A RESTATEMENT OF ANAESTHETIC PRINCIPLES

BY

JAMES PARKHOUSE
Nuffield Department of Anaesthetics, University of Oxford
AND
B. R. SIMPSON
Surgical Research Assistant, University of Oxford

For some twenty years prior to the introduction of the muscle relaxant drugs, the development of anaesthesia was characterized by increasing complexity of technique and apparatus. To ensure the best possible operating conditions for the surgeon, together with the least toxic combination of drugs for the patient, the anaesthetist had to be highly versatile. The scope of anaesthesia was being extended in many directions, and often the facilities for accurate physiological measurement in the operating theatre were not available. Under these conditions, it was often an "advance" to provide an anaesthetic method which would enable the operation to be completed without inflicting too much harm on the patient.

Since the introduction of the muscle relaxant drugs, several moves have been made towards a resimplification of clinical anaesthesia (Nowsorthy, 1953; Macintosh, 1955). Many of the more difficult, time-consuming and elaborate techniques have been relegated to positions of comparative insignificance. At the same time, many of the skills necessary to the anaesthetist of a previous generation have been rendered superfluous by the facility with which the difficult procedures of the past can now be bypassed. Furthermore, whereas the anaesthetist formerly had to choose which of several potentially toxic combinations of drugs would be the most suitable to a particular patient or for a particular operation, the anaesthetist is today in the position of being able to use combinations of drugs in dosages which are virtually innocuous to the patient whatever his condition may be, or whatever operation it is proposed to undertake. It is not surprising, therefore, that many of the classical indications for choice of a particular anaesthetic technique have ceased to exist.

Although this resimplification of anaesthesia has effected considerable changes, with evident benefit to the patient, many of our current practices still represent a hangover from the past. Anaesthesia has made great progress, and the time has now come to consider how much of our inheritance is superfluous, outdated, and needlessly unscientific. Having done this, it should be possible to envisage the essential requirements for safety and up-to-date usefulness. From this basis, by adding such refinements as are dictated by circumstance, it should be possible to develop a simple concept of anaesthesia which would eliminate most of the uncertainty and superstition that have grown up in the past.

CHOICE OF TECHNIQUE

This difficult problem has been discussed previously, and the pitfalls involved in the application of statistical conclusions to individual cases have been stressed (Parkhouse, 1957). A study of anaesthetic practice in different centres shows quite clearly how little general agreement there is concerning the value of different methods. In the United States, the Magill semi-closed system (the traditional "top circuit" of the Boyle machine) is almost unused. In most places a circle system is employed for every case, respiration being assisted or controlled whenever an indication is felt to exist. It is perhaps pertinent at this point to mention the popular belief that a closed circuit is essential for thoracic anaesthesia; even the latest edition of a well-known book perpetuates this myth (Beecher, 1958). As long as the patient's respiration is controlled, the closed system offers no possible advantages over the nonreturn. The latter, in fact, offers attractions which will be further referred to below.
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Ayre's T-piece is another example of the empiricism which surrounds the question of anaesthetic method. When first introduced, this purported to be one of the simplest means of anaesthetic maintenance, and yet it has proved to have mathematical and physical characteristics which defy all attempts at calculation. Despite many variations of the T-piece, speculation still runs high as to what flowrate of gases is required relative to any particular length of tubing, in order to ensure adequate elimination of carbon dioxide. In clinical practice, the claims made for the T-piece still result from supposition rather than fact. In the field of neurosurgical anaesthesia, for example, some skilled and experienced anaesthetists favour the T-piece, while others use the so-called semi-closed system. It is unlikely that most enthusiasts could produce a single piece of factual evidence for or against the method of their choice; their cases do equally well.

Neurosurgical anaesthesia has long been a stronghold against controlled respiration. For years we have been told that intermittent positive pressure ventilation during neurosurgical anaesthesia will raise the cerebrospinal fluid pressure, increase bleeding and hamper the work of the surgeon. Here again the statements have been the result of guesswork rather than investigation, and there is now good reason to believe that the opposite is true (Galloon, 1959; Mortimer, 1959). Many other examples could be given where the anaesthetist's choice is determined merely by habit, prejudice or pseudoscientific speculation. Enough has already been said, though, to bring out the point that the accepted indications for particular anaesthetic methods have little scientific backing, and have never been brought into line with the changing outlook of modern anaesthesia.

SHORTCOMINGS OF TECHNIQUE

Whichever of the conventional closed or semi-closed methods is finally selected, it will suffer from the disadvantage of not having been designed to facilitate measurement. The composition of the inspired gas mixture, for example, is usually unknown. Although it may be possible by the use of complex scientific apparatus to collect valid gas samples and discover retrospectively what the patient was breathing, and although it may be diverting for the mathematical physicist to relate these practical discoveries to his theoretical calculated values, such procedures are always likely to be outside the scope of the practising anaesthetist. In any case, the introduction of a non-return valve obviates the necessity for such measurements and calculations. Again, practically none of the apparatus in current use has provision for the quantitative administration of anaesthetic vapours. It is deplorable that after more than 100 years of anaesthetic progress, fatalities can still occur because the patient "probably" or "almost certainly" received a dangerously high concentration of a volatile agent. These concentrations should be known (Edwards et al., 1956).

Several other sources of error exist. There are numerous points at which a complex anaesthetic circuit can leak. The conventional shape of the anaesthetic bag makes for difficulty in measuring tidal volume. When the bag is squeezed about its middle, some of the content is expelled towards the patient while an unknown amount passes back into the distal end of the bag which becomes more distended. The corrugated anaesthetic tubing in common use is also distensible, and adds further to the difficulty of knowing how much gas reaches the patient's lungs (Dobkin, 1958). The use of the "near-closed" circuit, or "spill-over" technique, in which the patient is ventilated through a circle system with a Heidbrink valve left partially open, introduces a further uncertainty. With this method it is impossible to tell how much gas passes into the patient and how much spills out into the operating theatre. Should the compliance of the lungs suddenly change as a result of the surgeon's manipulations, it may well be some time before this alteration is adequately appreciated by the anaesthetist, since when he now squeezes the bag the only change is that a little less gas passes to the patient and a little more out of the valve. All these factors combine to make the estimation of tidal and minute volume so difficult that most clinical anaesthetists do not know within very wide limits what gas volume they are delivering to the patient. There is much glib talk of hyperventilation and hypoventilation, and much discussion of blood CO₂ levels, but little reliable data from which cause and effect can be correlated.

When these facts are considered, we may well pause to ask whether it is worth while burdening...
the minds of juniors with so many different cir-
cuits and arrangements, when one would suffice. We might go further, and ask ourselves whether it is worth our own while concerning ourselves so much with the applicability and efficiency of various different methods of anaesthesia, when we could more profitably be devoting our attention to the patient's welfare. When one is thoroughly conversant with a single method, and has used it many thousands of times, it becomes second nature to use it competently and effectively. Changes in the patient's condition are then far more readily appreciated.

THE CHOICE OF DRUG
Pride of place must be given among the anaesthetic agents, as far as current practice in this country is concerned, to nitrous oxide. Nitrous oxide has long been recognized as a nontoxic agent, and since the introduction of the muscle relaxants it has come into its own because its relative lack of potency is no longer a serious disadvantage. Ether, on the other hand, has an evil reputation as far as toxicity is concerned, and this is largely attributable to the fact that in the days when muscle relaxants were not available, ether was the drug principally used when deep anaesthesia was required. All anaesthetic agents are toxic when used to produce deep anaesthesia, and it is unreasonable that the reputation of ether in this respect should be allowed to persist. In fact, when 2—4 per cent of ether vapour is adminis-
tered to a patient, he will be awake and talking at the end of the operation just as if he had been given nitrous oxide, and recent carefully controlled studies (Dobkin, 1959) tend to support the commonsense view that all anaesthetic agents are equally harmless in equipotent small doses. When muscle relaxants are available, so that the quantities of general anaesthetic can be kept to a minimum, it is probably of rather small significance which agent is chosen. In these circumstances one of the most important considerations is ease of administration, and in this respect nitrous oxide is at a grave disadvantage.

The use of medical gases, which have to be specially prepared, purified and dried, presents many problems, particularly in remote countries. It is not suggested that we should modify our anaesthetic techniques merely because people in other parts of the world do not enjoy all the opportunities we do, but quite apart from this it seems needless to resort to using artificial mixtures of gases when nature has provided us with an atmosphere containing enough oxygen for our requirements. The use of cylinders in the operating theatre involves the anaesthetist in a constant vigil to ensure that the gases do not become exhausted. When a cylinder does have to be changed, this involves an interruption in his administration of the anaesthetic, it involves noise which may be disturbing to the surgeon, and it may even necessitate the anaesthetist leaving the operating theatre in order to bring in a fresh supply. When the full cylinder is brought in, possibly from the hospital backyard, it may be covered with dust and dirt. Apart from bulkiness and weight, gas cylinders add tremendously to the size and complexity of our anaesthetic apparatus by necessitating the use of reducing valves, flow-
meters, and other paraphernalia.

The use of artificial gas mixtures for anaesthetic maintenance involves a complete alteration of the gaseous physiology of the body. The necessity for denitrogenation before effective nitrous oxide anaesthesia is well known, and some anaesthetists now add as a further requisite, pre-oxygenation. At the end of the operation, nitrous oxide has to be eliminated, with the possibility of diffusion anoxia (Fink, 1955). This type of alteration of the patient's basic physiology introduces unnecessary complications, since it is perfectly feasible to maintain anaesthesia with air. This situation is rather analogous to the problem of maintaining the electrolyte and nutritional balance of the patient by means of intravenously administered fluids. The introduction of sodium chloride infusion was a major advance in therapy, but when the additional problems concerned with the metabolism of other electrolytes, and with the maintenance of body weight and full dietary re-
quirements are taken into consideration, it becomes extremely difficult to provide an adequate long-term alternative to natural feeding. Although remarkable therapeutic triumphs have been achieved, most physicians still agree that the best thing for a patient is to re-establish normal feeding by mouth at the earliest possible moment. In passing, it should be pointed out that by inter-
fering with the standard physiological methods of
gas analysis, the use of nitrous oxide has stood in the way of certain aspects of anaesthetic research for many years.

PRESENT-DAY REQUIREMENTS

Although it has been suggested that inhalational anaesthetic agents are destined to lose their place in the future (Armstrong Davison, 1958), they still offer considerable advantages. The non-reactive nature of these agents, together with the ease with which minute-to-minute adjustments can be made in the concentrations delivered to the patient, make for a degree of versatility which is unique, and most anaesthetists would agree that an anaesthetic apparatus without provision for delivering such agents to the patient would be, to say the least, incomplete. However, unless the apparatus for administering these agents is capable of delivering known and consistent concentrations, something much less than perfection has been achieved. Simple and reliable quantitative inhalers are currently available. Since the original description of the E.M.O. inhaler (Epstein and Macintosh, 1956), this apparatus has been modified and calibrated for use with trichloroethylene, halothane, and the halothane-diethyl ether azeotropic mixture, so that any of these agents can be administered quantitatively. Calibration is also possible for any other agent which may come into use. Such inhalers enable room air to be drawn over the selected volatile agent, so that known concentrations of its vapour in air are delivered to the patient. This is the simplest, most logical, and most reliable method of administering an anaesthetic. It is a method which has been in constant use in the Nuffield Department of Anaesthetics for many years, and has given complete satisfaction in many thousands of cases. More recently, other workers have begun to think along the same lines, and have designed apparatus of their own (Nandrup, 1959; Lancet, 1959).

A reliable means of inflating the patient's lungs must be available, and such an appliance can be used in conjunction with the inhaler. The Oxford Inflating Bellows (Macintosh, 1953) was designed for this purpose, and since then Ruben has described a self-filling bag which fulfills the same function by drawing air into itself through a nonreturn valve system. Each of these pieces of equipment is very satisfactory, although a bellows offers certain advantages over a bag. Firstly, it can rather more conveniently be connected to an inhaler. Secondly, its shape enables a more accurate estimation of the tidal volume to be made. Thirdly, by virtue of its relatively inelastic characteristics, the bellows makes it easy to appreciate small changes in resistance to ventilation. A further advantage is that the bellows can very simply be mechanized, as in the well-known Radcliffe series of pumps, to make a mechanical respirator (Russell et al., 1956). Provision is also made, both on the bellows and on the Ruben bag, for the addition of extra oxygen should this be deemed necessary.

The anaesthetic apparatus can now be completed by adding a piece of wide-bored tubing (preferably nondistensible) leading to the patient. Since a nonreturn valve is incorporated in the bellows, a standard expiratory valve at the face mask or endotracheal tube connector will ensure that the patient inspires the mixture that is delivered from the inhaler, and that all his expirations pass into the operating theatre. For controlled respiration, the standard expiratory valve may be replaced by an inflating valve such as the one described by Mitchell (1959). Alternatively, the nonreturn valve of the bellows unit may be immobilized by means of the magnet provided, and a Ruben valve may be used at the face instead. In this way a simple nonreturn system is provided whether the patient's respiration is spontaneous or controlled. This complete anaesthetic arrangement is not only simple and easily portable, but is applicable to all the circumstances of clinical practice. It offers a single reliable arrangement which can be used for every case, comprising the minimum number of mechanical appliances that can give trouble, and offering the anaesthetist the least possible distraction from his patient. When the inhaler and the bellows have been used sufficiently often for confidence to be acquired the advantages of consistent reliability become apparent to the anaesthetist.

One further addition to the equipment outlined, which might be regarded as a kind of "optional extra", is a dry gas clock which can be connected by means of a piece of corrugated tubing to the expiratory side of the Ruben valve.
With this addition, it becomes a simple matter for the anaesthetist to monitor the patient's ventilation.

**ADVANTAGES OF AIR**

Apart from dispensing with cylinders, reducing valves, flowmeters and humidifiers, the use of atmospheric air as a vehicle for inhaled vapours offers positive advantages both to the patient and the administrator. However, anaesthesia has become such a sophisticated specialty that any suggestion that air, without additional oxygen, is adequate for anaesthetic maintenance is liable to be greeted with suspicion and frank disbelief. With the liquid anaesthetics in common use, the quantity of vapour required for the maintenance of light anaesthesia makes only an insignificant difference to the percentage of oxygen in the inspired air, and an unconscious patient immobile on the operating table can be fully oxygenated with this mixture. Although it has been suggested (Cullen et al., 1956) that under anaesthesia ventilation must be two or three times the normal resting volume in order to ensure adequate clearance of carbon dioxide, this is manifestly untrue. It is a well-established fact that completely paralyzed patients can be maintained on intermittent positive pressure ventilation with air alone for many months without adverse effects. Such patients, in fact, invariably show low CO₂ levels even if only moderately hyperventilated. In clinical anaesthesia, anoxia rarely occurs as an isolated event. It is commonly due to inadequate ventilation, the result of either respiratory depression or respiratory obstruction, and it is consequently associated with carbon dioxide retention. If a patient is breathing room air and is not ventilating his lungs adequately, cyanosis results, and recent studies have suggested (Scurr, 1956) that this cyanosis becomes evident at a time when the blood level of carbon dioxide is approximately twice the normal. Such a carbon dioxide level will not result in serious harm, and with the warning of cyanosis, the anaesthetist's attention is drawn to the necessity for increasing ventilation by some means or other. If the patient is breathing an oxygen-rich mixture, it is an appreciable time before cyanosis becomes manifest, and this may lull the anaesthetist into a false sense of the patient's wellbeing. If the patient were to turn bright green when his blood carbon dioxide level rose to, say, 80 mm Hg, anaesthetists would be just as alarmed at this phenomenon as they now are by cyanosis, and they would feel equally obliged to take brisk action. The accurate determination of blood carbon dioxide levels is a complicated, time-consuming and suspiciously inaccurate procedure, and yet the routine employment of high oxygen concentrations in anaesthetic practice is the very reason why such measurements are essential. Indeed, much of the exaggerated importance that has been attached to carbon dioxide tensions in recent years has been a result of the fact that with conventional anaesthetic methods these tensions represent one of the very few indices of the adequacy of ventilation. Whenever arterial oxygen saturation measurements have been made on patients ventilated with air they have proved to be within normal limits, and a recent study (Nandrup, 1959) reveals that adequate ventilation with light ether and room air results in oxygen saturations equal to or higher than normal. It need hardly be added that air offers a uniquely constant composition mixture of gases already humidified to such a degree that prolonged administration is possible, even through a nonreturn system, without fear of detriment to the patient's lungs.

In thoracic anaesthesia, one's first instinct is to add oxygen to the inspired mixture in view of the fact that the lung is partially collapsed and may be retracted out of the surgeon's way. Once again, however, the problem is not exclusively one of anoxia, but of carbon dioxide retention as well, and the answer lies not so much in the addition of oxygen as in the institution of adequate ventilation. In any event, at least in the lateral position, much of the pulmonary blood flow passes through the dependent lung and, furthermore, blood passing through unventilated areas of lung will not be oxygenated even if the patient is inflated with pure oxygen. It is not intended to imply that there are no circumstances under which oxygen should be added to the inspired mixture, but it is worthy of note that Continental workers have observed that during thoracic anaesthesia a switch from open ventilation with air to closed circuit ventilation with oxygen produces no noticeable difference in the blood oxygen saturation (Poppelbaum, 1959).
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THE ADVANTAGES OF THE NONRETURN SYSTEM
Some advantages of this type of system have been referred to already. It recommends itself because of its inherent simplicity, and because it frees the anaesthetist from dependence on soda lime and elaborate apparatus. It ensures that the patient receives a fresh supply of gases with each inspiration, and that the composition of the inspired gas mixture is accurately known.

Quite apart from these advantages, a nonreturn system has a distinct appeal on purely hygienic grounds. Whatever may be said about the self-sterilizing qualities of anaesthetic tubing, and however many negative bacteriological reports may have been obtained, there still remains something inherently distasteful in the thought of inhaling from tubing through which a previous patient has coughed. If the anaesthetist himself were invited to take a few deep breaths from a piece of anaesthetic tubing which a chronic bronchitic patient had just sprayed with particles of sputum it might be brought home to him that present standards of anaesthetic cleanliness are not all that they might be. Most anaesthetists engaged in thoracic work are in the habit of boiling or otherwise sterilizing their anaesthetic tubing after a tuberculous patient has been anaesthetized. This speaks for itself, and the confinement of this practice to those patients known to be tuberculous is a half-hearted gesture in view of the fact that many other cases are undiagnosed, and that there are, in any case, far commoner chest infections. With a nonreturn system, the only parts of the apparatus through which the patient can rebreathe are the endotracheal tube and its connector, and the valve. All of these can be sterilized between cases.

CONCLUSION
When simple methods for using air in anaesthesia were first introduced, they were, under many circumstances, the only methods available. Most people are prepared to admit that under field conditions and in backward communities such techniques are admirable, but it has never occurred to many people to consider the possibility that these same methods actually offer certain advantages over the ones they currently use. Now that the muscle relaxant drugs are available, satisfactory operating conditions can be provided by the use of nontoxic doses of volatile agents, the patient can be assured of an adequate airway by means of an endotracheal tube, and he can also be assured of adequate pulmonary ventilation. It would seem that the quantitative administration of volatile liquid anaesthetic agents in air, through a nonreturn system, is the logical method of anaesthesia for the present day. It is the method which assures constancy, and which by measurement eliminates as many as possible of the unknown factors in anaesthesia.

REFERENCES
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