Nitrous oxide given with 21 per cent of oxygen is a very safe non-toxic, non-inflammable, and non-irritant anaesthetic agent. Recovery from it is almost immediate. In fact the only drawback to nitrous oxide is its lack of potency, which is only about 15 per cent as compared with the 100 per cent of ether (Guedel, 1945).

Why, then, is this agent, which is claimed to be the ideal anaesthetic (Seevers and Waters, 1941), not in general use in cases where its potency is sufficiently great. According to Guedel (1945) nitrous oxide can carry the anaesthesia to a depth which will allow practically every operation apart from laparotomies and pelvic operations to be performed, and this, it is stated, without reducing the oxygen in the anaesthetic mixture to below the normal metabolic requirements. Nevertheless, nitrous oxide is a weak anaesthetic, and failure in the technique of its administration may easily result in an anaesthesia which is not deep enough to allow any operation at all to be performed.

In fact, to obtain the optimum results whenever nitrous oxide is the anaesthetic agent, every precaution must be taken to ensure the highest possible partial pressure of the gas in the lungs. Seemingly, omitting to fulfil this requirement is one of the main reasons for failure encountered with nitrous oxide, and this paper deals with considerations of how to obtain the highest possible partial pressure of nitrous oxide...
oxide in the alveoli without reducing the amount of oxygen delivered to the patient.

When anaesthetizing with the potent anaesthetics, a higher concentration of the anaesthetic is required to hasten the induction than later during maintenance. In fact quite frequently concentrations are used initially which, if continued for a longer time, would kill the patient. When the desired depth of anaesthesia is obtained, then the concentration obviously has to be reduced to safer proportions. As nitrous oxide is such a weak anaesthetic, this usual procedure must be modified. The highest possible partial pressure which is obtainable can be used throughout, because anaesthesia with nitrous oxide can never be too deep, provided it is accompanied by the same amount of oxygen, as was available to the patient from the ambient atmosphere*. On the other hand, nothing is gained by keeping the patient in a lighter anaesthesia than nitrous oxide can accomplish, because the gas has no side effects either on the tissues or on the normal physiology of the patient. The one and only aim of a nitrous oxide technique is thus simple, viz. to produce in every case the highest possible partial pressure of the gas in the lungs and, for practical reasons, to accomplish this as fast as possible.

EFFECT OF REBREATHEING AND DEAD SPACE

Let us first consider the importance of the gas percentage in the mixture delivered vis-a-vis the partial pressure of the gas actually inhaled at the mouth. When there is any rebreathing at all in the anaesthetic system, the inhaled mixture will only be of the same composition as the mixture delivered from the machine, if the gases are exhaled in the same proportions, i.e. with the same partial pressures as they

* It is assumed that this was enough to ensure full oxygenation before the patient was anaesthetized, and that conditions have not changed during the anaesthetic procedure.
Rationalized Nitrous Oxide–Oxygen Anaesthesia are delivered from the machine. In practice this means that no rebreathing at all can be permitted, because the exhaled gases must always have different partial pressures from those inhaled; oxygen is always used, and, even after saturation of the tissues with nitrous oxide, the partial pressure of the latter in the lungs will never reach that of the 79 per cent concentration we can allow the patient to inhale. This applies to a semi-closed system. In theory, if we were able to administer nitrous oxide in a closed system, we could add oxygen according to its consumption for metabolic requirements, and nitrous oxide, as much as is necessary for maintenance of anaesthesia. In practice, however, it is well known that this is almost impossible because of the fine control required for the addition of these gases. A variation of the supply of one of the two gases by a few cubic centimetres will change the state of the patient perhaps from hypoxia to inadequate anaesthesia. As a result of these considerations we were led to try and decrease, and even avoid, rebreathing as far as possible.

All rebreathing can be eliminated, of course, by employing an intermittent flow machine which, if no bag is interposed in the system after the gas mixture has left the mixing chamber, acts as a non-rebreathing system per se. Also, however, it is possible to ensure no rebreathing with a continuous flow system; the important factor here governing the amount of rebreathing is the ratio of the flow from the machine to the patient’s minute volume (Macintosh and Mushin, 1947). Only if the total flow exceeds the respiratory volume per minute will there be a possibility of avoiding rebreathing, that is if the back-flow is not great enough to enter the bag (Molyneux and Pask, 1951). In most arrangements this is, however, impossible. Using the bag-and-mask set-up, it is quite impossible to avoid all rebreathing. This can be easily and practically demonstrated by interposing
an absorber, as in the Waters absorption to-and-fro method. Even with flows very much in excess of the respiratory minute volume, the canister becomes warm, indicating that there is CO\textsubscript{2} in the system, and implying some degree of rebreathing.

Rebreathing will entail, incidentally, not only a lowering of the nitrous oxide concentration, but also a lowering of the partial pressure of oxygen when giving 79 per cent nitrous oxide.

To be sure of avoiding all rebreathing with a continuous flow it is necessary to interpose a non-rebreathing valve, as close as possible to the mouth. This arrangement, in addition to avoiding rebreathing, permits the rapid elimination of nitrogen. It has not all the advantages of a true intermittent flow machine, e.g. economy and breath to breath control of the composition of gas inhaled (Clement, 1951). However, in practice we do not require to change the mixture being administered and intend to maintain it at 79 per cent nitrous oxide and 21 per cent oxygen throughout.

The next factor resulting in rebreathing is the dead space, which is made up of dead space due to the anaesthetic system, and the physiological dead space. It is not possible to avoid this factor altogether, but the dead space should be as small as possible. This means, amongst other things, that the smallest possible masks should be used. It may, for example, be preferable to substitute a nasal mask for the face mask, for in doing this we are reducing the volume of the mask and also by-passing the mouth, thus producing some decrease in the physiological dead space, which helps further to decrease the total dead space. The same applies to the use of endotracheal intubation, where the tube is connected directly to the machine. If the arrangement is correct (that is, the tube is connected directly to the non-rebreathing valve) there will be almost complete
elimination of the mechanical dead space. Reducing the physiological dead space in this way will actually result in an increased oxygen tension in the patient's lungs, though the oxygen flow is kept the same as before the intubation. For example, with a decrease in the physiological dead space from say 150 to 100 ml., then the effective tidal volume will be increased from about 70 per cent to 80 per cent (namely from 350 to 400 ml.). In other words, though the actual flow still only contains 21 per cent oxygen, the patient is now offered the same intrapulmonary tension of oxygen as would be given by more than 23.5 per cent in the flow from the machine when the dead space has not been so reduced.

It may be concluded from the above discussion, that we will never be able to exceed or even reach the partial pressure of nitrous oxide which is delivered from the machine, but if we want to get as close as possible, then it is of importance to avoid any rebreathing in the system, and to try and avoid unnecessary dead space, lest the optimum possible nitrous oxide tension which is attainable be forfeited.

**EFFECT OF LEAKAGE IN THE SYSTEM**

A contamination of the nitrous oxide-oxygen mixture with the ambient air can only result in a reduction of the concentration of the gases in the system. It is therefore obvious that an airtight system in direction outwards-inwards must be guaranteed, the only leak allowed being at the expiratory valve. This also applies to the intubated patient as far as the space between the tube and the tracheal wall is concerned. If a leak here is permitted, then whether the patient is breathing by his own effort or being ventilated with positive pressure, air may enter the circuit and a diminution of the partial pressure of nitrous oxide
will follow. If, for example, a leak as small as 1 mm. is allowed all round a tube with a diameter of 2.4 cm., then calculation will show that almost 20 per cent of the inhaled gas mixture may be drawn in around the tube. A flow containing 79 per cent nitrous oxide may thus be no more effective than a 63 per cent flow of nitrous oxide in an airtight system.

EFFECT OF INCREASED PULMONARY VENTILATION, CONTROLLED RESPIRATION AND BAROMETRIC PRESSURE

Up till now we have discussed how to get the highest possible percentage of the anaesthetic gas to enter the patient's respiratory system. Our next purpose is to get this highest possible concentration transmitted to the alveolar air. The patient will do this by breathing spontaneously and, with every respiration, will mix a certain amount of nitrous oxide (as well as oxygen) with the alveolar air. How long it will be before equilibrium is reached between the alveolar air and the mixture inspired will depend partly on the relationship between the alveolar respiratory minute volume and the capacity of the lung, and partly on how fast the nitrous oxide is carried away (absorbed into the blood) from the lungs. A big respiratory volume compared with the capacity of the lung will favour a rapidly established equilibrium.

Practically we are able to influence this process by asking the patient to breathe as quickly and especially as deeply as possible and not, as so commonly practised, by asking the patient to breathe quietly. Because nitrous oxide is non-irritant and the mixture contains 21 per cent oxygen, this hyperventilation is not resented by the patient. Sometimes a patient will overventilate, and acapnoea may result. In this case controlled respiration with big excursions is easily instituted. Assisted or controlled respiration when the
patient is asleep, seems to be a convenient way of hastening the establishment of equilibrium.

When equilibrium between the gases inhaled, the alveolar air and the body tissues is obtained there will be no need to continue further the hyperpnea but, of course, an air-tight system has to be maintained throughout the anesthesia.

Quite apart from its use during induction controlled respiration seems to potentiate the effect of a given partial pressure of the anesthetic gas. It is not finally certain why this should be so. An important factor may be that controlled respiration, even when performed properly, will always result in a mean intrathoracic pressure above atmospheric, which will result in an increased partial pressure of the inhaled gases. As it is the partial pressure of a gas, and not the actual percentage, that determines its absorption and therefore the depth of anesthesia it produces (Faulconer et al., 1949) this rise, though small, may play a part in the increase of depth of anesthesia during controlled respiration.

The normal changes in the atmospheric pressure influence the partial pressure of the inhaled gases, and thus the depth of anesthesia obtained with a fixed percentage delivered from the machine. The significance of this factor is evident from the quite simple calculation which shows that an increase of the atmospheric pressure from 760 to 790 mm. Hg increases the nitrous oxide pressure in a 79 per cent mixture from 600 to 624 mm. Hg, which means that the effect will be equal to that of a mixture containing 83 per cent nitrous oxide at 760 mm. Hg. Calculations likewise shows that a decrease in atmospheric pressure to 730 mm. Hg lowers the effect, so that it corresponds to only 75 per cent nitrous oxide. While these changes in the partial pressure mean nothing with the more potent anesthetics, they may combine with the other points mentioned to make
the anaesthesia more or less adequate when nitrous oxide is employed. It is therefore not only because of the feeling of wellbeing during fine weather, that it seems easier to give a good nitrous oxide anaesthesia!

In summary, it may be emphasised that because nitrous oxide is a weak anaesthetic, special attention must be paid to avoid lowering of the administered gas tension or, expressed slightly differently, unless all possible pressure increments are made use of to give the highest possible total pressure, the use of nitrous oxide is bound to be disappointing, or supplementation with depressants is apt to be greater than otherwise necessary.

**USE OF 1 LITRE FLOWS OF NITROUS OXIDE AND OXYGEN IN A SEMI-CLOSED CIRCUIT**

In contrast to the above condition let us discuss in terms of nitrous oxide partial pressures the result of administering 1 litre of nitrous oxide and 1 litre of oxygen per minute during anaesthesia induced by other means, for example with thiopentone and curare. This mixture is selected because of the contemporary popularity of such a technique.

The highest possible partial pressure of nitrous oxide in the lungs ever obtainable with this mixture at atmospheric pressure will be 50 per cent of the available pressure (normally 760 mm. Hg) less the alveolar partial pressures of carbon dioxide and water vapour. This gives a maximum possible nitrous oxide pressure of less than 335 mm. Hg as compared with the 535 mm. Hg with 79 per cent nitrous oxide in the flow. Apart from this relatively low nitrous oxide tension, the time taken to eliminate nitrogen will be prolonged as a result of the rebreathing, and consequently the establishment of maximal blood concentration with nitrous oxide will take longer. The percentage of oxygen actually inspired into the lungs will be lower than that
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administered because of the rebreathing, but as equilibrium is approached the partial pressure of oxygen will rise towards that in the mixture being given. Unless hypoxia exists initially there is, however, no evidence to show that more than the normal 21 per cent of oxygen is beneficial (Comroe and Dripps, 1950); therefore, if the comparatively low nitrous oxide tension resulting from this technique means that it is necessary to administer larger doses of central depressants or muscle relaxants than otherwise necessary, it seems irrational to give an oxygen per cent higher than 21.

The term “otherwise necessary” in the preceding discussion is deliberately chosen because, although the technique which has been discussed above achieves the highest possible nitrous oxide tension with any given mixture, it will be impossible in most cases to keep the patient quiet even during those operative procedures which, according to Guedel (1945), can be performed under very light anaesthesia. If the common opinion is valid that flexible anaesthesia is preferable to non-flexible, and an “anaesthetic” with the fewest possible side effects should be used, then it seems rational to let the nitrous oxide play the biggest possible role in techniques combining the use of nitrous oxide and supplements.

A drawback to the nitrous oxide technique proposed here is that the high flow of nitrous oxide increases the gas expenses. With a total flow of about 12 litres per minute, the cost of the gases will be about 10 shillings per hour (calculated in accordance with the price of gases in Denmark). On the other hand, as no rebreathing is allowed at all, the expenses for sodalime are nil, and also those for supplementary agents will be reduced.
POSTSCRIPT

It is an exhilarating thought that if a mixture containing 21 per cent of oxygen and 79 per cent of nitrous oxide is the only one used, then the anæsthetic machine will be a cylinder containing this mixture of gases, a reducing valve, and a flow-regulator. A bag, a non-rebreathing valve, a mask and a syringe or two will complete the anæsthetic equipment.

REFERENCES


