CARBON DIOXIDE IN ANÆSTHESIA.

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DURING the last twenty years striking advances have been made in the study of the regulation of the respiratory mechanism. It is true that Galen in the 2nd century (A.D.) noted that section of the spinal cord at the level of the second vertebra produced death, but it was not until 1851 that Flourens definitely described the Respiratory Centre or "Nœud Vital" in the floor of the fourth ventricle just above the Calamus Scriptorius. For many years after this attention was chiefly centred upon the nervous control of respiration, but during the present century physiological investigations have largely been devoted to the study of the chemical control of respiration, and results of incalculable value, both in the explanation of phenomena during anaesthesia, and in the improvement of anaesthetic practice, have been obtained. It is now generally agreed that the chemical control of the Respiratory Centre is more important than the nervous factor, for respiration still continues after section of all afferent nerves to the centre, but ceases when the circulation through this area is stopped. It can readily be experimentally demonstrated that injection of carbon dioxide, dissolved in blood, into the carotid artery produces almost at once a marked deepening of the respirations, and a similar result is obtained if the gas be inhaled into the lungs in the human subject. Variations in the supply of oxygen have, however, no effect until a stage is reached when oxygen lack begins to show itself, which occurs when the oxygen percentage in the atmosphere falls below thirteen. Injection of lactic acid and warming of the carotid blood also produce intensification of the respiratory movements. The action of carbon dioxide on the centre is by far the most delicate, and possibly specific, entitling us to regard CO₂ as a definite respiratory hormone.
Whether the condition of the arterial blood or the special metabolism of the respiratory centre is the essential factor is as yet undecided, but from a practical point of view it is fortunately immaterial, for an increase in the CO₂ tension of the arterial blood produces a deepening of respiration, whether the action is direct or whether the increase of CO₂ tension of the blood delays the removal of the carbon dioxide produced by the centre's own metabolism.

The practical utilization of these principles in the interpretation of respiratory phenomena and their bearings on anaesthetic practice can now be briefly considered.

Every student of general anaesthesia is familiar with the so-called "automatic breathing," but how many realize its true significance, or that the whole safety and development of general anaesthesia depends upon this specific respiratory hormone. Pharmacologists tell us that the various narcotic and anaesthetic drugs depress the nerve centres in a descending sequence, and yet the action of the anaesthetic is continued until lower spinal centres, such as those which control the knee-jerk, are put out of action. The respiratory reflex action is similarly dulled, but, thanks to carbon dioxide, the activity of the respiratory centre is still preserved, and safeguards the patient when all reflexes are abolished. The so-called "automatic breathing" of anaesthesia is analogous to the physiological experiment of section of all afferent nerves to the respiratory centre, and the respiration becomes slow, deep and regular (unless anoxæmia simultaneously develops), the centre being now entirely under chemical control, all usual peripheral stimuli being cut off. In addition to this safeguard CO₂ supplies one with a delicate control over the induction, maintenance, and termination of anaesthesia, for the scientific development of which we are largely indebted to Professors Yandell Henderson and Haggard, whose valuable researches on this subject should be studied by every anaesthetist. The visit of Professor Henderson to this country, together with the lectures he has given, has served as a stimulus to this work in relation to anaesthesia, and a few practical observations by one who has for many years followed their work, and tried to put these principles into actual practice, may not be out of place at the present juncture.
The applications of this gas in anaesthesia are extremely numerous and varied, and, whilst in some instances utilization of the patient's own CO₂ may suffice, if one is to attain the maximum benefits it is advisable to have 5 per cent. of carbon dioxide added to one's oxygen cylinders. This presented an initial difficulty, but the writer succeeded in obtaining cylinders filled with this mixture nearly two years ago. It was thought that two gases having such different condensation points could not be blended, yet the satisfactory nature of the mixture can be verified by the physiological test, when intensification of breathing is readily observed. Further casual specimens taken at intervals and analyzed with a Haldane gas analysis apparatus have invariably yielded a mixture a point or two on either side of 5 per cent. CO₂. Formerly, when chloroform was extensively used for the induction stage of general anaesthesia, the patient was apt to pass into a somnolent state, associated with shallow breathing. Various devices, such as rubbing the lips, ribs, condyle of jaw, and even slapping of the face were not uncommonly resorted to. The effects produced are quite transient and insignificant unless the stimulation is severe enough to be painful, in which case struggling is often precipitated. Efficient regular breathing can easily be instituted if the nostrils be gently compressed so as to eliminate nasal breathing. This raises the partial pressure of the alveolar CO₂, and in consequence the CO₂ tension in the blood. If respiratory tracings be taken the constancy and effectiveness of the procedure is strikingly demonstrated. To the clinical observer the effect is equally pronounced. In the case of "open ether" the presence of the mask interferes with this procedure, but an exactly similar result is obtained by adopting a semi-open method (such as the three towel method) which conserves the carbon dioxide in the patient's expired air. Henderson has suggested that the CO₂ oxygen mixture might be used for this purpose, especially as Haggard states that the ether tension in the carotid blood becomes the same as that in alveolar air within a few seconds, and that in this way rapid deep ether anaesthesia might be produced. In actual practice the problem is not so simple, for during the induction stage the nervous control of the respiratory centre is still active, and the presentation of
strong ether vapour is resisted by the patient and produces undesirable reflex effects (coughing, retching, swallowing, and holding of the breath with accompanying cyanosis). It is true that if CO\(_2\) be persevered with, respiration will eventually occur, but the procedure is analogous to the old-fashioned method of choking a patient with a closed ether inhaler, and is somewhat barbarous and apt to lead to undesirable accompaniments, such as excessive secretion and swallowing of mucus. Many years ago the writer experimented with rapid ether inductions, but, although the patient could be got deeply under in two to three minutes, adequate muscular relaxation did not occur any earlier than with more gradual methods. Ideal induction must still depend on judicious utilization of the patient’s own carbon dioxide, combined with the practical skill of the administrator in coaxing the patient not to resist the presentation of a gradually increasing strength of ether vapour. At the end of the induction period, if the patient is not quite deep enough the CO\(_2\) oxygen mixture bubbled through the ether bottle of a Shipway’s appartaus will rapidly deepen the anaesthesia and produce effective relaxation. It is now generally recognized that the excessive ventilation of the open ether method leads to washing out of carbon dioxide and to the production of acapnia with its associated undesirable effects, and most anaesthetists adopt some method of conservation of carbon dioxide under these circumstances, either by covering up the open mask or by resorting to a certain amount of re-breathing with a closed bag. The limitation of oxygen consequent upon this is corrected by the delivery of Oxygen-ether mixture underneath the mask. Personally conducted analyses of the gases under a Schimmelbusch mask under these conditions revealed—

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\text{CO}_2 \text{ 6—8 per cent. Oxygen 23—28 per cent.}
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As far back as 1907 I noticed that the old Clover ether inhaler was a most effective method of dealing with surgical shock, and christened the instrument “the Shock Absorber,” and the work of Henderson and Haldane has disclosed the reason of its effectiveness. Apart from all theoretical considerations the value of re-breathing is strikingly evident clinically in cases of shock and severe hæmorrhage.

Another class of case in which the mixture is extremely
valuable is in upper abdominal surgery, especially in extensive operations on the bile-passages. Many factors combine to render the anaesthetist’s task a difficult one. The presence of a metal bridge under the lower thorax fixes the chest in a partial inspiratory position, and prevents its full expansion. Observations were made with a Douglas bag with a view to testing the pulmonary ventilation under these conditions. A reduction of 30—40 per cent, in the output of the lungs was recorded, clearly demonstrating the serious embarrassment to breathing which this surgical posture produces. Further deep anaesthesia is required, and at such a depth respiration is almost entirely abdominal. The respiratory centre is rendered less sensitive by deep anaesthesia, and the traction exerted by the surgeon and his assistant embarrasses this sole respiratory movement. It is extremely difficult to get the anaesthetic into the patient, and inhibition of breathing is prone to occur. Under such conditions I have found the mixture invaluable, especially in combination with a Shipway ether bottle. Not infrequently stoppage of respiration occurs for a minute or two when the gall-bladder is pulled upon, although the circulation remains in good condition. If this inhibition takes place the mixture should be delivered directly into an oral tube in the patient’s mouth. In the absence of the mixture a similar result is obtainable by blowing down a yard of rubber tubing inserted into the oral tube, and this is also a most effective method of conducting artificial respiration. I have christened it the Biblical Method as it is really a modern application of the method of mouth to mouth insufflation used by Elijah in restoring the widow’s son to life (I. Kings, ch. 17, v. 21) and later by Elisha in raising from the dead the good Shunammite’s son (2 Kings, ch. 4, v. 32—35). The latter description being much more detailed. We have also tested the procedure in animals overdosed with ether until respiration was definitely stopped for some time and a marked fall of blood pressure produced, and found it to be highly effective. Overdose in cases of rectal etherization can also be effectively combated by the above methods.

In nearly all the above instances the effects can to a large extent be obtained by accumulating the carbon dioxide in the patient’s expired air, but there is one case in which the CO₂
Carbon Dioxide in Anaesthesia

oxygen mixture is of supreme advantage. I refer to the process of de-narcotization, in which case, if we try to utilize the patient's own carbon dioxide, we are also retaining the ether excreted in the breath and so neutralizing the process. All general anaesthetics are toxic agents in varying degrees and prone to produce undesirable after-effects on the patient. It is therefore advantageous to effect their elimination the moment their work is completed. Henderson and Haggard have investigated the rate of excretion of ether after general anaesthesia and provided us with accurate data on this subject. They found that half the total ether in the body was eliminated in the first half hour after the administration is stopped. Half the remainder is excreted during the next one to two hours, but complete elimination does not occur until one to two days. If it is possible to accelerate this process undesirable after-effects can be greatly reduced or completely avoided. Now, if 5—6 per cent. CO₂ be added to the oxygen pulmonary ventilation is increased two, three or four times. The writer has tested these experimental observations in actual clinical practice during the last two years with most gratifying results, both to himself and the patients concerned. The apparatus required consists of one's ordinary gas-bag with stopcock and face-piece. The gas-bag is connected by rubber tubing to a cylinder of oxygen containing 5—6 per cent. carbon dioxide. The cylinders are distinguished from ordinary oxygen cylinders by their having a white star painted on them just above the middle of the body. Observations were chiefly made on severe abdominal cases and cases which had exhibited bad after-effects in previous anaesthesias. The face-piece is applied when facile suture of the peritoneum is assured. In a few moments the breathing will become vigorous and blowing, and the corneal reflex will become brisk, even if it were completely absent at the commencement of the application. About the time of insertion of the last suture slight movement may occur, and the patient will usually open the eyes when ordered to do so before leaving the theatre, though they will have no conscious recollection of it. With returning consciousness morphine, if it has not been previously administered, may be given for post-operative pain. This drug, if injected before the anaesthetic is excreted, doubles the period of
elimination. The application can, if necessary, be continued after the patient has returned to bed, but actually it has not proved necessary. In the case of young children it has been thought desirable to avoid a valved system, and the mixture is delivered beneath an ordinary open mask devoid of anaesthetic. The chief benefits constantly observed are rapid recovery of the patient and absence of post-anaesthetic sickness. Prevention of shock, raising of lowered blood pressure, and steadying of the pulse. Lessening of gas pains and diminished liability to intestinal paresis. In this connection it should be remembered that diminished peristalsis after abdominal operations is largely due to draining off of carbon dioxide from the exposed viscera. The striking effect of CO₂ in causing intestinal contractions has been clearly demonstrated in animals, and the giving of the above mixture might with advantage be resorted to in cases of post-operative intestinal paresis. After-toxæmia is enormously reduced in acute septic abdominal cases. The liability to post-operative bronchitis and pneumonia is greatly diminished. In one instance a two stage operation was performed on a very unfavourable subject, naturally prone to a weak chest. The first stage consisted of colostomy, and was conducted by ordinary methods. The patient was fairly ill after the operation and developed a bad chest. The second stage was undertaken about a fortnight later with some trepidation. It consisted of perineal excision of the rectum, and lasted about one and three-quarter hours. De-narcotization was employed, and the patient made a good recovery free from shock and chest complications. Rapid elimination by this method is very valuable in dental cases requiring ether, as it ensures rapid recovery and speedy return of the patient home. Yandell Henderson has drawn attention to the efficiency of the procedure in cases of gas poisoning and acute alcoholic intoxication, and the services of anæsthetists might with advantage be requisitioned on these occasions, as possessing the necessary apparatus and experience in its use.

Finally, I would urge all anaesthetists to study and put to practical use this valuable respiratory hormone, which gives them delicate control over the period of anaesthesia and a means of eliminating many of its distressing after-effects.