GENERAL ANÆSTHESIA IN TRAUMATIC SHOCK:
SOME THEORETICAL CONSIDERATIONS

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It is widely agreed that general anaesthetics administered to a patient suffering from traumatic shock can, and usually do, significantly modify the course of the disorder. It seems certain, however, that this procedure must continue and the choice of the most suitable form of general anaesthesia is necessary though by no means simple.

In war time the problem is pressing because of the large number of patients who must be operated upon while suffering from shock, and because practitioners who are not normally engaged in the practice of anaesthesia must of necessity carry out this task. It is therefore necessary to evolve some scheme of general narcosis which shall be as widely applicable as possible with the minimum of individual modification.

It is frequently stated that the safest form of anaesthesia in shocked, as well as all other cases, is that form with which the practitioner is most familiar. This statement is true,
within certain limits, but is certainly untrue beyond them. Most of us, if we were suffering from congestive heart failure, would rather receive chloroform from an expert chloroformist than be the first subject to whom he has attempted to administer ether. Yet we would not contend that chloroform is the best anaesthetic agent for patients suffering from congestive heart failure.

It is undoubtedly better to administer an established agent safely and well rather than to seek always to use the latest method. Nevertheless if one method can be shown to be better than others for a particular type of case, it is clearly the duty of anaesthetists to seek proficiency in its administration.

The final solution of the problem is only to be found in clinical trial, but there are many pitfalls in the gleaning of such information from our clinical experience because of the complexity of the material which we must seek to analyse. In addition to the variability of patients any anaesthetist nowadays can readily write down at least 60 different forms of general anaesthesia, each with its special advantages and each having its own advocate. The difficulty of solution of our problem by unassisted clinical trial is therefore likely to be considerable.

For two reasons, therefore, it seems worth while to examine the theoretical and indirect evidence which is available. In the first place by a clearer understanding of the interaction of narcosis and traumatic shock it may be possible to narrow down the field somewhat and to eliminate certain agents and methods as being unlikely to prove useful. In the second place isolated pieces of experimental evidence are from time to time advanced in support of a particular line of action in such a way that they carry a weight and a meaning which does not seem justified when they are viewed against the general background. It might thus be possible to render the answering of our question as to what is the most widely suitable form of general anaesthesia for a shocked patient, more easy. Finally, the question can be answered only by clinical experience.
The Nature of Traumatic Shock

There is no general agreement upon the nature of traumatic shock, nor does the evidence necessarily justify us in regarding it as a homogeneous condition.

For our purposes there are, however, certain observations which can reasonably be made about it.

1. It is a clinical state following on physical injury, with or without haemorrhage, in which some or all of the following signs and symptoms are found. Pallor or cyanosis, coldness of the skin, depression of the body temperature, low blood pressure, sweating, diminished metabolic rate, apathy, restlessness, lack of muscular tone and shallow sighing respiration.

2. The following disorders of function may be present in patients suffering from established shock. The list does not constitute a complete picture of the pathology of traumatic shock, but an attempt has been made to select those disorders about which there is least dispute, and which are relevant to the problems of anaesthesia.

   (1) Diminution of the effective volume of the circulating blood. Amongst the causative mechanisms of this disorder which have been suggested, are the following:

   (a) Frank haemorrhage.

   (b) Loss of whole blood into the traumatised tissues.\textsuperscript{34}

   (c) Loss of plasma from the blood into the tissue spaces of the traumatised area.\textsuperscript{35}

   (d) Loss of fluid in a similar manner into the tissues of the whole body.\textsuperscript{36}

   (e) The pooling of blood in the dilated capillaries of certain tissues due to atony of the capillary walls and dilatation of their lumen.

   (2) Impairment of the Venous Return, and therefore of the heart output, consequent upon the loss of effective circulatory volume.

   (3) Altered tissue metabolism. The whole organism suffers from anoxia because of the deficient circulation.

   In the traumatised tissue itself, as well as in tissues damaged by anoxia, circulatory toxins may be released.
which act as capillary dilators and in this and other ways lower the systemic blood pressure."

(4) **Increased capillary permeability.** Whether solely as a result of dilatation, or due to this and other causes, the capillary endothelium becomes more than normally permeable to protein molecules. It is also possible that it permits more rapid passage of certain crystalloids such as glucose, sucrose, iron and calcium with which the equilibrium state is normally rather slowly reached."

(5) **The heart is not directly affected.** The heart muscle is not directly poisoned. The failure of the circulation is primarily peripheral and failure of the heart to maintain an efficient blood supply to the tissues results secondarily because the venous return is insufficient.

(6) **Death, if it occurs, is due to Anoxia.** The generalised anoxia of shock affects most severely the vital centres of the nervous system and it is probable, though not certainly established, that failure of the respiratory centre is the first incident in the immediate process of death.

While it is not here in place to discuss the complex and controversial theories of the causation of shock, it is necessary, if we are to deal with the interrelation of anaesthesia and the disorders outlined above, to consider the following two points.

**Acidosis in Shock**

A state of diminished alkali reserve in the blood during shock was for some time accepted as an integral part of the syndrome. The M.R.C. Report of 1918\(^4\), however, concluded that "acidosis" is not a causative factor in the production of the symptoms of shock. Shock of great severity may be present without "acidosis" and a marked "acidosis" does not necessarily accentuate the symptoms. Cannon,\(^1\) Coonse et al.\(^\text{26}\) also found diminution in plasma alkali reserve in some animals and Guthrie\(^41\) recorded actual diminution in the pH of blood of as much as .02. McEllroy\(^7\) recorded only small changes in plasma alkali reserve during experimental shock. Raymund\(^61\) found considerable decrease in alkali reserve in animals subjected
to trauma under local anaesthesia but his evidence indicates that the degree of shock is not correlated with the degree of "acidosis".

It seems safe to conclude that a state of diminished alkali reserve of the blood is a relatively common occurrence in traumatic shock, but that it is not a factor in the causation of symptoms. Thus the diminution in the alkali reserve which is known to be caused by most anaesthetic agents is not likely to accentuate the symptoms of shock. On the other hand, however, it is possible, as the M.R.C. Report 1918 suggests, that the existence of a condition of diminished alkali reserve, from whatever cause, may render the subject abnormally sensitive to anaesthetic agents.

**The "Vicious Cycle" in Shock**

The impairment of the circulation due to diminution in the effective circulating blood volume leads to anoxia of the tissues. It is strongly suggested that this anoxia precipitates a further transudation of fluid from the blood, a further decrease in the effective blood volume and yet more severe tissue anoxia. The cycle is thus complete.

There are at least three ways in which anoxia might cause loss of fluid from the blood:

1. By the formation of small protein molecules owing to the abnormal tissue metabolism which, by exerting an abnormally high colloidal osmotic pressure, would alter the water balance between the blood and tissue fluid.

2. By the formation of metabolites, in the anoxic tissues, which act as dilators of the capillaries, thus rendering them more permeable.

3. By a direct action on the capillary epithelium making it more permeable to protein molecules, so that in this way protein could escape into the tissue fluid and the water balance between tissue fluid and blood be disturbed.

The occurrence of increased capillary permeability due to anoxia is demonstrated by the work of Krogh and Landis. Landis produced stasis of the blood flow and hence anoxia in a capillary of a frog's mesentery which was bathed in oxygen-free Ringer's solution. The rate of out-
flow of fluid was much increased and the capillary wall became permeable to proteins and to such dyes as Trypan blue and brilliant red. Changes in calcium ion concentration or in pH did not alone produce this change in capillary permeability and it is significant that if the period of stasis was short the change in the capillary wall was reversible.

Danielli* experimented with a preparation on the hind legs of a frog. When this preparation was perfused with Ringer’s solution it gained weight because fluid passed through the capillary walls into the tissues. If such substances as albumen, gum acacia or purified haemoglobin were added to the perfusing fluid, the changes in rate of weight gained were those which would be expected from the colloidal osmotic pressure which the added colloids exert. The state of oxidation of the haemoglobin did not affect the rate of fluid loss into the tissues. When ox red cells were added to the perfusion fluid, however, their degree of oxidation did affect the rate of gain in weight, but with sheep’s cells no such response to oxygenation was found. Danielli concludes that “the oxygen-carrying power of the red cells and haemoglobin must play a very minor role in the maintenance of normal permeability. There is, of course, no doubt from the results of Landis that severe oxygen lack does cause increased permeability, but it is quite certain that the capillaries of resting tissue need only a very moderate amount of oxygen such as can be conveyed in ordinary serum”. Danielli’s experimental method is, however, not free from possible sources of error. Saslow** perfused frogs with Ringer’s solution containing gum acacia and ox red cells and measured the time taken for the appearance of microscopical evidence of oedema in the web of the foot. He found that this did not occur for at least 6 hours, whereas when Ringer’s solution containing acacia at a similar pH and of similar colloidal osmotic pressure was used, the oedema appeared in 35 minutes. He eliminated changes in viscosity, arterial blood pressure, heart rate or buffering power produced by the red cells, as operative factors, and believes that the effect of the red cells was due to the oxygen which they carried. He demonstrates that this oxygen was given out to the tissues, and certain
experiments performed under increased pressure suggest that when the Ringer-acacia solution, owing to the increased pressure, carries 9 volumes of oxygen per cent in solution, it also is capable of delaying the onset of oedema. Schnedorff\textsuperscript{10} anaesthetised dogs with amytal and then performed cisternal puncture. Thirty-five per cent to 50 per cent of the volume of the cerebrospinal fluid was removed and then immediately replaced. Schnedorf thinks that this leads to a condition of "brain shock" and that the meningeal capillaries become more permeable. He found that the intracranial pressure rose from 160 to 260 mm. and the protein content of the cerebrospinal fluid and cell count also increased following this procedure. If nasal oxygen was administered to the animal these changes were less—the pressure rising only to 160 mm. Maurer\textsuperscript{7} measured the lymph flow in the cervical trunk of dogs breathing atmospheres deficient in oxygen. The anaesthetic was nembutal and curare was injected to prevent violent respiratory movement which would have made the lymph flow irregular. In general, anoxia increased the rate of lymph formation and the total protein content of the lymph. The increase in flow of the lymph commenced when the oxygen content of the arterial blood was 50 per cent to 80 per cent and reached its maximum when the oxygen content was 15 per cent to 30 per cent. It will be seen that the observations are quite relevant to conditions occurring during nitrous oxide anaesthesia. Increased carbon dioxide concentration produced similar, but smaller, changes when concentrations of up to 17 per cent in the inspired air were used. The observations of Schnedorf and Saslow indicate that anoxia such as may occur during anaesthesia—and certainly during anaesthesia in shocked patients—may lead to abnormal loss of fluid from the circulation in mammals. From all this evidence it seems reasonable to conclude that the anoxia of shock itself leads to loss of fluid from the circulation and that the further anoxia which may accompany the anaesthesia in shocked patients might well impair their condition and progress.
The Effect of Anaesthesia on the Blood Volume

The evidence for examination is of three types.

(1) Measurement of the actual volume of the circulating blood during anaesthesia in man and experimental animals.

(2) The records of changes in the concentration of the circulating blood. An increase in the corpuscular volume or of the plasma proteins is often called a haemoconcentration and may be shown by an increase in the specific gravity of the blood, an increase in the haematocrit reading of the haemoglobin value or of the erythrocyte count. Haemococoncentration provides presumptive evidence of a decrease in the volume of the circulating blood, whereas haemodilution provides presumptive evidence of an increase in the blood volume.

(3) We have already considered how tissue anoxia may lead to a decrease in the blood volume. We must therefore bear in mind the fact that if it can be shown that anoxia may occur during anaesthesia, this would provide evidence which would lead us to expect a decrease in blood volume.

The Diminution of Blood Volume

Experimental determinations of blood volume under anaesthesia do not provide much evidence to show whether anaesthesia directly alters the blood volume. McAllister using intravenous dye methods showed that ether anaesthesia reduced the blood volume of dogs by from 8.3 to 17.2 per cent. Mann found that 76 per cent of the blood volume as estimated from the body weight could be removed from normal animals by bleeding but only 64 per cent of this estimated volume could be removed after 6 to 9 hours of "light" etherisation. Stewart found similar changes in blood volume in patients under ether though his results were of course complicated by blood loss at the operations.
The Evidence from Hæmoconcentration

Moon⁸¹ is the chief exponent of the view that hæmoconcentration is a reliable index of an invariable decrease in circulatory volume in traumatic shock. Hæmoconcentration is not universally admitted to be an essential component of the shock syndrome. Most of the clinical evidence to the contrary is open to the criticism that hæmorrhage and trauma are usually associated and since the one may be expected to lead to hæmodilution and the other possibly to hæmoconcentration, the actual clinical result may depend upon the preponderance of either element.

Amongst controlled experiments, however, Guthrie⁴¹ found that the blood volume increased in animals which were shocked by a combined method of nerve stimulation and nerve trauma, trauma to limbs and manipulation of the intestines!!! Freedlander and Lenhardt⁴⁴ produced shock in cats by hitting the thigh 150 times in three minutes with a wooden mallet. They do not record hæmoconcentration though they believe that the blood volume was reduced by actual hæmorrhage into the traumatised tissues.

The Effect of Anaesthesia on Hæmoconcentration

1. Nitrous oxide. It is generally believed by anæsthetists that nitrous oxide produces only slight changes in the plasma-cell ratio of blood when anoxæmia is absent. Hamburger and Ewing⁴² found transient increases in the hæmoglobin and red blood corpuscular counts of 15—20 per cent during nitrous oxide anæsthesia both clinically and in experimental dogs. Anoxia was, however, almost certainly present.

2. Ether. It is generally believed that the administration of ether leads to an increase in the cell-plasma ratio or hæmoconcentration. Searles¹⁰³ records a 15 per cent increase in the hæmatocrit reading during ether anæsthesia in dogs. Only about half of this increase occurs in a splenectomised animal. Hamburger and Ewing,⁴² clinically and experimentally, and Barbour and Bourne⁶ found similar changes.
The spleen is known to contract during ether anaesthesia provided that its innervation is intact, and the resulting discharge of corpuscles into the circulation probably accounted for some, though not all, of the haemoconcentration. To this extent therefore the haemoconcentration after anaesthesia does not indicate a diminution of effective blood volume. An element of haemoconcentration remains, however, which is not explained by splenic contraction and this may to some extent be brought about by a loss of fluid through the vascular (capillary) epithelium into the tissues. Fay, Andersen and Kenyon comparing the effect of ether and cyclopropane found an increase in the red blood corpuscle count of the order of 12 per cent with both anaesthetics in dogs anaesthetised by a closed circuit method. Taylor and Waters, however, found no significant change in the red blood cell count in 8 clinical cases anaesthetised with cyclopropane.

The Barbiturates

Bourne, Bruger and Dreyer found that a decrease in corpuscular volume of about 30 per cent occurred in dogs during sodium amytal anaesthesia. Adolph and Gerbasi noticed a decrease in the total blood solid during sodium amytal anaesthesia. Searles finds a decrease of 15 per cent in the hematocrit reading, hemoglobin reading and red blood corpuscle count in dogs given sodium amytal. This apparent "hemodilution," however, does not occur in splenectomised animals; with an intact spleen it is known that this organ dilates during barbiturate anaesthesia. In this case, hemodilution would not appear to indicate an increase in the total blood volume. The plasma volume is not increased, but rather the corpuscular volume is diminished.

In an interesting investigation Seeley, Higgins and Mann, by investigating the effect of ether and sodium amytal on the blood, were able to select from a batch of 16 dogs those which had been experimentally splenectomised. Elman, Weiner and Cole differed from other workers in this field. They found that hemorrhage of 4
per cent of body weight which resulted in a decrease of 18—29 per cent of the red blood corpuscular count within 5 hours in conscious animals, might be followed by haemococoncentration in animals under sodium amytal anaesthesia. This haemoconcentration disappeared and was replaced by haemodilution when the animals recovered consciousness.

Evidence of this kind will not permit us to say with certainty that a certain anaesthetic produces certain changes in the blood volume. In some of these experiments the clinical anaesthetist is dissatisfied with the method of administration employed or with the data concerning the depth of anaesthesia. Even the occurrence of haemodilution or haemoconcentration does not, as we have seen, necessarily mean that a change in blood volume occurred.

Cressman and Rigdon\textsuperscript{3}, however, by investigating the manner in which injected dyes appear in the weal produced on the skin surface of rabbits by the action of toluene, have shown that narcotics do definitely affect the permeability of the capillary epithelium. Further, evidence has been offered that anoxia increases the capillary permeability, and if it can be shown that anaesthetics cause anoxia their influence on capillary permeability will be indicated. This constitutes indirect evidence which will lead us to anticipate that anaesthetics will modify the effective circulatory volume.

Anoxia

The failure of the oxygen supply to the tissues is probably the central disorder of traumatic shock, in the sense that it is brought about by such primary changes as impairment of the circulation and it results in the secondary formation of abnormal metabolic products and re-acts upon the primary disorders to accentuate them.

There are two main ways in which anaesthesia might produce anoxia, apart of course from defects in administration. (1) Where the anaesthetic agent must be administered in an atmosphere deficient in oxygen. One would expect from an examination of the normal oxygen dissociation curve of blood that the inspiration of an atmosphere
containing more than 10 per cent of oxygen at atmospheric pressure would, under normal conditions, result in the blood haemoglobin being fully oxygenated, and that if the inspired atmosphere contained less than 10 per cent of oxygen the blood haemoglobin would be only partially oxygenated. When the inspired atmosphere contains 10 per cent of oxygen, though the haemoglobin might be expected to be fully saturated the plasma oxygen tension immediately after the blood leaves the lungs is, of course, only half that which obtains when air is breathed normally.

There is some evidence, however, that when a mixture of 20 per cent of oxygen in the presence of 80 per cent of nitrous oxide is administered the blood is not fully oxygenated. During obstetrical anaesthesia when 20 per cent oxygen and 80 per cent nitrous oxide plus ether were used Smith estimated the oxygenation of the arterial blood of the femoral artery and found this to be only about 12.5 volumes per cent, that is to say, the haemoglobin was only 75 per cent saturated. The reason for this unexpectedly low figure may perhaps lie in the altered conditions of respiration and circulation which occur under anaesthesia.

It is not certain, however, that the inspiration over limited periods of mixtures deficient in oxygen necessarily diminishes the oxygen utilisation of the tissues, even though the arterial blood may be incompletely saturated. Hunt using nitrogen/oxygen mixtures on human subjects found a diminution of oxygen consumption of only about 10 per cent when the inspired mixture contained less than 10 per cent oxygen. This figure is not large enough to provide convincing proof of diminished oxygen utilisation, in view of the difficulties of this type of experiment, which will be discussed more fully in a later section. Warburg was unable to detect any change in the oxygen utilisation of isolated nucleated cells (red blood corpuscles of geese) under oxygen tensions of 5—75 mm. of mercury (0.7—10 volumes per cent). Kempner, however, though he confirms Warburg’s finding when the temperature was low or when the medium was alkaline and carbon-dioxide-free, found that with young undamaged cells (human erythroblast leucocytes or fowl
red blood corpuscles) in a medium containing carbon
dioxide, a decrease of 40 per cent in the oxygen utilisation
occurred when the oxygen tension in the gaseous atmosphere
was reduced to 3.4 per cent (26.4 mm. tension).

Clearly anoxia of a lesser degree than that produced by
breathing an atmosphere containing 10 per cent of oxygen
is not without effect on the organism, though it may not
produce a *generalised* diminution in oxygen utilisation.
Armstrong* states that exposure to an atmosphere such that
the *alveolar* oxygen tension is 53 mm. of mercury will re-
sult in unconsciousness if the exposure is sufficiently long.

When dealing with a shocked patient we believe that the
whole organism is suffering from oxygen deficiency. We
wish to know whether when we administer atmospheres
deficient in oxygen the oxygen utilisation of the whole
organism is still further reduced. It is possible that we
must reduce the oxygen consumption of certain regions
(for example the cortex or medullary centres) in order to
produce unconsciousness at all, but it is clearly undesirable
to produce further disturbance of the metabolism of the rest
of the organism by increasing its oxygen want. Certain
anaesthetics can be administered in atmospheres containing
much more oxygen than does air. It is relevant to enquire,
therefore, not only whether atmospheres deficient in oxygen
may harm a shocked patient but also whether we might
actually benefit a shocked patient by using an atmosphere
enriched in oxygen.

Boothby, Mayo and Lovelace* have demonstrated that
respiration of an atmosphere containing 100 per cent oxygen
could, owing to the small amount of extra oxygen which
can be taken up by the corpuscles and plasma, increase the
low venous oxygen content of a shocked patient’s blood by
as much as 50 per cent. Wood, Mason and Blalock" experi-
menting with dogs subjected to traumatic shock found
that the inhalation of a 100 per cent oxygen increased the
oxygen content of the blood from the femoral vein by 13
per cent. At the same time the rate of blood flow increased
a little. In "shock" from haemorrhage the benefit from
oxygen inhalations was rather greater.

Smith* found that the arterial oxygen content of patients
breathing cyclopropane and oxygen mixtures was higher than when they were conscious. He also found that the venous oxygen content was much increased and believes that this probably indicates a specific effect of cyclopropane in hindering oxygen utilisation by the tissues.

In summary, therefore, the experimental evidence is not here conclusive. It appears at present to indicate that oxygen-deficient atmospheres such as are employed in anaesthesia may produce more oxygen deficiency in the blood than might be expected from a consideration of oxygen dissociation curve alone, and this deficiency of oxygen in the blood may be sufficient to produce definite diminution in oxygen utilisation by the tissues generally and not merely transient local changes in the brain.

Thus, other things being equal, it would seem desirable to avoid the respiration of such atmospheres in shocked patients. The practical difficulty is, of course, that our only alternative to the use of atmospheres deficient in oxygen may be the use of agents which may produce equal anoxia of the tissues by other means and in addition they may have subsidiary harmful effects. Such a balance of disadvantages can only be estimated in clinical practice but in this connection we should remember that as Armstrong points out, the effects of anoxia are, in general, often insidious or delayed. Immediate apparent recovery from a period of anoxia does not necessarily mean that a patient, and particularly a shocked patient, has not suffered harm from the event.

The So-called "Lipoid Soluble" Anaesthetic

According to the widely accepted theory of Verworn these anaesthetics, such as chloroform, ether, or the barbiturates, produce a general inability of the cells to utilise oxygen—a histotoxic anoxia. This general histotoxic anoxia is thought to be more intense in certain areas of the brain owing to conditions of blood supply, cellular lipoid content, etc., and this accentuated anoxia is believed to be responsible for the symptoms of anaesthesia.

If the theory be correct some depression of oxygen
utilisation of the whole body must be accepted since the production of histotoxic anoxia is the operative characteristic of these narcotics.

In shocked patients such general histotoxic anoxia would be particularly harmful and we must therefore recall that this hypothesis of narcosis is a hypothesis only and that there is considerable evidence against it.

Owing to the ready applicability of the hypothesis it is in danger of being considered an established observation and quite unjustified deductions are sometimes drawn from it.

Henderson** reviewed a great deal of evidence on this point and particularly that relating to the simpler organisms. He concludes that "these facts distinctly show that oxidative processes and narcosis are separate phenomena" and "further no theory of anaesthesia will prove acceptable which is based on a proof of a depression of the resting oxidation of the cell".

We cannot, however, conclude that generalised anoxia does not occur during narcosis with these agents since it may occur as a side effect having nothing to do with their narcotic action.

Experimental evidence however gives little ground for thinking that the use of lipoid soluble anaesthetic necessarily involves general histotoxic anoxia of the whole organism, even as a side effect.

The oxygen consumption of an intact organism under narcosis has been measured. These experiments are subject to so many errors due to alterations in the muscular activity, muscular tone, respiratory rate and effort, or to activity of a particular organ, that it is difficult to draw rigid conclusions from them. In addition, in animals especially, there is always difficulty in establishing a basal rate of oxygen consumption before narcosis.

Amongst such evidence, however, is the following. Kruse*** estimated the oxygen consumption in dogs under ether. He found that the oxygen consumption fell by about 40 per cent when the animals were subjected for 2 hours to anaesthesia with a 7 per cent volume ether/air mixture. Peoples** estimated the oxygen consumption of
The animals were put into a closed vessel into which oxygen was drawn through a flowmeter from a bag as fast as the animals used it. The temperature of the chamber was carefully stabilised and carbon dioxide was absorbed by means of soda lime. Every precaution was taken to see that the rats were motionless when the pre-anaesthetic oxygen consumption was estimated. Peoples does not contend that this pre-anaesthetic figure is necessarily the basal consumption of the rat.

In these circumstances the rate of consumption of oxygen by eight rats fell by between 20 per cent and 50 per cent during deep ether anaesthesia, when they were respiring approximately 11 per cent by volume of ether. Under lighter anaesthesia (approximately 6 per cent by volume of ether) no constant change in oxygen consumption was found over 2 hours. Similar results were found when Vinesthene was the anaesthetic, except that changes under deep anaesthesia were less marked. With both drugs under light anaesthesia, some animals showed an increase in oxygen consumption. Lee measured the consumption of oxygen of rats under amytal anaesthesia. The decrease in oxygen consumption was always small, the maximum decrease being 20 per cent when 7.5 mg. of amytal per 100 gm. of body weight was given. In his experiments, under urethane most animals showed an increase in oxygen consumption. Griffith, Emery and Lockwood experimenting with cats found that under chloralose anaesthesia the oxygen consumption rose by some 7 per cent. Anderson, Mei-yo Chen and Leake measured the effect of sedative doses of barbital, ipral, phanodorm, neonal, dial and amytal on the oxygen consumption of human subjects. The figures showed some increases and some decreases. In one subject an increase in oxygen consumption seemed to occur with all drugs. All of their variations noted were very small.

Stark measured the metabolic rate for human subjects after the administration of morphine. Considerable care was taken to obtain a true basal reading beforehand. The decrease in oxygen consumption varied from 10—25 per cent with doses of $\frac{1}{4}$ gr. to $\frac{1}{2}$ gr. morphia. Anderson was unable
to find changes of more than 5 per cent following morphine injection. The degree of reduction of oxygen consumption bore no relation to the magnitude of the doses. Campbell measured the oxygen tension in artificially produced deposits of air in the subcutaneous tissues. Urethane anaesthesia diminished the oxygen tension.

Experiments in which the Oxygen Consumption of Isolated Tissues is Measured

In these circumstances many of the incidental changes in rate of oxygen consumption are eliminated, but others arise. For example if we take a mass of cells isolated from the organism and find that the addition of a narcotic diminishes the rate of oxygen consumption, we do not know whether all the cells are using less oxygen or whether some are now using none and the remainder continuing to use their normal amount. Further the complex compensating mechanisms, which in the intact animal tend always to maintain the cell environment constant and which allow us to introduce the narcotic as the only variable factor, are absent.

Quastel and Wheatley incubated mashed brain tissue in saline and measured its rate of oxygen consumption. They found that the introduction of such narcotics as somnifane did not alter this rate of oxygen uptake when the tissue was metabolising, but added glucose was reduced by the addition of the narcotics. Among the gaseous narcotics they found that ety-lene and propylene produced no change in the oxygen uptake of brain metabolising glucose but that acetylene reduced it. Bülow criticised this last finding and produced evidence showing that the reduction of oxygen uptake produced by acetylene was an irreversible one which persisted even when the acetylene had been removed. It is not likely therefore that the acetylene was acting as a narcotic under these circumstances. Jowett and Quastel made similar observations on a series of brain tissue slices and slices of other organs. They showed that the rate of uptake of oxygen on all tissues in the absence of added glucose was less sensitive to narcotics than was their rate when glucose substrate was present. Tissues other
than brain were less sensitive to narcotics than was brain. For example the addition of .033 per cent of soluble hexobarbitone produced a diminution of oxygen uptake in the presence of glucose of 33 per cent for brain slices, 17 per cent for spleen and 2 per cent for liver. They demonstrated that changes in oxygen consumption might possibly be produced by narcotics in concentrations of the same order as those required for narcosis. In 1937, Jowett and Quastel demonstrated the effects of ether on the oxygen uptake of brain slices. In the absence of added substrate ether produced little or no change in the rate of oxygen uptake. When glucose was added ether did produce reduction in rate of oxygen uptake but when ether concentrations of narcotic order were used these reductions were only about 10 per cent and this change was not beyond the limit of experimental error. Concentrations of ether which were sufficient to produce definite changes in rate of oxygen uptake usually produced changes which were not readily reversible.

Evidence for Histotoxic Anoxia during Anaesthesia from Bio-chemical Changes

Bio-chemical changes have been reported during anaesthesia with certain lipoid soluble anaesthetic which would be consonant with the idea that a generalised histotoxic anoxia was present. These changes include an increase in blood sugar, a diminished plasma alkali reserve, an increase in blood lactate, a diminution of liver glycogen, changes in the blood phosphoric acid level and the excretion of acetone bodies in the urine.

In the first place the occurrence of all of these changes is not beyond dispute; for example, Pratt was unable to record constant or considerable changes in blood-sugar level in patients under ether. More important than this, however, is the fact that we are unable at present to eliminate the great variety of secondary effects such as sympathetic activity, the liberation of adrenalin or changes in body temperature which could also bring about these changes. It is not possible
therefore to evaluate this material as evidence for or against
generalised histotoxic anoxia.

We may conclude that a generalised histotoxic anoxia
is not logically inevitable during the action of the so-called
lipid soluble anaesthetics, and further that the experimental
evidence does not, as yet, suggest that it in fact occurs.

The Acapnial Theory of Shock

This theory which was advanced by Y. Henderson is of peculiar interest to anaesthetists because
it postulated that the symptoms of traumatic shock were
due to a deficiency of carbon dioxide in the blood, and this
is a matter which to a large extent is under the control of
the anaesthetist during anaesthesia. Henderson observed
that voluntary hyperventilation in conscious subjects some-
times lowered the blood pressure and led to syncope. In
anaesthetised animals by forced hyperventilation on the
respiratory pump, collapse and death could be brought
about. He believed that prolonged hyperpnoea was always
a feature of injury, and suggested that this hyperpnoea
brought about a state of acapnia, which was followed by
diminished tone of the skeletal muscles, impairment of the
venous return to the heart, and shock.

Much of the experimental evidence is inconclusive, and the
clinical observations are not in concord with general experi-
ence. Hyperventilation is not commonly seen in severely
injured patients and the administration of carbon dioxide
to such patients does not improve their condition, but may
lead to sudden collapse.

Janeway and Ewing performed experiments similar to
those of Henderson. They found that very great pressures
were necessary to produce a sufficient degree of forced
hyperpnoea in anaesthetised dogs to bring about shock, and
that the degree of shock bore a close relation to the intra-
tracheal pressure and none to the carbon-dioxide content
of the blood. In experiments on animals in which the
abdomen was opened and the intestines manipulated the
rate of development and degree of shock bore no relation
to the amount of carbon dioxide in the inspired air.
Wiggers\textsuperscript{122} produced prolonged hyperpnoea in animals by nerve stimulation. Even when this was prolonged for 90 minutes permanent apnoea and death did not follow as Henderson had suggested. At most there was temporary apnoea or shallow breathing.

Roome, Keith and Phemister\textsuperscript{97} could not produce the signs of traumatic shock by forced hyperventilation in anaesthetised animals.

**Afferent Nerve Impulses and the Vaso-motor System**

Clinical experience suggests that the stimulation of afferent nerves under inadequate general anaesthesia may lead to a fall in blood pressure and a condition clinically indistinguishable from traumatic shock. Notable examples of such stimulation are the pulling on the diaphragm which occurs during high abdominal operation and the tension of the hilum of the lungs which occurs during pneumonectomy. It must be remembered that in such cases the effect is not necessarily produced by the afferent impulses acting directly. It may result from changes which occur in consequence of undesirable reflexes set up by these impulses. Thus many clinical workers have reported that if an endotracheal tube is used during high abdominal operations so that despite traction of the diaphragm the airway remains clear and the respirations easy, then the patient does not suffer even though the anaesthesia be light.

Experimental evidence does not support the idea that afferent impulses of themselves can cause a fall in blood pressure. Mann\textsuperscript{77} found that the continuous stimulation of afferent nerves in lightly anaesthetised animals did not cause a fall in blood pressure over a period of 4 hours. Porter, Marks and Swift\textsuperscript{88} reported similarly. W. T. Porter\textsuperscript{77} showed that stimulation of the brachial or sciatic nerves of cats, rabbits and dogs always produced a rise in blood pressure even though the blood pressure had been artificially lowered by trauma and haemorrhage before stimulation.

Parsons and Phemister\textsuperscript{95} considered that equivalent trauma to an intact and a denervated limb produced equal
degrees of shock and so conclude that afferent impulses are unimportant in the production of the lowered blood pressure of shock. Wiggers\textsuperscript{112} stimulated the sciatic nerves of animals so lightly anaesthetised with ether that the lid reflex was retained. He concluded that stimulation of afferent nerves will not produce the serious fall in blood pressure seen in shock. The pulse pressure curve retained its normal form with a slowly falling pressure during diastole, indicating that the blood flow was not seriously disturbed. Guthrie\textsuperscript{11} and Porter,\textsuperscript{117} amongst many others, conclude that shock is not associated with a condition of vaso-motor exhaustion in which the over-stimulated vaso-motor system has finally lost its tone.

Freeman\textsuperscript{118} and Freeman, Freedman and Miller\textsuperscript{118} have advanced a view which may help to reconcile clinical experience with experimental findings. It is suggested that unprolonged \textit{vaso-constriction} produces tissue anoxia and that this leads to the loss of fluid from the circulation. Such vaso-constriction presumably might result from afferent stimulation under inadequate anaesthesia. Cats, in which a condition of "sham rage" had been produced by decerebration at a suitable level, showed a decrease in plasma volume over a period of hours. In later experiments vaso-constriction was produced by the continuous fusion of adrenalin. In this case the plasma volume and blood pressure fell gradually until death occurred. The writers state that the quantities of adrenalin used were much greater than those which would occur naturally in the blood but they regard the substance merely as a convenient means of producing vaso-constriction. It is to be noted that in their experiments the rectal temperature of the animals rose and the animals had to be cooled artificially. The venous pressure also rose. Both of these effects may be due to the use of adrenalin and it is not possible to conclude unreservedly that the decrease in plasma volume would necessarily result from vaso-constriction from any other causes. Campbell\textsuperscript{119} demonstrated that vaso-constriction reduced the oxygen tension in pockets of air artificially deposited in the subcutaneous tissues.
Bhatia and Burn contend that one of the effects of ether anaesthesia is a general sympathetic stimulation involving vaso-constriction. As evidence of this sympathetic activity they cite the contraction of the innervated spleen, the inhibition of the intestine and uterus and the rise in heart rate. If such a vaso-constriction occurs it might give rise to an ultimate fall in blood pressure as indicated in the previous section. Such a vaso-constriction does not, however, appear to be general under most forms of anaesthesia. Herrick et al. demonstrated that the administration of ether to dogs abolished the temperature gradient of the skin of the lower limb and that the rate of blood flow in the femoral artery definitely increased. Scott and Morton measured not only the skin temperature, but also the temperature in the muscle mass between the metatarsals, and found that the temperature gradient in the lower limbs of human subjects could be abolished with ether, tri-bromethanol and in many cases with nitrous-oxide anaesthesia also. Sheard, Rynearson and McCaig showed that the lower limbs of dogs under amytal gave no vaso-constrictor response to sudden cooling from 27°C. to 0°C.

Generally speaking the experimental evidence indicates that the slow injection of either soluble hexo-barbitone or the thio-barbiturates produces no considerable fall in blood pressure. The rapid injection of large doses of these drugs may however determine a fall in blood pressure which is partly peripheral in origin, partly due to an effect on the vaso-motor centre and partly due to a direct effect on the heart. The effect is however less marked than that caused by avertin in similar circumstances.

Olmstead and Girogossintz consider that amytal and anaesthesia do not modify the vaso-motor response to splanchnic stimulation, but that the early rise in blood pressure usually seen in asphyxia is prevented.

Morphine in its usual doses is apparently without effect upon the blood pressure of experimental animals if anoxia is prevented. This finding is in accord with general
clinical experience. Capps and Matthews found that large doses of morphine lowered the arterial pressure of dogs markedly, but in their experiments anoxia was not certainly absent. Catell artificially reduced the blood pressure in cats by producing a positive pressure within the pericardium. At intervals of one hour the pressure was released and the ability of the organism to raise its blood pressure towards the normal figure was noted. Usually after five hours the blood pressure no longer rose on release of the positive pressure. Morphine given just before the initial application of positive pressure did not diminish this time.

The Effect of Anaesthesia on the Heart

1. Ether. Catell found that there was no sustained fall in blood pressure in normal cats during light ether anaesthesia, but that the blood pressure of shocked cats fell without any preliminary rise when they were anaesthetised only to the level of abolition of the eye-lid reflex. With nitrous oxide, similar falls in blood pressure occurred if the mixture administered contained less than 20 per cent of oxygen. In some of the animals it was impossible to abolish the eye-lid reflex without reducing the oxygen content below this level and encountering the fall in blood pressure.

This fall in blood pressure Catell attributes to the direct depressant action of the anaesthetic on the heart muscle which in the normal animal is masked by a compensatory vaso-constriction so that the arterial pressure does not fall. In shocked animals maximal vaso-constriction is already present, owing to the diminished blood volume, and the depressant action of the anaesthetic on the heart muscle is therefore evident. The inability of ether to produce further vaso-constriction in shocked animals was demonstrated by arterial perfusion experiments.

Such a direct effect on the heart muscle must hasten the occurrence of complete failure in shock, even though the failure is primarily peripheral in origin.

Vernon demonstrated the action of ether on the isolated
perfused heart of the tortoise. He found that the ratio of concentrations of alcohol, ether, and chloroform necessary to produce a similar diminution in the force of contraction of the ventricles was 1:6:140, and that in the case of ether and alcohol there was no cumulation of effect with repeated treatments, though the effect of chloroform increased with each repeated similar dose.

Electrocardiographic records under ether anaesthesia during operations often show evidence that the point of onset of the beats has changed (displacement of the pacemaker) but extrasystoles and other irregularities are very rare.* In experimental animals, similar observations have been made.

With light ether anaesthesia, therefore, it does not seem that the direct effect on the heart muscle is likely to be a considerable factor in increasing the circulatory failure of shock.

2. Morphine. Several observers have reported that morphine produces a slowing of the pulse by vagal action. Irregularities of the pulse may also occur, particularly if certain other anaesthetic agents such as chloroform or cyclopropane are administered as well. Both of these effects closely resemble those produced by anoxia.

3. The Barbiturates. Olmstead and Ogden, working with a heart lung preparation, report that a concentration of amytal of 27 mg. kilo. B/W. produces a definite dilatation of the heart. That this effect is not a serious one is perhaps shown by the fact that a similar dilatation was produced by three "breaths" of ether vapour. Kennedy and Nary showed that a concentration of 1:200 of evipan in the perfusion fluid of an isolated frog's heart completely stopped it in two minutes, but that the effect was immediately reversible by perfusion with saline.

Intravenous injection of evipan does not seem to produce changes in the electrocardiographic record. Rapid injection of thio-barbiturates, especially if anoxia is present, may however give rise to extrasystoles in dogs. Monkeys are less susceptible, but after morphine pre-medication the
effect may be seen in this animal too. Similar changes have been recorded in a clinical case where a large dose of pentothal was given and severe anoxia developed. When the thio-barbiturates are given slowly and in moderate dosage, electrocardiographic irregularities are rare and unimportant. Reynolds, examining the pharmacological effects of pentothal, warned against its use in prolonged anaesthesia. He suggested that there seemed to be a limit to the organism's ability to excrete the drug and that though respiration failed before circulation during overdose in short anaesthesia, after many repeated doses they may fail together and efforts at resuscitation be ineffective.

In the case of evipan, at all events, Das and Raventos have shown that the gross clearance of the drug is, as one would expect, exponential, and there does not seem to be any reason to anticipate peculiarities of cumulation.

However, the work of Koppanyi and Dille may throw some light on the increased and possibly abnormal responses to repeated doses of barbiturates which are occasionally reported. They show that during the excretion of barbital from dogs which had received diuretic doses of ammonium chloride the concentration of barbital in various tissues did not decrease at the same rate. Thus, for example, when 5 per cent of the drug had been excreted the blood contained 0.15 mgs. per cu. centimeter and the brain 0.1 mgs. per gm. When 40 per cent had been excreted the blood contained only 0.05 mgs. per cu. centimeter whereas the brain still retained .08 mgs. per gm.

It is probable that the mode of clearance of the "short" acting barbiturate is different from that of barbital itself, so that no definite inference can be drawn, yet it is possible that this observation of differential retention may explain some of the observed abnormalities of prolonged barbiturate anaesthesia.

In contrast with the warning of Reynolds we have such reports as that of Carraway who records satisfactory anaesthesia in 3,810 cases of all types using continuous pentothal narcosis.
Clinical experience indicates that such narcotic substances as cyclopropane, morphine and the barbiturates, depress the respiration and that nitrous oxide, in the absence of anoxia, does not. Bock found however that rats succumbed to a pressure of 2,200 mms. Hg of nitrous oxide even though the oxygen pressure was abundant to secure full oxygenation.

This respiratory depressant action of many anaesthetics is thought to be at least in part due to a reduction in sensitivity of that part of the neural mechanism known as the "respiratory centre."

It is not therefore surprising that in the case of one anaesthetic substance it has been shown that its presence increases the ease with which this "respiratory centre" is damaged by anoxia. According to Binet and Strumza, under chloralose anaesthesia, respiratory arrest in dogs occurred when the oxygen concentration in the inspired air fell to 4.67 per cent. In unanaesthetised dogs respiratory arrest did not occur until the oxygen concentration in the inspired air was as low as 3.39 per cent. This effect the authors attribute to an action of chloralose on the "respiratory centre."

There is thus a possibility that when, in shock, the respiratory centre is already suffering from anoxia many narcotic drugs may lead to its earlier failure.

Substances which reduce the effective ventilation may harm the shocked patient since the reduction in ventilation of itself will tend to increase the existing tissue anoxia.

It is usually advised that morphine should be administered to shocked patients in large doses, yet in 1917 Marshall advanced the opposite view and contended that patients who received morphia before operation withstood further shock badly. It is possible that the respiratory depression produced by morphine may be an adverse influence in shock.

Hardy, Wolff and Goodell have recently brought evidence to show that the analgesic effect of morphine is roughly proportional to the magnitude of the dose only up to a certain level (about 15 mgs. for a 10-stone man) and that above this
dosage the analgesic effect lags far behind the increasing dosage. They suggest that there is a saturation point for morphine.

They demonstrate, however, that pain pré-existing the administration of morphine seriously inhibits its analgesic effect and, unfortunately for our purposes, they did not investigate the effect of pré-existing pain on doses in excess of 15 mgs. Thus while we do not know in practical circumstances (when pain exists before the morphine injection) whether doses larger than 15 mgs. might show proportionate increase in analgesia, the results do suggest that in all circumstances there is probably a saturation dose of morphine beyond which, from an analgesia point of view, it is unprofitable to go. The administration of morphine in excess of that necessary to relieve pain is probably harmful in shock.

Anæsthesia and Fluid Balance

The diminished blood volume of traumatic shock may or may not be accompanied by an actual loss of fluid from the organism, depending upon the method of causation of the shock. In any case, further loss of fluid will undoubtedly be harmful, and the intake of fluid is one of the first essentials of treatment.

Anæsthesia may determine fluid loss by causing excessive salivation, mucous secretion, sweating and fluid loss from the lungs, or by causing vomiting. Prolonged unconsciousness after the operation prevents oral ingestion of fluid at a time when it is most necessary.

Full ether anæsthesia offends in most of these respects. Seeley, Essex and Mann anaesthetised dogs with ether until the lid reflex was dulled, and then produced a state of shock by intestinal manipulation. The average time of survival of seven dogs so treated was 5 hours 33 minutes from the onset of anæsthesia. When the anæsthesia was produced by 50 mg./kilo. of amytal, three dogs survived this proceeding by 14 hours 44 minutes, and when 25 mg./kilo. amytal and supplementary ether was given the average time of survival was 13 hours 31 minutes. Hæmoconcen-
tration was less marked in both of the experiments in which the animals received amytal.

It was observed that the animals which received amytal displayed less salivation and lost less fluid by mucous secretion and surface of the intestines. The authors do not however contend that amytal anaesthesia would necessarily show corresponding advantages if administered to a subject whose blood volume was already reduced by shock. Clinically, any advantages of diminished fluid loss would have to be offset against the disadvantage of the prolonged recovery period which normally follows barbiturate anaesthesia, and during which the subject is unable to take fluid by mouth.

Nitrous oxide is a satisfactory agent in these respects, provided that it can be administered without anoxia or excessive morphinisation. Vinesthene is almost as satisfactory, because little vomiting occurs and recovery is quick. Cyclopropane is generally held to produce considerably less salivation and mucous secretion than ether, and slightly less vomiting. Waters’ figures are as follows:—Proportion of patients nauseated or vomiting at least once after leaving the operating room, after nitrous oxide, 23 per cent; after ethylene, 33 per cent; after cyclopropane, 39 per cent, and after ether, 57 per cent. In all such estimates, however, it is safe to assume that most of the patients receiving ether were deeply narcotised and it is by no means certain that light ether narcosis produces vomiting so frequently, nor is recovery from it necessarily prolonged.

While it is true that prolonged recovery from an anaesthetic delays the possibility of oral intake of fluid, it is well to remember that advantage may be taken of the period of unconsciousness to administer fluid rectally. This is generally easier and more effective in the unconscious patient (Hewer)..

Heat Loss during Anaesthesia

A shocked patient is usually cold and his condition will be made worse if his body loses heat. The question of heat loss under anaesthesia is a complicated one and the measure-
ment of body temperature at a particular point on the surface will not necessarily give a true indication of heat loss or gain.

Vaso-dilatation of the surface vessels, increased respiratory rate and depth and the inhalation of cold, dry gas mixtures may all be expected to increase the rate of heat loss. When the open-mask method of administering ether is used it is feasible that the patient may inspire a gas mixture at 0°C. which contains practically no water vapour. If in the lungs this mixture is raised to 37°C. and fully humidified at this temperature the heat loss might be of the order of \( \frac{1}{5} \)th of the total heat loss of the patient.

This factor would be serious in a badly shocked patient and in this respect closed-circuit anaesthesia shows a theoretical advantage.

Increased minute volume of respiration with consequent increase in heat loss may occur with some anaesthetics, for example, nitrous-oxide anaesthesia and ether. It is well known also that ether tends to produce dilatation of surface vessels in the normal patient. Barbour and Bourne\(^4\) concluded from experiments that dogs under ether anaesthesia were unable to maintain their body temperature constant and that this rose or fell in accordance with the environmental temperature unless the latter was near to 31°C. Experimental measurements of body temperature under ether,\(^112\) evipan\(^9\) and amytal\(^8\) all indicate small decreases. Watkins and Wilson\(^120\) measured the rectal temperature in patients under open ether anaesthesia (atropine pre-medication) and found an initial fall followed by a slow gradual fall in temperature which was greater in lightly anaesthetised patients than during deep anaesthesia. The changes were of the order of 1 to 2°F.

**Vaso-dilatator Substances**

Any attempt to examine the relation of our knowledge of general anaesthesia to the very great number of possible mechanisms and changes suggested by the varied theories of traumatic shock would at present result only in confusion. For this reason an attempt has been made to consider only those observations concerning shock which seem least in
dispute and little attention has been given to such theories as that of the circulation of toxins produced in damaged tissues.

Two experimental results seem however to be of such interest as to demand recording, and this interest would increase if the "toxic" theories of traumatic shock once more became generally accepted. Dale" (Brit. J. Exp. Path. 1920, i, 109) examined the effect of anästhetics upon the response of cats to the intravenous infusion of histamine. Briefly, he showed that during and shortly after the administration of ether a fatal degree of "shock" could be produced by the intravenous infusion of 2 mg./kilo. of histamine whereas in the unanästhetised animal recovery occurred after the infusion of 10 mg./kilo., at a comparable rate. Cats anästhetised with nitrous oxide proved almost as resistant as unanästhetised animals. The recording of depth of ether narcosis is however not as precise as the clinical anaësthetist requires, and the occurrence of super-added anoxia is not excluded in some of these cases. The concentration of nitrous oxide used was very low, and the periods of anaesthesia were shorter than those where ether was used. The loss of 50 c.c. of blood from the jugular vein produced a sensitivity to histamine as great as that produced by ether anaesthesia.

Kellaway and Trethewie" perfused the isolated lung of a dog with Tyrodes solution and rhythmically inflated the lung with air containing anaesthetic vapours. They measured the amount of histamine which appeared in the perfusate coming from the lung. Using ether vapour in concentrations of less than 10 per cent the output of histamine was negligible, and in their view it became serious only when concentrations of over 19 per cent were used. The latter figure is of course outside the usual range of concentrations used in anaesthesia. Definite concentrations of histamine appeared when 4.6 per cent of chloroform vapour in air was used, but with all concentrations of nitrous oxide and ethylene no important amount of histamine was released from the lung during periods of up to two hours. Similarly, anoxia produced by inflating the lung with nitrogen liberated no significant amount of histamine.
Duration of Narcosis

In general, during the period of narcosis, whether during the operative procedure or after it, a patient’s respiration is depressed and his muscular tone diminished.

Among many others Wiggers has shown that in traumatic shock the venous pressure is usually diminished and as a result of this the systolic discharge diminishes. This fall in venous pressure is no doubt due mainly to the fact that the volume of circulating blood is diminished, but any influence which might reduce the pressure still further is clearly harmful. These two factors, muscular tone and movement, and respiratory movement, are believed to be operative in maintaining the venous return in normal animals and on this basis it seems desirable that in shocked patients narcosis should be as brief as possible.

Recorded measurements of the venous pressure under anaesthesia are unfortunately few. Meyer and Middleton found that during induction with nitrous oxide, ethylene, and nitrous-oxide-oxygen and ether, the venous pressure is, as would be expected, raised. During maintenance with these anaesthetics they found that the venous pressure was also somewhat above the conscious resting level, but unfortunately it is not possible to be certain of the degree of muscular relaxation which obtained during the operations concerned.

Severs, Waters and Davis found that .1 grm./kilo. doses of tri-bromethanol, in man, and normal intraperitoneal doses in rabbits, both lowered the venous pressure. This anaesthetic usually produces considerable relaxation of the muscles and depression of the respiration, and it seems likely that the depression of venous pressure is dependent on these factors rather than on any particular characteristic of the anaesthetic. It may be expected to occur whenever similar conditions are reproduced with other agents.

Taking into account also the possibility of anoxia during prolonged post-operative coma, one is led to the view that other things being equal, for a shocked patient the shorter the period of narcosis the better.
The administration of general anaesthesia to a patient suffering from traumatic shock is a proceeding which requires all the skill and discrimination of an experienced anaesthetist. It can never be a stereotyped or uniform procedure and one cannot hope that the problems of the correct selection of agent and mode of administration will ever be solved merely by an examination of indirect evidence.

Taken in conjunction with our general clinical experience, however, the evidence which has been discussed does seem to indicate certain conditions which a general anaesthetic should fulfil if it is to be suitable for widespread application in this field.

These conditions are (1) Physiological and Pharmacological, and (2) Practical.

**Physiological and Pharmacological Conditions**

The chosen method of anaesthesia should fulfil as many as possible of the following conditions:

1. It must be capable of producing surgical conditions which permit of rapid operating.
2. It should not produce anoxic anoxia (anoxaemia) even when employed by less experienced administrators.
3. Preferably it should be possible to administer the chosen agent in atmospheres enriched with oxygen.
4. The method should allow of rapid induction and recovery so that the patient is unconscious for the minimum possible period in excess of that required for the operation.
5. It should be readily controllable so that the lightest possible plane of anaesthesia which the surgical procedure permits may be attained and maintained. It must therefore be possible to maintain light planes of anaesthesia for prolonged periods without risk of interrupting the smoothness of the anaesthesia.
6. It should be reliable and predictable in action.
7. It should produce the minimum of subsidiary toxic effects.
8. It should not increase seriously the patient's heat or fluid loss nor interfere with fluid administration.

Practical Considerations

1. The technique should be fundamentally straightforward, yet capable of adaption so that special requirements, such as for endotracheal or controlled respiration administration, can be met.

2. Under war conditions, only apparatus which is readily portable should be required. If the use of cylinders of compressed gases can be dispensed with without loss of efficiency, problems of transportation will be materially easier.

3. It should preferably be susceptible to, though not dependent upon, closed-circuit administration with carbon-dioxide absorption.

4. The method should be as inexpensive as possible.

It is clear that no known method at present fulfils all of these conditions.

Nitrous-Oxide-Oxygen Anaesthesia

This form of anaesthesia is considered by many experienced anaesthetists to be the most widely suitable in cases of shock. It fulfils well the physiological conditions Nos. (1), (3), (4), (5), (6) and (8), tabulated above, but is not without disadvantages.

Even when administered by skilled anaesthetists it seems by no means certain that anoxia can always be avoided in shocked patients. When nitrous oxide is given to shocked patients by less skilled administrators serious anoxia is probably not uncommon since shocked patients do not give the florid, obvious response to anoxia which occurs in the healthy.

From a practical standpoint, nitrous oxide is expensive and completely dependent upon a supply of heavy cylinders, the latter being a serious disadvantage in many situations during war.
When nitrous-oxide-oxygen is administered with a supplementary agent such as di-vinyl or di-ethyl ether, the risks of anoxia are much diminished because an abundant supply of oxygen can be given and the necessary depth of anaesthesia secured by the addition of the supplementary agent. It must be admitted, however, that in practice the nitrous oxide very often serves only as a vehicle for the administration of the supplementary agent which alone produces any significant degree of narcosis.

The practical disadvantages of the method are not less than those of nitrous oxide alone.

**Barbiturates**

The practical advantages of the short-acting intravenous barbiturates are considerable, but from the physiological and pharmacological point of view they have many disadvantages which seem to me to render them unsuitable for this particular application of anaesthesia. Briefly, they cannot be said to fulfil the physiological conditions Nos. (2), (3), (4), (5), (6) and (8).

**Cyclopropane**

This agent has many advantages and it fulfils admirably all of the physiological conditions tabulated. It will undoubtedly be used in chosen cases by experienced anaesthetists, but the technique of safe administration is specialised and exacting and it cannot therefore be said to be suitable for widespread application.

**Di-Ethyl and Di-Vinyl Ethers**

I believe that insufficient attention has been given to the possibilities of light narcosis with these agents, preferably with the addition of oxygen.

With the common methods of administration it is difficult, for example, to exploit the lighter planes of di-ethyl ether narcosis and such anaesthesia is rather rare. Much of the
surgery which must be performed on patients suffering from traumatic shock, however, requires only light narcosis.

The condition of a patient under deep ether narcosis is familiar and it is clear that the production of such a condition in a patient suffering from traumatic shock is very harmful. But the condition of a patient under light ether narcosis is quite different and indeed such light narcosis probably fulfils well the physiological conditions Nos. (1), (2), (3), (4), (6), (7) and (8).

The main problem is to fulfil condition (5), that is, to make the anaesthesia readily controllable so that the lighter planes can be maintained. Advances have been made in this direction and are likely soon to issue in practical form.

From a practical aspect the advantages of the use of these liquid agents are considerable. The technique can be fundamentally simple and safe, yet capable of adaption to almost any form of administration which the skilled anaesthetist may wish to employ. The apparatus can be readily portable and cylinders of gases are not essential.

To reiterate, the question remains an open one and the answer to it will be found only in the operating room and wards. It seems possible, however, that there are potentialities in di-ethyl ether which have not yet been exploited and which should not lightly be ignored.

References