTRAL LONDON OPHTHALMIC HOSPITAL

There is need for a mountaineering and industrial goggle which, while affording protection from a scientific point of view, also fulfils certain psychological and physiological requirements.

In mountaineering of the more ambitious type the tint of the glass has, at very high altitudes, a pronounced effect on the psychology—a fact which has hitherto been overlooked, and yet which may make all the difference between success and failure. The protection against ultra-violet light must be as complete as is possible and compatible with difficult and dangerous climbing in foggy conditions. A compromise must thus be attempted between what is scientifically the best protective glass and what is, from the practical point of view, the glass giving the best vision for climbing. It may be mentioned here that snow-blindness, which in certain situations is a matter of life and death, is more likely to supervene in conditions of mist and fog than in bright sunlight, for the fog, or "white darkness," due to myriads of ice particles in the air, reduces the sense of perspective and stereoscopic vision, thus increasing the difficulties under which the eyes are used. Again, the field of vision must be the fullest possible in order to eliminate any strained attitude of the head when watching the ground near the feet, and to avoid the need of frequent head movements. Finally, in both mountaineering and industrial goggles, the cost of production must be reasonable.

With these facts in view an investigation was carried out, with the assistance of Messrs. Theodore Hamblin Ltd., to provide the Everest Climbing Expedition with goggles conforming as nearly as possible to the above criteria—an investigation which also resulted in the evolution of an industrial goggle which may be adapted to any type of occupation. Not the least of the difficulties encountered in the investigation was the fact that a glass affording the best protection was either too depressing to the mentality or too expensive in production.

PROTECTIVE MEASURES AT PRESENT USED

The Eskimos, who, despite the fact that they travel only comparatively short distances and take shelter when conditions are unfavourable, are nevertheless subject to snow-blindness, use slotted wooden spectacles. These do not afford absolute protection. The Tibetans employ "tourmaline," a semi-precious stone, which blocks

* Paper read in the Section of Ophthalmology at the Annual Meeting of the British Medical Association, Dublin, 1933. (For report under Sectional Proceedings see *Journal*, August 19th, p. 347.)