Anaesthesia may influence intraoperative bleeding in several ways, both physiological and pharmacological. Hydrostatic arterial pressure may be altered physiologically by changes in ventilatory pattern, positive end-expiratory pressure (PEEP) and posture, and also by pharmacologically induced alterations in myocardial contractility and peripheral vascular tone. Other factors, such as hypoxia and hypercapnia, may affect vascular diameter, while the use of regional sympathetic block induced by extradural or spinal anaesthesia is also very effective in the reduction of intraoperative blood loss.

Elective hypotension is a specific anaesthetic technique which goes beyond the ability of a good, safe, non-stress-inducing anaesthetic to reduce blood loss. Its use may be classified broadly as applicable to situations in which the particular operation would otherwise be impossible (for example cardiovascular or cerebrovascular surgery), situations in which excessive blood loss might be detrimental (for example orthopaedic, spinal and maxillo-facial operations) and situations in which blood loss interferes with surgical visibility or technique (such as middle ear and cosmetic surgery). The demands of elective hypotension in such situations are very different, ranging from acute, short-term "dial-a-pressure" hypotension, to sustained, moderate hypotension for reduction of blood loss. The use of significant hypotension for cosmetic surgery has always been surrounded by controversy, but with modern monitoring techniques, and in the hands of experienced anaesthetists, it is undeniably advantageous and contributes to remarkable results, particularly after injury and trauma. A further controversial topic is the use of hypotension to conserve blood loss in patients in whom the preoperative haemoglobin concentration is reduced or those in whom transfusion is undesirable for various reasons.

The effects of anaesthesia alone and in combination with surgery on blood coagulation and fibrinolysis have been investigated extensively. Although normal coagulation is unaffected by both general and regional anaesthesia, enhancement of fibrinolysis has been demonstrated, particularly in association with extradural techniques.

The problem of perioperative deep venous thrombosis and its prevention is also of considerable anaesthetic importance. While the use of extradural anaesthesia to enhance fibrinolysis has been shown to reduce the incidence of deep venous thrombosis, particularly in patients with hip fractures, additional or alternative prophylactic measures are frequently necessary. The influence of such measures on perioperative blood loss and their suitability during operations in which postoperative haematoma formation may produce critical complications is a difficult problem necessitating close liaison between surgeon and anaesthetist, particularly in the high risk patient and those taking oral contraceptive drugs.

Although operative blood loss is dependent primarily upon bleeding from cut vessels, its extent may be influenced in several ways. Bleeding may be arterial, in which case it is related directly to the mean arterial pressure, capillary, when it is dependent upon local flow in the capillary bed, or venous, when it is related to venous return and venous tone and is therefore posturally dependent. Arterial bleeding can be abolished only by the use of a tourniquet, but may be reduced considerably by a reduction in mean arterial pressure or heart rate. Capillary flow is reduced also by elective hypotension and by localized vasoconstriction caused, for example, by infiltration of adrenaline or release of vasoactive amines. Venous tone may be abolished completely by spinal or extradural anaesthesia and by direct acting vasodilators such as sodium nitroprusside.

Although the use of limb tourniquets to produce localized ischaemia during amputation has been practised for centuries, the first use of generalized hypotension to reduce local blood flow was reported by Griffiths and Gillies in 1948 [12]. Their use of "total spinal" anaesthesia to produce pharmacological sympathetic block was followed by Enderby's introduction of ganglion block using pentamethonium in 1950 [8]. In both cases, posture leading to venous pooling enhanced the hypotensive effect. Subsequent techniques have included the use of controlled depression of cardiac output with volatile agents such as halothane [30] and alternative ganglion blocking drugs such as hexamethonium, pentolinium and trimetaphan. More recently, directly acting vasodilators such as sodium nitro-
well known. Conversely, operations below heart level, for example those on the lower limb, may be borderline. The arm may be considered adequate for cerebral hypotension. While the pressure measured in the arm while tilting the patient is of extreme importance when measuring arterial pressure in the dilated venous vascular bed. Hypotension caused by reduction in total peripheral resistance can be achieved, therefore, centrally by drugs such as volatile agents acting on the vasomotor centre, peripherally at the level of the sympathetic ganglia, postganglionic noradrenergic (alpha) terminals, or directly on the blood vessels themselves. It may seem strange that techniques which induce vasodilatation may also reduce bleeding, but it is their effect on mean arterial pressure which effectively reduces local blood flow. In order to produce a measurable effect, local arterial pressure must be approximately 30–40 mm Hg to produce optimal effects and, in addition, venous drainage of the area must be unimpaired.

Effects of posture. Posture influences intraoperative bleeding both by producing regional ischaemia if the operation site is elevated above the level of the heart, and by augmenting the effect of agents such as sympathetic ganglion blocking drugs, by pooling of blood in the dilated venous vascular bed. The effects of head-up positioning on regional cerebral perfusion pressure in relation to mean arterial pressure at heart level are considerable. For each 2.5 cm of vertical height above the heart, the local arterial pressure is reduced by 2 mm Hg. This is of extreme importance when measuring arterial pressure in the arm while tilting the patient significantly head-up during a period of elective hypotension. While the pressure measured in the arm may be considered adequate for cerebral perfusion, the posture of the patient may make this borderline.

The use of posture to improve the operating field and to reduce bleeding in head and neck surgery is well known. Conversely, operations below heart level, for example those on the lower limb, may be improved by a head-down tilt. However, this is not such an effective way of reducing arterial pressure, as it tends to improve venous return and therefore maintain arterial pressure, in contrast with the head-up position which reduces venous return. Whenever possible, posture should be used to augment pharmacological methods of induced hypotension, particularly those which depend upon venous pooling.

Effect of intermittent positive pressure ventilation (IPPV). Under normal circumstances, venous return to the heart occurs during inspiration when a negative intrathoracic pressure enhances blood flow to the heart, even against the force of gravity. During IPPV, inspiration is associated with positive intrathoracic pressure, inevitably resulting in a reduction in venous return. If such an effect is augmented by posture, the resultant reduction in venous return and therefore cardiac output might be expected to be considerable. Prys-Roberts and colleagues [29] have shown that, in normotensive, anaesthetized subjects, IPPV has little effect on cardiac output, primarily because of the reflex vasoconstriction produced in response to what is effectively a limited Valsalva manoeuvre. In addition, the baroreceptors respond to hypotension by inducing a reflex tachycardia. There are, however, two methods of inducing hypotension in which cardiac output may decline considerably in response to IPPV, as a result of temporary autonomic paralysis. Both ganglion blocking drugs and beta adrenoceptor antagonists may partially or completely block the Valsalva response [3], thus limiting the normal compensatory mechanism.

In general, IPPV is a useful adjunct to any hypotensive technique, largely because it augments pharmacological methods of reducing arterial pressure, thus limiting the dose necessary to produce the desired effect and the postoperative duration of hypotension. In addition, controlled ventilation allows the application of positive end-expiratory pressure (PEEP) to the airway, which is another method of limiting venous return and assisting in arterial pressure reduction. During the inspiratory phase of controlled ventilation, blood flow to the heart is reduced considerably and this therefore occurs predominantly during the passive process of expiration. If PEEP is applied to the airway, both venous return and cardiac output are further reduced.

Respiratory physiology

Effects of carbon dioxide control. Carbon dioxide is a vasodilator and hyperventilation leading to hypocapnia induces vasoconstriction. Hypocapnia can be achieved by moderate hyperventilation. However, care must be taken during hyperventilation with patients in the head-up position, as vasoconstriction may reduce cerebral blood flow to critical values.

Effects of hypotension on pulmonary gas exchange. As pulmonary blood flow is dependent upon gravity, the head-up position leads to a reduction in blood flow to the apical parts of the lung. However, alveolar ventilation occurs throughout the lung, including the upper segments, resulting in considerable ventilation perfusion (V/Q) mismatch and
an increase in physiological deadspace. This may be as great as 80% of the tidal volume [7] and is of particular importance in spontaneously breathing patients. The reduction in alveolar ventilation and increased physiological shunt are additional reasons for the use of IPPV during elective hypotension.

In addition, many anaesthetists increase the inspired oxygen concentration during elective hypotension, to minimize the effects of this $V/Q$ imbalance.

**MECHANICAL METHODS OF BLOOD FLOW REDUCTION**

**Tourniquets**

Tourniquets are suitable only for application to limbs or parts of limbs, for example fingers and toes. Their use should be monitored critically for two main features: first, the duration for which the tourniquet is applied, as prolonged ischaemia may result in permanent damage to the limb; second, the pressure applied, as pressure to the tissues underneath the tourniquet may cause necrosis and neurological damage. Measurement of the patient's arterial pressure is essential, so that the tourniquet may be inflated to a pressure sufficiently greater, to occlude the arterial circulation. The pressures commonly used in normotensive patients are 250 mm Hg in the arm and up to 300 mm Hg in the leg. Finger tourniquets are usually applied with pieces of elastic and therefore their pressure is not measured.

It is essential that only correctly designed tourniquet cuffs with a method of pressure measurement and regulation are used, as these incorporate safety devices both to prevent the tourniquet slipping and to prevent accidental deflation. Tourniquet time must be limited to 60 min in the upper limb and 90 min in the lower limb, although ischaemic damage may occur even during these short periods. Tourniquets should not be used in patients suffering from sickle cell disease, as the local acidosis produced may induce sickling as a result of alteration in haemoglobin S.

**Local infiltration with sympathomimetic amines**

Adrenaline and other related amines are used frequently to induce local vasoconstriction. The concentration of adrenaline should be sufficient to induce vasoconstriction without causing intense or persistent vasospasm which may induce local necrosis. Concentrations of 1:200 000–1:400 000 are used commonly, similar to those used with local anaesthetics. The total dose of adrenaline should be limited to 500 µg. Accidental intravascular injection of adrenaline may occur during infiltration, and for this reason the use of a volatile anaesthetic with a high arrhythmic threshold, for example isoflurane, is preferable to halothane.

**PHARMACOLOGICAL METHODS WHICH REDUCE BLOOD LOSS**

**Volatile anaesthetic agents**

**Halothane.** Although halothane causes a moderate degree of vasodilatation, the overall reduction in total peripheral resistance is approximately 15–18%. Vasodilatation in the skin and splanchnic vascular beds is balanced by vasoconstriction in skeletal muscle, any additional hypotension caused by halothane being a direct result of myocardial depression. In addition, bradycardia induced by halothane further reduces cardiac output. While halothane is often used successfully in small concentrations as a background to hypotensive anaesthesia, its use as a sole hypotensive agent in larger doses should be discouraged. This is of particular importance in neurosurgery if an increase in intracranial pressure is to be avoided.

**Enflurane.** The mechanisms and effects of hypotension induced by enflurane are similar to those of halothane. Myocardial depression and vagal stimulation are still significant factors if excessive doses of the drug are used and for this reason it also should be used only in moderate doses, simply as a background agent.

**Isoflurane.** Unlike both halothane and enflurane, isoflurane has minimal effect on myocardial contractility at low inspired concentrations. The peripheral vasodilator effect is readily adjusted by alterations in inspired concentration. For this reason, it is becoming used increasingly as a hypotensive agent, particularly when only a moderate reduction in arterial pressure is required. It has the additional benefit that increasing doses cause not only vasodilatation and hypotension, but also central nervous depression, thus minimizing any reflex vasoconstriction or tachycardia which may occur as a result of baroreceptor stimulation under relatively light anaesthesia. Isoflurane also appears to have less effect than either halothane or enflurane upon intracranial pressure in patients with normal preoperative values [22]. It has been suggested that, by decreasing afterload, but not simultaneously reducing cardiac output, isoflurane may be detrimental in patients with ischaemic heart disease. This so-called "coronary steal" however, has not been associated with any increase in morbidity or mortality in such patients [36].

**Sympathetic ganglionic block**

**Trimetaphan, pentolinium.** These drugs cause autonomic ganglion block by competitive inhibition of acetylcholine. Their effects are not confined to the sympathetic system, as cholinergic transmission also occurs in parasympathetic ganglia. Interruption of sympathetic outflow causes vasodilatation which tends to be relatively slow in onset and recovery. The duration of hypotension induced by trimetaphan is relatively short (10–15 min) and for this reason the drug is often administered by i.v. infusion (3–4 mg min$^{-1}$). In contrast, a single injection of pentolinium 5–15 mg produces hypotension for about 45 min and allows a slow return of arterial pressure to normal values.

Although several gastrointestinal and urinary symptoms may result from concomitant parasympathetic block, mydriasis and tachycardia are clinically important during induced hypotension. The increase in heart rate which often accompanies hypotension caused by ganglion block may severely
impair the effectiveness of these drugs in reducing bleeding. Tachyphylaxis, that is the need for increasing doses of the drug to produce the same effect, is particularly marked with trimetaphan and may make a stable arterial pressure difficult to achieve. Continuous infusion is considerably superior to intermittent bolus dose administration in this respect. Pentolinium is at present unobtainable in the U.K., but may be reintroduced.

Non-depolarizing neuromuscular blocking drugs

Alcuronium, tubocurarine. The use of non-depolarizing neuromuscular blocking drugs to facilitate IPPV as an adjunct to elective hypotension has been advocated for some time. Tubocurarine, the drug used most widely in this situation in the past, and now alcuronium initially were thought to induce a degree of sympathetic ganglionic block. More recently, it has been shown that the main reason for their hypotensive effect is release of histamine, which induces vasodilatation. This far outweighs any effect caused by mild ganglion block.

Alpha adrenoceptor block

Phentolamine, phenoxybenzamine, chlorpromazine, droperidol. Alpha adrenergic blocking agents produce vasodilatation by competitive block of postsynaptic noradrenergic receptors within the sympathetic system. While the effects of phentolamine are relatively short (20–40 min) and easily reversible, those of phenoxybenzamine may last several days as this drug, a nitrogen mustard derivative, forms an irreversible receptor complex. Phentolamine also exerts a myocardial stimulant (beta adrenergic) effect, increasing both oxygen consumption and heart rate. Phenoxybenzamine may cause considerable sedation. While phentolamine 5–10 mg is used in the rapid induction of intraoperative vasodilatation, phenoxybenzamine 0.5–2.0 mg kg$^{-1}$ for 10 days is used more commonly for chronic vascular expansion before surgery, to minimize the effects of circulating catecholamines, for example in the surgical removal of phaeochromocytoma. Both chlorpromazine and droperidol cause mild alpha adrenergic block which is often useful in the preparation of patients before hypotensive anaesthesia or hypothermia.

Beta adrenoceptor block

Propranolol, oxprenolol, labetalol, atenolol, esmolol, practolol. The main advantages of the beta adrenoceptor antagonists for induced hypotension are in the reduction of heart rate and cardiac output. Many anaesthetists believe that the maintenance of a slow heart rate without any additional hypotension considerably reduces operative bleeding. Propranolol has often been used to produce this "rheostatic" hypotension. Although preoperative oral therapy (propranolol 40 mg three times daily) is probably best, propranolol 1–2 mg i.v. may be used during anaesthesia. Beta adrenoceptor block with either propranolol or oxprenolol is used also either before or during operation to counteract the tachycardia produced as a side effect of induced hypotension with either ganglion blocking or direct acting vasodilator drugs. Again, it is best to administer the drugs orally rather than i.v., as this produces a steady intraoperative blood concentration. Although the combined alpha and beta adrenoceptor blocking drug, labetalol, would seem ideal for use in induced hypotension, it is important to realize that the alpha blocking effects of the drug last only for 30 min, compared with a 90-min duration of beta block. In addition, the beta blocking effects are five to seven times as potent as the alpha block. The perioperative use of beta block with either propranolol or labetalol may have considerable benefit in the prevention of wide fluctuations in arterial pressure, particularly in patients with subarachnoid haemorrhage and vasospasm.

Direct acting vasodilators

Sodium nitroprusside. The recent interest in direct acting vasodilator drugs began with the reintroduction into clinical practice of sodium nitroprusside (SNP) [15, 25]. The main advantage of this drug is its evanescent duration of action, allowing rapid reduction of arterial pressure and equally rapid restoration to normal values. It is the only drug capable of predictably producing "dial-a-pressure" hypotension over relatively short periods, for example in the reduction of bleeding during removal of meningiomas and major vascular surgery or to facilitate clipping of cerebral aneurysms. As a vasodilator, SNP inevitably causes an increase in intracranial pressure, and for this reason should not be used during neurosurgery before the skull is open in a patient with increased intracranial pressure. Nevertheless, during induced hypotension with nitroprusside, autoregulation is maintained at cerebral perfusion pressures considerably less than with other drugs [37].

Shortly after the introduction of SNP into clinical practice, reports of fatalities during its use were attributed directly to cyanide poisoning [6, 14, 21]. Each molecule of SNP contains five cyanide radicals which are liberated during the breakdown of the drug in either plasma or red blood cells. Several studies, however, have failed to demonstrate significant effects upon red cell oxygen transport by cyanide liberated during the routine clinical use of SNP [4, 41].

The normal metabolic pathway of SNP breakdown is non-enzymatic, occurring in both red cells and plasma (fig. 1). The intracellular reaction is catalysed by the conversion of haemoglobin to methaemoglobin. Ultimately, more than 98% of the cyanide produced from SNP is contained within the red blood cells, while a small proportion is combined with either methaemoglobin or vitamin B$_{12}$. The majority of cyanide is metabolized in the liver, by the enzyme rhodanase, to thiocyanate which is then excreted in the urine. The rate-limiting factor in cyanide metabolism appears to be the availability of sulphhydryl groups and the administration of sodium thiosulphate can considerably enhance thiocyanate production and therefore reduce blood cyanide concentrations [18]. The use of thiosulphate does not appear to affect the hypotension produced by SNP. At the maximum safe doses recommended for
administration of SNP, (1.5 mg kg\(^{-1}\) [40] or 10 \(\mu\)g kg\(^{-1}\) min\(^{-1}\) [38]), small increases in plasma lactate concentration occur which are mirrored by increases in arterial base deficit. These changes are only minor, the maximum base deficit being approximately —6 to —7 mmol litre\(^{-1}\), and are reversible spontaneously upon discontinuation of SNP therapy. The routine measurement of acid–base balance during SNP therapy would appear to provide adequate clinical information of the development of cyanide toxicity during routine clinical use.

The use of SNP in patients already anaesthetized with a background hypotensive anaesthetic technique is the method of choice for the production of extreme hypotension for neurosurgery. At present, no other drug provides the predictable and rapid hypotensive effect necessary for many aspects of intracranial surgery. Natural apprehension over the potential toxicity of SNP has centered largely around a few reported cases, all of which were attributable directly to cyanide poisoning [6,14,21]. Close examination of these reports confirms that in all cases doses of SNP greatly in excess of those required for routine clinical use were needed to produce toxic symptoms. If the dose of SNP is limited to that already stated above, toxic symptoms do not occur in patients with normal renal and hepatic function. For longer term infusion and in the presence of adequate sulphhydryl groups as the substrate for cyanide detoxification by rhodanase, a maximum dose rate of 8 \(\mu\)g kg\(^{-1}\) [23] has been shown to be satisfactory.

\textit{Trinitroglycerin (TNG).} Nitroglycerin metabolism involves hepatic breakdown of trinitrate, producing di- and mono-nitrate and finally glycerol. The vasodilator activity of these smaller nitrate molecules is reduced as their size decreases.

TNG produces a steadier and less dramatic reduction in arterial pressure, with a greater effect on systolic than diastolic pressure and tending to maintain blood flow. Recovery from nitroglycerin-induced hypotension is also less rapid, taking between 10 and 20 min, in contrast with the 2–4 min for SNP. It has been suggested that this slower effect of nitroglycerin produces less overshoot of arterial pressure, either at induction of hypotension or after restoration of normal pressure, but as the drug appears less effective in some patients in the production of extreme hypotension, its use may not be ideal in all situations. Although TNG has been advocated as a direct acting vasodilator for neurosurgery, in one study [5], hypotension to 50 mm Hg was not possible in three of 22 patients. Unlike SNP, which dilates both resistance and capacitance vessels equally, TNG exerts its effect principally upon the venous capacitance system. As a result, diastolic pressure is maintained at greater values than with SNP; for this reason TNG maintains coronary artery perfusion more effectively than SNP. While this is probably of little importance in healthy patients, it may be of considerable advantage in patients with impaired myocardial or cerebral circulation. However, the increase in intracranial pressure produced by nitroglycerin may be even greater than with SNP.

\textit{Spinal and extradural anaesthesia.}\n
Pharmacological sympathectomy using local anaesthetic agents is an effective way of inducing hypotension. Lumbar extradural anaesthesia causes arteriolar dilatation and hypotension, together with a reduction in venous tone. This is enhanced by posturally dependent pooling of venous blood, leading to a decrease in venous return and therefore cardiac output. If the block is extended to the mid-thoracic region, the cardiac sympathetic fibres passing in segments T1–4 are also blocked, preventing compensatory tachycardia which would otherwise occur. This also limits any baroreceptor response, and prevents tachycardia occurring as a result of other pharmacological methods of induced hypotension.

Regional anaesthesia is used most commonly in lower abdominal or pelvic surgery to minimize blood loss, particularly that occurring from the pelvic venous plexuses. The complete abolition of venous tone is extremely effective in minimizing blood loss without the need for profound arteriolar hypotension.

If adrenaline is added to the local anaesthetics used, systemic absorption may partially counteract the hypotensive effect of the regional block. Adrenaline has the advantage of prolonging the effects of the local anaesthetics used, although this
can be achieved satisfactorily by the use of intermittent or continuous extradural injections.

**MONITORING DURING INDUCED HYPOTENSION**

Routine monitoring should include ECG, arterial oxygen saturation, end-tidal carbon dioxide concentration and either direct or indirect arterial pressure measurement, in the knowledge that, assuming a normal intracranial pressure and with the appropriate postural adjustments, the measurement is directly related to cerebral perfusion pressure. In addition, the electrocardiogram provides an indication of the development of relative myocardial ischaemia [33]. Although instruments such as the cerebral function monitor are available for use during hypotensive anaesthesia, their use and, indeed, their possible benefits are relatively limited [28].

**Electrocardiographic monitoring**

ECG monitoring is essential to demonstrate two vital signs of inadequate myocardial perfusion: the development of ectopic beats and ST segment depression. Although a single-channel ECG is not capable of demonstrating the exact site of any ischaemia, ST segment changes do occur and are usually readily reversible by increasing the arterial pressure. The myocardial response to relative hypoxaemia and hypoperfusion is a sensitive monitor of hypotension being exploited excessively.

**Measurement of arterial pressure**

- **Indirect measurement.** All these methods involve modifications of the traditional cuff technique and are subject to errors in observation and interpretation. Those chiefly used are the oscillotonometer and, more recently, the automated versions of this method, such as the Dinamap. Hutton and Prys-Roberts [13] have shown that errors in interpretation of oscillotonometry have tended to err on the side of safety, as what was originally thought to be systolic arterial pressure has now been demonstrated to represent more closely the mean pressure. The automatic versions are an improvement as they remove the observer bias and, indeed, display not only systolic but also mean and diastolic pressures. All these methods depend upon regular detection of pulsation at the cuff, which is rendered inaccurate by irregular cardiac rhythms such as atrial fibrillation. Moreover, as with all indirect methods of arterial pressure measurement, they are most accurate within the normal ranges of pressure and become increasingly inaccurate at excessively small or large pressures. If hypotension to a systolic pressure of less than 70 mm Hg is anticipated, direct arterial monitoring should be considered essential.

- **Direct measurement.** Although indirect methods of arterial pressure measurement are used during relatively mild hypotensive techniques such as intermittent ventilation with isoflurane, extradural anaesthesia or even, in some cases, the use of ganglion blocking drugs, direct monitoring is an essential part of the technique when vasodilators such as SNP are used and wide variations or rapid changes in arterial pressure are anticipated.

The position of the transducer is the level at which arterial pressure is actually measured and if the mean arterial pressure at head level is desired, the transducer should be placed at this height. Assuming a normal intracranial pressure and with the appropriate postural adjustments, the measurement is then related directly to cerebral perfusion pressure.

**Oxygen saturation and end-tidal carbon dioxide monitoring**

Induced systemic hypotension inevitably results in a reduction in pulmonary artery pressure and, as pulmonary perfusion is gravity dependent, leads to an increase in V/Q mismatch within the lung. The ability to monitor respiratory gas exchange non-invasively allows alterations in inspired oxygen and minute volume to be made in specific relation to the patient's needs, rather than on an empirical basis. The inspired oxygen concentration may need to be increased during a period of hypotension to compensate for changes in lung perfusion. In addition, end-tidal carbon dioxide analysis is a sensitive method of detecting air embolism, which may also occur during some cranial or head and neck operations, particularly if PEEP is not used.

**PRACTICAL TECHNIQUE OF INDUCED HYPOTENSION**

When induced hypotension is superimposed upon a general anaesthetic technique, no single agent is capable of providing the ideal conditions for all operations, the requirements of surgery falling into three broad groups. The first demands relatively slow onset and sustained moderate hypotension with a slow return to normal pressures, and is ideal for most plastic, maxillo-facial and ear, nose and throat surgery when rapid return to normal pressures may cause reactionary haemorrhage. In the second, in which massive blood loss is anticipated, moderate sustained hypotension together with a reduction in heart rate is probably all that is required. In the third group, some operations are not only impossible without profound hypotension, but also require short periods of excessively small pressures, for example during clipping of a cerebral aneurysm. Further indications include resection of aortic coarctation, when rapid fluctuations in arterial pressure necessitating immediate control frequently occur. In general, there is a need for two basic methods of hypotension: elective, slow onset, slow recovery hypotension, or "dial-a-pressure" hypotension.

In all cases of elective hypotension, a background anaesthetic against which hypotension can be induced is essential, the principles of balanced anaesthesia dictating that it is better to use individual agents to achieve specific effects rather than to pursue the toxic properties of an agent such as halothane in the production of hypotension by myocardial depression. An ideal background anaesthetic consists of omission of atropine premedication and the use of generous sedation or analgesia.
Induction of anaesthesia with thiopentone, fentanyl and a long-acting, non-depolarizing neuromuscular blocking drug, for example, alcuronium, should be used. After topical anaesthesia of the larynx, intubation is performed with a non-kinking tracheal tube to remove any possible risk of partial airway obstruction and carbon dioxide retention. Moderate hyperventilation with nitrous oxide and oxygen together with 0.5–1.0% isoflurane provides a background technique against which hypotensive agents can be used.

Under these stable conditions, specific hypotensive drugs may be used with the minimum of side effects such as tachycardia or excessive hypotension. During hypotension, the inspired oxygen concentration may be increased to 40% or even 50% if excessively small pressures are being used over a short period, for example during neurosurgery.

Postoperative management

Recovery staff must be made aware of patients in whom elective hypotension has been used. Not only will they need to monitor arterial pressure accurately and regularly in the recovery room, but they should also continue the anaesthetic management in the same way. Airway care to avoid carbon dioxide retention and partial obstruction is essential, together with frequent recordings of arterial pressure. The patient's position should be determined by the measured arterial pressure, and postural changes may be necessary for several hours to ensure adequate cerebral perfusion. Supplementary oxygen should be administered in all cases until the patient is adequately awake, and may be required for longer where oxygenation is thought to be critical. In patients in whom pharmacological modification of sympathetic responses has been undertaken, such as with the use of ganglion blocking drugs, patients should remain in bed for 12–18 h after operation and, if necessary, lying virtually flat until they are able to sit up without feeling faint.

Contraindications to induced hypotension

Although many anaesthetists are reluctant to use induced hypotension, there are very few patients in whom it cannot be used safely. Most anaesthetists would refrain from utilizing the technique in patients with evidence of severe cardiovascular or cerebrovascular disease, although both these are relative contraindications if, for example, cerebral aneurysm surgery is proposed.

Myocardial ischaemia. This is made worse by an increase in the rate–pressure product. Because hypotensive techniques are designed to reduce both heart rate and arterial pressure, cardiac work is reduced considerably. Many such patients are already receiving beta adrenoceptor blockers and this should be continued during operation. In patients in whom a reduction in afterload is produced by direct acting vasodilators, myocardial work may be further reduced.

Hypertension. Although patients with treated hypertension may be abnormally sensitive to hypotensive drugs, hypotensive techniques may still be used with care. Untreated hypertension, however, is a relative contraindication, as the arterial pressure may be extremely labile and profound hypotension result. It is also important to remember that volatile anaesthetic agents enhance the hypotensive effects of drugs which the patient is already receiving. Monitoring the ECG is essential. Rollason and Hough [32] demonstrated ST depression in hypertensive patients and Simpson, Bellamy and Cole [33] noted similar changes during anaesthesia with nitroprusside-induced hypotension. While the importance of such changes is doubtful, they do demonstrate the need for care when utilizing hypotension in such patients.

Respiratory disease. Limitations in the use of hypotensive anaesthesia in patients with chronic respiratory disease are related to disturbances of normal pulmonary physiology. The increase in physiological deadspace caused by V/Q imbalance is more important in patients in whom preoperative gas exchange is impaired. Under normal circumstances, hypoxic pulmonary vasoconstriction occurring in poorly ventilated segments of the lung prevents gross disorders of ventilation/perfusion. Vasoconstriction induced by direct acting drugs abolishes this response and makes shunting worse.

Reversible airways obstruction and bronchospasm may be made worse by the use of either ganglion blocking drugs or beta adrenoceptor antagonists which are not cardiospecific, and such drugs are contraindicated in asthmatic patients. Increased inflation pressures may lead to carbon dioxide retention and severe hypotension, by impairment of venous return.

Diabetes mellitus. The contraindication to induced hypotension associated with diabetes mellitus is related to the drugs used rather than to the technique. Ganglion blocking drugs, by producing sympathetic block, impair stress-induced gluconeogenesis mediated by adrenaline. Beta blockers may also potentiate hypoglycaemia in insulin-dependent diabetics and it is the combination of hypoglycaemia and hypotension which may produce severe consequences, particularly on cerebral metabolism. Under normal circumstances, however, it is safe to use volatile agents, direct acting vasodilators or local anaesthetic techniques without disturbance of blood sugar concentrations.

Complications of hypotensive anaesthesia

Inadequate hypotension. Although inadequate hypotension is not regarded by many as a complication of hypotensive anaesthesia, failure to appreciate this problem may lead to the excessive use of certain agents and consequent toxic effects. Some patients, for example, with an “overactive” renin–angiotensin system have been shown to be “resistant” to SNP. Before this was appreciated, excessive doses of the drug sometimes were used in the mistaken belief that, eventually, hypotension would be achieved. This led in some cases to SNP toxicity, cyanide poisoning and even death [6, 14, 21]. If hypotension using one drug is not sufficient, then a second agent acting at a different site in the sympathetic system should be used. This has been put to good effect, for
PERIOPERATIVE BLOOD LOSS

example, by combinations of ganglion blocking drugs such as trimetaphan with SNP or, more recently, the combination of isoflurane and SNP.

Excessive hypotension. Moderate hypotension is produced frequently during anaesthesia and many patients are subjected to systolic arterial pressures of 60 mm Hg during routine surgery. It is unlikely that hypotension to this degree, particularly when induced by vasodilatation and accompanied by additional oxygen administration in fit patients, should lead to any permanent adverse effect. Nevertheless, situations have arisen in which permanent damage has resulted from the use of elective hypotension. This is related to excessive hypotension, impaired oxygenation or inadequate arterial pressure monitoring. Lindop [20], surveying the evidence concerning the effects of hypotension on vital organs, stressed the importance of flow rather than pressure in the development of complications. This is particularly important, as normal oxygen extraction by most organs (with the exception of the heart) is only about 25%.

In considering the effects of hypotension on the brain, autoregulation becomes important. It has been shown that the lower limit of autoregulation is better preserved with SNP-induced hypotension than with TNG, flow remaining constant down to mean pressures of 40–50 mm Hg [37]. These data should be interpreted with some caution when extrapolated to humans, because of the effects of anaesthesia and other metabolic derangements upon cerebral blood flow. More detailed studies, such as continuous EEG monitoring [28] and jugular venous oxygen measurements [19], have produced inconclusive results. Probably the most important rule is not to reduce the systolic pressure during operation to less than the diastolic pressure before operation, and to avoid where possible severe head-up tilt unless arterial pressure is being measured at the head level.

The monitoring of ST segment depression to detect myocardial ischaemia would appear to be the most reliable method of demonstrating adverse cardiac effects caused by hypotension [33]. Provided myocardial work is reduced and a compensatory tachycardia produced by hypotension does not occur, severe problems appear to be very rare.

Although those antagonistic to hypotensive anaesthesia may always cite cases of permanent damage or even death related directly to the decreasing of arterial pressure, large series, particularly that collected by Enderby [9], do not bear this out. At East Grinstead, the mortality rate was 1 in 4128 cases of induced hypotension and Kerr [17], in a separate series reported no mortality or morbidity in a series of 700 patients.

EFFECT OF ANAESTHESIA ON COAGULATION AND FIBRINOLYSIS

Several studies have demonstrated that a wide variety of both general and regional anaesthetic techniques have no significant effect on blood coagulation. Thiopentone, diethyl ether, cyclopropane, nitrous oxide, suxamethonium, tubocurarine and halothane have been investigated without detrimental effects [26, 39], as has neuroleptanaesthesia [2, 31].

Enhanced fibrinolytic activity, in contrast, occurs as a direct result of surgery and yet the influence of anaesthesia on the activation of this system is unclear. Engquist and Winther [11] did not find significant anaesthetic-related enhancement of fibrinolytic activity with halothane, cyclopropane, ether, neuroleptic drugs or pentobarbitone, pethidine and nitrous oxide anaesthesia and further studies have confirmed these results for halothane [26] and neuroleptanaesthesia [2, 31]. In contrast, Oyama and colleagues [27] found a significant increase in fibrinolytic activity during enflurane anaesthesia, but this has not been substantiated [34]. Engquist, Askgaard and Funding [10], in a study combining extradural block with general anaesthesia using either halothane alone or a halothane-fentanyl combination, found that increased fibrinolytic activity could be prevented only by a block of sufficient extent to suppress the cortisol response. In a comparative study of general and regional anaesthesia [34], while the use of halothane, enflurane, trichloroethylene or fentanyl, when superimposed on a standardized technique, failed to produce a demonstrable effect, lumbar extradural anaesthesia was associated with significantly enhanced fibrinolytic activity. These findings confirmed those of Modig, Malmberg and Saldeen [24], who demonstrated increased fibrinolytic activity during and after extradural anaesthesia for total hip replacement and suggested that this might be beneficial in the prevention of postoperative deep venous thrombosis. The actual mechanism responsible for the effect of extradural anaesthesia on fibrinolysis is unclear, but it is thought to be related to alterations in regional blood flow as a result of sympathetic block produced by the technique. While overall limb blood flow is increased during extradural anaesthesia, this is almost entirely caused by increased skin blood flow. The concomitant decrease in muscle blood flow, combined with areas of venous stasis, are thought to trigger the fibrinolytic cascade. The protein cascades involved in both coagulation and fibrinolysis are part of the acute phase response to inflammation, but release of all the proteins in this group is not affected significantly by anaesthesia [35].

Prevention of perioperative deep venous thrombosis

Although there are several mechanisms, both mechanical and pharmacological, which may be used to prevent perioperative deep venous thrombosis, many are relatively contraindicated in operations in which blood loss either may be excessive or may interfere with microscopic surgical technique. Full anticoagulation is obviously contraindicated under normal circumstances and many surgeons are wary even of using prophylactic subcutaneous heparin (5000 u., 8- or 12-hourly). Other pharmacological methods such as dextran infusion are similarly unsatisfactory. The recent introduction of the small molecular weight heparins (Fragmin, Clexane) may offer considerable advantage. The small molecular
REFERENCES


