INDUCED HYPOTENSION AND BRAIN ISCHAEMIA

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Global or focal brain ischaemia may result from the technique of induced hypotension. In the presence of a normal cerebral circulation, ischaemia is of the global type and this situation is considered first.

GLOBAL ISCHAEMIA

Autoregulation

Autoregulation is the term used to describe the maintenance of constant perfusion over a range of arterial pressures. Autoregulation occurs in all vascular beds, but other mechanisms also act on vascular control, for example autonomic activity and plasma concentrations of hormones. The influence of these other mechanisms varies widely between different circuits, so that the effect of induced hypotension is different on the vascular systems of the brain, lung and kidney. For example, sudden blood loss causes more marked vasoconstriction in kidney than in myocardium. In brain, the influence of mechanisms other than autoregulation is relatively small. Thus, maximal sympathetic activity reduces CBF by only 20% (Harper et al., 1972) which is approximately the same as the change produced by a decrease of 1 kPa in arterial PCO₂. Autoregulation is therefore predominant in the cerebral circulation and acts to maintain CBF constant over a range of mean arterial pressures (MAP) which extend from 60 to 130 mm Hg in man (Lassen and Christensen, 1976). If, during induced hypotension, MAP is reduced beyond the lower limit of autoregulation, CBF starts to decrease in parallel with MAP until the ischaemic thresholds discussed by Symon (1985) and Heuser and Guggenberger (1985) are reached. It is important to note that the lower limit of autoregulation is that arterial pressure at which flow starts to decrease, and it has no significance itself in indicating brain ischaemia. There is a considerable margin of blood flow and arterial pressure between the lower limit of autoregulation and the ischaemic thresholds for EEG silence and failure of cell membranes. On the other hand, it is true that there can be no ischaemia until MAP has decreased below the lower limit of autoregulation.

The autoregulation curve as usually reproduced is, in a way, an abstraction. It relates aortic pressure to overall cerebral perfusion, but the important pressure for tissue perfusion is the perfusion pressure, which is the pressure gradient across the vascular bed—that is, for brain, MAP minus mean ICP, when the skull is closed. In normal physiological circumstances, the differences between MAP and perfusion pressure hardly matter, since ICP is normally low and decreases further with hypotension.

In the neurosurgical patient with haematoma or oedema, ICP becomes a major component in determining perfusion pressure and this must be borne in mind if arterial pressure is reduced during the early stages of a neurosurgical operation before the dura is opened. In some circumstances, for example head injuries, perfusion pressure may be inadequate entirely on account of an increased ICP in the presence of a normal, or even increased, arterial pressure (Miller, 1985). The other problem regarding the conventional autoregulation curve is that it relates to mean blood flow, whilst in situations of hypotension, blood flow becomes heterogeneous and decreases more severely in some areas than others.

The boundary zones between the territories of vascular supply are the sites of lowest perfusion (Adams, 1967). These territories lie between the distribution areas of the anterior, middle and posterior cerebral arteries and the superior and inferior cerebellar arteries. The reason for the vulnerability of

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these areas is that local arterial pressure is lower at these sites than elsewhere because of branching of the arterial tree. Consequently, a critically low perfusion pressure is reached in these areas at higher values of aortic pressure than in other parts of the brain. The concept of boundary zones is discussed fully in this Symposium (Graham, 1985).

It has been known for a number of years that the position of the autoregulation curve on the pressure-flow diagram depends to some degree on the method used to reduce arterial pressure. As a generalization, the worst case is hypotension resulting from blood loss, while drug-induced hypotension has lesser effects on cerebral perfusion (Fitch et al., 1976). The autoregulation curve in drug-induced hypotension is to the left of the autoregulation curve associated with haemorrhage and, in particular, the lower limit of autoregulation is at a low arterial pressure in drug-induced, compared with haemorrhagic, hypotension.

The reason for this is thought to be that blockade of sympathetic innervation of the pial arteries by drugs such as trimetaphan prevents the vasconstriction which haemorrhage produces in these medium-sized vessels. As pointed out above, maximum sympathetic stimulation reduces CBF at normotension by not more than 20%. However, such small differences assume importance at low MAP (Harper et al., 1972). Furthermore, more recently it has become clear that there are differences in the autoregulation curve between different hypotensive drugs, with nitroprusside (NTP) being associated with the greatest leftward shift on the curve (Stoyka and Schutz, 1975; Michenfelder and Theye, 1977; Maekawa, McDowall and Okuda, 1979).

Autoregulation is often impaired in areas of brain pathology, for example around traumatic brain contusions, tumours and in areas of cerebral vasospasm (Palvogyi, 1969; Overgaard and Tweed, 1974; Enevoldsen and Jensen, 1978). In such cases, cerebral perfusion decreases with any reduction in arterial pressure and it has been suggested that critically low perfusion may occur at greater arterial pressures in the absence of autoregulation. The present author believes that this is only true if local tissue pressure is high as a result of oedema.

Changes in cortical $P_{O_2}$ and electrical activity

The pattern of $P_{O_2}$ on the surface of the cerebral cortex is moved to lower $P_{O_2}$ values during hypotension and this effect is more severe during trimetaphan (TMP) than NTP hypotension, whilst haemorrhagic hypotension produces the worst $P_{O_2}$ profile (Maekawa, McDowall and Okuda, 1979). However, it is difficult to define ischaemia on the basis of tissue $P_{O_2}$ measurement, because some neurones normally exist in an environmental $P_{O_2}$ of approximately 0.3 kPa. A more direct approach is obtained by looking for derangements in brain function.

As Prior (1985) describes elsewhere in this Symposium, one of the derangements of function produced by ischaemia is suppression of cortical electrical activity. It has been demonstrated that electrical activity, as measured by the cerebral function monitor (CFM), is depressed at greater values of MAP during TMP compared with NTP hypotension (Ishikawa and McDowall, 1981; Prior, 1985). This would suggest that ischaemic thresholds are indeed different between these two hypotensive drugs, the advantage being with NTP. Of course, suppression of electrical activity, although indicative of an ischaemic depression of function, should not be equated with structural damage to the brain. It is well established that the brain can recover from ischaemia sufficiently severe to cause isoelectric EEG. Indeed, in a retrospective analysis of intraoperative CFM recordings during cardiopulmonary bypass, Malone, Prior and Scholtz (1981) showed that the CFM had been isoelectric for more than 7 min in all patients who later died with histological ischaemic brain damage. The clinical message would appear to be that if, during drug-induced hypotension, marked depression of the EEG or the CFM is seen, structural damage may be avoided if immediate measures are taken to increase MAP.

Changes in cortical ECF $K^+$, $Ca^{2+}$ and $H^+$ activities

Below the MAP threshold for EEG depression lie the thresholds for $K^+$ release from and $Ca^{2+}$ entry into cells, both these changes being indicative of severe cell membrane failure (Astrup et al., 1977; Harris et al., 1981; Heuser and Guggenberger, 1985). Histological ischaemic cell damage occurs close to the threshold for $Ca^{2+}$ entry into the cells. It has been demonstrated that the MAP threshold for $K^+$ escape into the ECF in the cerebral cortex is higher during TMP-induced hypotension than in NTP-induced hypotension (figs 1, 2) (Morris et al., 1983). It would therefore seem that there are differences in the threshold MAP values for cell membrane failure in the cerebral cortex with different hypotensive drugs and that, in clinical circumstances which require the induction of severe hypotension, NTP may be the drug of choice.
During induced hypotension, an extracellular fluid acidosis develops in the cortex, and presumably elsewhere in the brain. This acidosis results in part from carbon dioxide accumulation secondary to reduced CBF, but its severity indicates that there must be a major metabolic component. Measurement of tissue lactate concentrations confirms this. The decrease in pH, unlike the changes in ECF K⁺ and Ca²⁺, is not a threshold phenomenon. pH starts to decrease at values of MAP which are well above the threshold values and the development of acidosis is a function not only of MAP, but also of duration of hypotension. Blood loss occurring during hypotension rapidly increases the acidosis and, as discussed by Siesjö and Wieloch (1985) in this Symposium, the degree of acidosis is influenced by the plasma glucose concentration.

The severity of the acidosis is surprising. Values as low as pH 5.5 have been measured during TMP-induced hypotension in the cat (Morris et al., 1983) and, during induced hypotension, these values occur because the residual reduced flow continues to deliver glucose to a brain which metabolizes it anaerobically to lactate because of the low oxygen supply. The acidosis is less severe during NTP-induced hypotension. It is likely that severe extracellular acidosis is in part responsible for ischaemic cell damage, although this is not completely established. It is certainly true that complete recovery is commonly seen in animals following hypotension which has caused marked ECF acidosis.

It has been demonstrated that the severity of the tissue acidosis in conditions of partial global ischaemia is related partly to the plasma glucose concentration; the greater the plasma glucose concentration, the more glucose enters the brain, where it is metabolized anaerobically to lactate, with a worsening of the tissue acidosis (Siesjö and Wieloch, 1985). The usual preoperative starvation regimen practised clinically probably reduces the brain acidosis which occurs during intraoperative hypotension by maintaining low values of plasma glucose. For the same reason, glucose infusions during surgery should probably be avoided before induced hypotension.

**Restoration of normotension**

In animal studies, restoration of normotension (by stopping hypotensive drug infusion and re-infusion of withdrawn blood) results in normalization of K⁺ and pH values, provided the time lag between K⁺ release and the recovery of MAP is not too great. The time required for normalization of pH depends on the severity of the acidosis, but, in the cat, an
muscle cells is a factor (Steen et al., 1983). Rehncrona, 1977; Steen, Milde and Michenfelder, which perhaps indicates that movement of calcium calcium entry blocking drugs improves blood flow, has been demonstrated that the administration of

...ision by administering barbiturates (Nordstrom and Welsh, 1978). Attempts have therefore been made to protect the brain from this secondary hypoperfusion by administering barbiturates (Nordstrom and Rehncrona, 1977; Steen, Milde and Michenfelder, 1978). The aetiology of this secondary period of hypoperfusion is not well understood, although it has been demonstrated that the administration of calcium entry blocking drugs improves blood flow, which perhaps indicates that movement of calcium from the extracellular space into the vascular smooth muscle cells is a factor (Steen et al., 1983).

Brain oedema

Klatzo (1985) has reviewed the subject of brain oedema in this Symposium and made the distinction between vasogenic and cytotoxic oedema. A question relevant to this review is: Does oedema occur after profound arterial hypotension?

Symon, Branston and Chikovani (1979) have shown that brain water increases if CBF decreases to less than 20 ml min⁻¹/100 g, that is at values of flow which may occur during the clinical use of hypotension and which lie close to those at which the EEG voltage decreases, but above the thresholds for K⁺ and Ca²⁺ movements. This excess brain water is, presumably, moving to the intracellular space, as a result of increases in the number of osmotically active small molecules produced by partially anaerobic metabolism. This, then, would be a form of cytotoxic oedema and is usually reversible on restoration of MAP. If the degree of ischaemia is more severe, so that blood flow decreases to the threshold for failure of cell membrane ion haemostasis, that is flows less than 10 ml min⁻¹/100 g, then further cytotoxic oedema occurs as a result of movement of sodium into cells. This form of oedema, which probably rarely occurs during induced hypotension, is also reversible unless the cell has been so severely damaged as to proceed to ischaemic cell death (Hossman, 1976; Iannotti and Hoff, 1983).

The hyperaemia which occurs early in the recovery period results in an increase in brain bulk and increases intracranial pressure in the closed skull. This hyperaemia subsides rapidly after induced hypotension, certainly within 60 min and usually within 15 min. If MAP is allowed to increase rapidly to hypertensive values in this very early stage of recovery, fluid containing plasma proteins may be forced through the dilated capillary walls to produce vasogenic oedema (Klatzo, 1985). It is possible that the presence within the circulation of vasodilatory drugs, such as nitroprusside or halothane (Forster et al., 1978) may accentuate this vasogenic oedema. Ishikawa and colleagues (1983) have demonstrated, in dogs, the penetration through the blood–brain barrier of Evans Blue (a dye which attaches to plasma albumin) following induced hypotension with nitroprusside, but not after trimetaphan. It is probably good practice, therefore, to allow arterial pressure to recover rather slowly after induced hypotension, especially if a direct dilator such as nitroprusside has been used, in order to avoid vasogenic oedema. On the other hand, it is known that, following total circulatory arrest, re-perfusion may be patchy and that the uniformity of blood flow is improved by a rapid return of MAP. The situation is therefore unclear, but it is probably true that the degree of cerebral ischaemia which could occur during deliberately induced hypotension (in the absence of circulatory arrest) is not severe enough to cause patchy re-perfusion and so, in the author’s opinion, restoration of MAP should be gradual over 10–20 min. It is important to remember that ischaemia itself rarely results in vasogenic oedema in the early recovery period because the blood brain–barrier is resistant to ischaemic damage. It is the combination of hypertension, cerebral vasodilatation and hyperaemia which causes postischaemic vasogenic oedema.

If the brain ischaemia during induced hypotension has been severe enough, neurones are damaged irreversibly, particularly in the selectively vulnerable areas — that is the boundary zones, hippocampus and basal ganglia. Brain oedema in these areas of dying cells continues to progress and may lead to compression of surrounding capillaries, with further ischaemia and extension of the area of infarction (Ames and Nesbitt, 1983). In these circumstances the blood–brain barrier may again become permeable to plasma proteins, resulting in increased oedema formation.
The management of a patient who is thought to have suffered brain ischaemia during induced hypotension requires treatment for brain oedema spreading from the foci of neuronal cell death: controlled hyperventilation and infusion of hypnotic drugs. Mannitol is probably also valuable, except at times when the blood–brain barrier is “open”. Unfortunately, at present there is insufficient knowledge to define when this occurs in man.

In summary, a degree of cytotoxic oedema may occur after profound induced hypotension, and this is reversible within 1 h. Vasogenic oedema may occur if MAP is allowed to increase rapidly at the end of hypotension, especially in the presence of vasodilator drugs. Irreversible cytotoxic oedema occurs only with ischaemic cell death, but may lead to an extension of the area of infarction by compressing local blood vessels as a result of increased local tissue swelling and pressure. In these circumstances, the blood–brain barrier may open to plasma proteins.

FOCAL ISCHAEMIA

Up to this point we have discussed only the normal cerebral circulation. Congenital variations in the Circle of Willis are not uncommon and, in some patients, these may cause shifts in the location of the boundary zones. The main effect of pathology of the cerebral circulation, however, is to render some area of the brain more susceptible to ischaemia from induced hypotension. A common example would be atheromatous narrowing of the internal carotid artery resulting in a low intravascular pressure on the ipsilateral side, with the possibility of ischaemic flow values, particularly in the middle cerebral artery territory. Whether ischaemic damage occurs or not in such a patient depends on the level of hypotension used and the adequacy of the collateral circulation through the Circle of Willis and on the cortical surface. The problem with such patients is that the anaesthetist has no knowledge of the vascular pathology, which may be clinically silent (fig. 3). It is the possibility of clinically silent partial obstructions to flow, together with variations in the efficacy of the collateral vascular supply, either at the Circle of Willis or at the pial surface, which makes it impossible to generalize on the lowest arterial pressure which may be tolerated by the brain and which indicates the importance of monitoring electrical activity (Prior, 1985).

The sequence of electrical and ionic events which occur in focal ischaemia is the same as that reviewed above for global ischaemia during induced hypotension and the relationship between local ischaemia and local intravascular pressure is identical. However, the local intravascular pressure distal to the site of partial vascular obstruction is much lower than the systemic arterial pressure, which would be the pressure monitored by the anaesthetist.

The main differences between global and focal ischaemia are:

FIG. 3. Carotid angiogram showing fibromuscular dysplasia of the internal carotid artery. The condition consists of segmental overgrowth of the fibrous and muscular tissues of the media of the artery and is usually symptomless, although associated with an increased incidence of intracranial aneurysms. The induction of hypotension in a patient with this condition could have marked effects on cerebral perfusion.
(i). In focal ischaemia, there is a central densely ischaemic zone surrounded by a rim of partial ischaemia (this is often termed the "penumbra" (Astrup et al., 1977)—a word which originally described the rim of partial shadow during an eclipse of the sun).

(ii). The presence in focal ischaemia of maintained perfusion in the surrounding territories of arterial supply.

It is because of these two factors that vasoactive anaesthetics can influence the perfusion of the ischaemic cells, especially the cells in the penumbra zone, by constricting or dilating surrounding vascular territories, so inducing "steal" or "inverse steal" through collateral circulations, mainly at the pial surface.

ANAESTHETIC TECHNIQUES

General considerations

Some hypotensive drugs maintain cerebral perfusion better than others, presumably because they cause more marked cerebral vasodilatation. However, dilatation of the circulation may not be beneficial if it causes steal of blood away from a partially ischaemic area (in focal ischaemia); for example, the administration of NTP to a patient with unilateral internal carotid stenosis might increase flow on the contralateral hemisphere at the expense of the at-risk hemisphere. Smith and colleagues (1974) demonstrated that halothane increased the area of infarction following experimental middle cerebral artery occlusion, presumably by this mechanism. In circumstances of focal ischaemia, vasoconstrictive drugs may therefore be preferable, for example a thiopentone infusion.

An additional disadvantage of vasodilators is the increase in ICP produced, and this results in a decrease in cerebral perfusion pressure during hypotension. This factor, however, is only operative until the dura has been opened, for thereafter ICP is close to atmospheric pressure.

Although vasoconstrictor drugs decrease ICP and might therefore be advocated for this reason, the change produced is small in a patient whose ICP is normal. The situation is different, however, if ICP is increased as a result of intracranial tumour or oedema following recent subarachnoid haemorrhage. Cerebrovascular spasm is a problem when induced hypotension is used following subarachnoid haemorrhage, since reduced arterial pressure may exacerbate ischaemia in the territory of the spasm.

Unfortunately, little is known of the effect of drugs on spasm, except in animal models, the relevance of which to clinical "spasm" is debated. The use of vasodilator drugs, however, may produce local areas of steal when spasm is present.

There is much debate on the optimal arterial $PCO_2$ during induced hypotension. Some authorities advocate spontaneous ventilation in order to produce normocapnia or mild hypercapnia, with a view...
to maintaining cerebral perfusion. However, Harper and Glass (1965) showed that changes in arterial $PCO_2$ during haemorrhagic hypotension did not influence cerebral blood flow and this has been demonstrated also to apply during hypotension induced with halothane (Okuda et al., 1976) or trimetaphan (Gregory, Ishikawa and McDowall, 1981) (figs 4, 5). With nitroprusside, cerebral blood flow is greater during hypotension and therefore the cerebral vessels show some continuing but reduced sensitivity to $PCO_2$ change (Gregory, Ishikawa and McDowall, 1981). It seems that, when flow decreases to the level at which EEG depression occurs, there is no responsiveness to $PCO_2$ change. At greater arterial pressures there is some reduced carbon dioxide responsiveneness.

In the presence of focal pathology (atheroma or spasm) increases in carbon dioxide may be detrimental, as a result of the "steal" mechanism. However, since spasm affects medium-sized vessels and carbon dioxide changes affect small arteries and arterioles, a low carbon dioxide concentration, combined with spasm, may produce two segments of increased vascular resistance in series and reduce flow to very low values. This disadvantage may outweigh the possibility of achieving inverse steal by hypocapnia. Most clinicians conclude from these experimental findings that induced hypotension is probably best conducted at arterial $PCO_2$ values of approximately 4 kPa.

### Choice of hypotensive drugs

Beta blockers seem to have little direct action on the cerebral circulation. TMP acts mainly by ganglion blockade, with little dilator action on the cerebral vessels, as indicated by the lack of increase in ICP with this agent (Turner et al., 1977). As already discussed, the autoregulation curve shows better-maintained perfusion, compared with haemorrhagic hypotension. Other ganglion blockers such as pento- linium and hexamethonium probably resemble TMP in their cerebrovascular effects. NTP produces better cerebral perfusion at low MAP than does TMP, presumably because of its potent direct dilatory action, and nitroglycerine behaves similarly. Where very low arterial pressures are required for short periods, NTP is probably the agent of choice, provided its toxic limit is kept in mind. However, it does markedly increase ICP (Turner et al., 1977), an effect which is even greater with nitroglycerine (NG) (Rogers and Traystman, 1979). Also, the marked dilatation may produce steal in circumstances of focal ischaemia when TMP would have the advantage. Grubb and Raichle (1982) reported that cerebral oxygen utilization was increased during NTP hypotension in baboons under ketamine–nitrous oxide–oxygen anaesthesia. This would be disadvantageous, but concomitant anaesthesia with halothane or other volatile agents would probably block such an increase in oxygen requirements.

Adenosine triphosphate (ATP) has been used in a few centres for some years for inducing hypotension and at present there is increasing interest in this agent. It is a dilator of the cerebral circulation and may probably be considered to be in the same group as NTP and NG in its effects on CBF, ICP and autoregulation (Van Aken et al., 1984). It would therefore be anticipated that ATP, in common with NTP, may allow MAP to be reduced markedly without producing cell membrane failure, but a preliminary report from Heuser, Morris and Guggenberger (1984) suggests that this may not be the case. As yet, there is inadequate evidence on the profile of ATP action.

### Choice of anaesthetic drugs

Both thiopentone and Althesin reduce cerebral metabolism and CBF. Their cerebral vasoconstrictive action might be advantageous in focal ischaemia through the inverse steal mechanism (Rasmussen, Rosendal and Overgaard, 1975). Their action in reducing ICP tends to provide a higher perfusion pressure for a given systemic hypotension, provided the dura is closed. The inverse steal and the ICP effects probably account for the observation, in experimental animals, that the size of an infarct following temporary focal ischaemia is smaller when these drugs have been given (Smith et al., 1974). If hypnotic drugs of this group are given in high dosage with the objective of protecting the brain, EEG and CMR monitoring to detect ischaemia become insensitive and unreliable (Prior, 1985).

Nitrous oxide, halothane, enflurane and isoflurane are cerebral vasodilators. Despite this disadvantage volatile anaesthetics are commonly used to potentiate the i.v. hypotensive drugs. Inspired concentrations of halothane up to 1% and enflurane up to 1.5% are used for this purpose but, should circulatory arrest occur, cardiac resuscitation may be difficult (Prys-Roberts et al., 1974). Isoflurane is likely to become the agent of choice for supplementing the hypotensive effect of drugs such as TMP, since it reduces MAP and cerebral metabolic activity.
with only moderate cerebral vasodilatation (Newberg, Milde and Michenfelder, 1983). Indeed, Lam and Gelb (1983) were able to produce satisfactory hypotension with isoflurane alone.

**General anaesthetic considerations**

The margins of safety in respect of cerebral ischaemia are narrowed by the use of induced hypotension, so that any anaesthetic accident or mistake which would be only temporarily embarrassing under normal circumstances, may have catastrophic effects during induced hypotension. Anaesthetic technique must be meticulous: the airway must be absolutely secure, for an incident of hypoxia in a situation of marginally adequate cerebral perfusion could result in ischaemic brain damage, and could also cause sudden cardiac arrest. It should be remembered that a short period of total cardiac arrest following a period of low cerebral perfusion during induced hypotension would be more damaging to the brain because of the pre-existing cerebral tissue acidosis. Induced hypotension impairs pulmonary gas exchange and an increase in inspired oxygen to 40 or 50% is required to maintain full saturation of haemoglobin in many patients. Equally dangerous during induced hypotension is an incident of partial or complete obstruction on the expiratory side of the anaesthetic circuit, which produces a further dramatic decrease in MAP and an increase in central venous pressure.

Cerebral ischaemia may occur, not only in the operating theatre, but also in the recovery room, or after the patient has returned to the ward. For example, partial airway obstruction may occur in a patient still moderately hypotensive in the early period after operation, leading to cardiac arrest. Alternatively, severe orthostatic hypotension may result from propping the patient up in bed on return to the ward, as a result of persisting sympathetic blockade produced either by ganglion-blocking drugs or extradural or spinal anaesthesia.

Of course, the final arbiter of the avoidance of brain ischaemia from induced hypotension is the postoperative condition of the patient. However, it is very difficult to obtain firm evidence from mortality and morbidity surveys on the incidence of brain damage following induced hypotension, partly because of the possibly detrimental effect of anaesthesia, surgery and the primary pathology present. Older patients are commonly found to be less capable mentally after surgery and anaesthesia, whether or not induced hypotension has been used, whilst in young people the brain adapts so efficiently that even quite major degrees of ischaemic damage can be missed clinically.

The literature on mortality and morbidity surveys up to 1975 has been well-reviewed and critically assessed by Lindop (1975). He pointed out that the interpretation of data on mortality and morbidity from large series is impeded by lack of comparable control groups not subjected to induced hypotension. On the other hand, in the smaller series in which more subtle and time-consuming tests of cognitive and neurological function have been performed (including control groups) the small sample size precludes assessment of the incidence of complications. Nonetheless, he noted that all large reported series contain one or two anaesthetic deaths attributed to induced hypotension and he considers that a survey of the literature indicates a mortality incidence of 1 in 167 and a morbidity incidence of 1 in 39. The complications were mainly cerebral thrombosis, presenting as failure to recover consciousness or neurological deficits. Other complications included myocardial infarction and retinal artery thrombosis. Perhaps it needs to be emphasized again that these figures cannot be interpreted to indicate the degree of risk associated with induced hypotension in the absence of control data. Furthermore, the papers on which Lindop (1975) based these calculations extended back to the 1950s, when knowledge of the techniques and the availability of monitoring were much less than today. It is to be hoped, although it has not been proved, that hypotension is now safer than it was 20 years ago.

**CONCLUSIONS**

1. Cerebral perfusion is better maintained during drug-induced hypotension; of the drugs commonly used, perfusion is maintained best with nitroprusside.
2. As a result of (1), cortical PO$_2$ and electrical activity are least disturbed during hypotension when nitroprusside is used. The arterial pressure at which ischaemic failure of cell membrane function occurs is lower with nitroprusside than with trimetaphan.
3. At low values of arterial pressure, hypocapnia does not further reduce CBF.
4. Cerebral metabolic depressant drugs such as thiopentone and isoflurane may have a place in clinical techniques of induced hypotension.
5. A short period of hyperperfusion and loss of autoregulation follows induced hypotension and indicates a need to avoid hypertension in the recov-
Cytotoxic oedema may occur in the first hour following recovery from extreme hypotension. The blood–brain barrier may open also at the end of hypotension, especially if the arterial pressure is allowed to increase above control values in the presence of dilator drugs such as nitroprusside. (7) Margins of safety are narrowed during the use of induced hypotension and therefore the technique should be used only when it may benefit the patient and only by those trained and experienced in the method.

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REFERENCES


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