Pharmacologically induced hypotension is an important technique in the management of many surgical procedures. In this article, the author discusses three drugs currently in use for this technique, as well as clinical indications for induced hypotension.

Various hypotensive agents and techniques have been recognized by the medical field since the mid 1800s. Sodium nitroprusside (SNP) was known to chemists as early as 1849. In 1886, scientists realized that the administration of this drug could result in cyanide poisoning. It was not until 1928, however, that Johnson first used SNP to lower the blood pressure of three hypertensive patients.¹

Clinical use of SNP did not begin until 1951. During this period there was much interest in the control of hypertension. Enderby investigated the use of ganglionic blockade with pentamethonium, hexamethonium, and pentolinium.² In 1955, Page and colleagues began investigating SNP.³ The use of SNP and other agents for control of severe hypertension was quickly accepted but the use of drugs for eliciting deliberate hypotension did not begin until 1961 under the direction of Gardner.⁴ And, it was not until 1977 that SNP was approved for the intraoperative purpose of inducing hypotension.

During this beginning investigative period, reports were being collected on the use of controlled hypotension. The results of the technique were not always benign. In 1953, Gillan reported two cases of unilateral blindness following hypotensive anesthesia.⁵ In 1955, Little collected statistics from 27,930 hypotensive anesthesia cases and found a morbidity rate of 1:31. The incidence of complications worsened when the systolic pressure was below 80 mmHg. The overall mortality rate was 1:291.⁶ However, as familiarity with hypotensive techniques improved, knowledge expanded and technology increased, the results have not been quite as negative. In 1961, Enderby reported a mortality rate of only 1:9,107.⁷

Controlled hypotension is essentially what its name indicates: a controlled, deliberate lowering of the blood pressure to a predetermined level. But, it also involves the ability to return the pressure to its previous range. Frequently, we see hypotension during the course of anesthesia that is not deliberate or under our control. This situation is not to be mistaken with the technique to be reviewed here. How we lower the blood pressure and to what level it is lowered will be discussed in this article.

Hypotensive limit

Before we begin our discussion of the hypotensive limit, it is important to understand a basic concept concerning cerebral perfusion. Cerebral perfusion is significant since essentially no healthy organ is more susceptible to the effects of a lowered blood pressure than the brain. The important point to note is that if cerebral perfusion-pressure (CPP) is between 60 and 160 mmHg, cerebral perfusion is not related to the cerebral perfusion pressure. Cerebral autoregulation is remarkably reliable until the perfusion pressure is below 60 mmHg.
But what happens below 60 mmHg? At this point, cerebral perfusion is related to perfusion pressure. Sundt and colleagues, who studied more than 500 patients undergoing carotid endarterectomy, never saw changes in EEG if the cerebral blood flow (CBF) was greater than 25 ml blood/100 gm of brain/min. CBF is normally 50 ml/100 gm of brain/min. Light halothane anesthesia increases this figure to 60 ml/100 gm/min. Therefore, the critical 25 ml/100 gm/min is actually a 60% reduction in CBF from the awake value. Other factors may influence CBF such as a change in ventilation. Therefore, when determining a maximum hypotensive limit, these other variables must be considered. To give a safe margin of error, the CBF is only reduced 30% instead of the experimental 60%.

To determine this low limit in terms of blood pressure, we assume that the CBF decreases linearly after the perfusion pressure decreases below the lower limit of autoregulation (60 mmHg). At this point, (using the safety factor) a 30% reduction of CBF is allowable. This corresponds to the following formula: 60 mmHg-(60 mmHg x 30%)=42 mmHg. The answer, 42 mmHg, is the cerebral perfusion pressure. If we now assume the jugular venous pressure to be 8 mmHg, then, to achieve a CPP of 42 mmHg, the minimum allowable mean arterial pressure should be 50 mmHg.

This calculated mean arterial pressure of 50 usually corresponds to a systolic arterial pressure of 65-70 mmHg. This lower limit is permissible for use over several hours during an operation. However, most patients will tolerate lower pressures for short periods of time, for example when a surgeon needs to clip an intracranial aneurysm. It is imperative to remember that certain conditions will alter the calculated “safe low limit”. Hypoxemia will drastically shift the low limit upward. The hypertensive patient is another example. Strandgaard and associates have shown that in these patients, the limits of autoregulation tend to shift to the right by an amount proportional to the degree of hypertension. Therefore, if the patient’s pressure is 20% above normal, then his safe limit should be increased by 20%.

Having set the low limit, the next step is to induce hypotension. When doing this it is important to be aware of those factors that are opposed to the goal. Factors leading to elevated venous or arterial pressure result from either venous engorgement, increased cardiac output, or increased mean arterial pressure. Increased pCO₂ increases the output of catecholamines, thereby increasing blood pressure and cardiac output. A decreased pO₂ results in vasodilation and chemoreceptor stimulation with the ensuing increased cardiac output.

Alterations in intrathoracic pressure can result in an increased central venous pressure (CVP). Resistance to expiration may produce the same result. Improper posture is one of the most important factors resulting in venous bleeding. Lastly, inadequate analgesia causes an increased cardiac output with a resultant increase in blood pressure and bleeding.

Considering these factors, hypotension can be induced by agents that result in either vasodilation, arterial dilation, or a decrease in cardiac output. Three main drugs, SNP, ganglionic blockers and nitroglycerin are available to pharmacologically lower the blood pressure.

**Sodium nitroprusside (SNP)**

Sodium nitroprusside is a hydrated ferrous pentacyano compound which is not related to any other drug available for the treatment of hypertension. It is photosensitive and decomposes on exposure to light, changing in color from brown to blue. This change is due to a reduction of ferric ion to ferrous ion. It comes commercially packaged in a 50 mg vial to be reconstituted with sterile water. This solution is then mixed in 250 cc or 500 cc of D₅W and wrapped in aluminum foil. The mixture’s usage span is only four hours.

The pharmacologic action of SNP is due to the nitrusso group. This results in direct muscle depression. However, SNP does not work like any other smooth muscle relaxant (papaverine, theophylline) because it does not increase cyclic AMP (adenosine 3':5'-cyclic phosphate). The muscle depression results in arterial and slight venous dilation. An immediate decrease in mean arterial pressure and total peripheral resistance occurs upon infusion. However, SNP has not been found to depress uterine or cardiac smooth muscle. In general, studies have shown that SNP produces a dilation of peripheral resistance and capacitance vessels, resulting in a pooling of blood, decreased filling pressure and afterload reduction.

Tachycardia is frequently seen with the administration of SNP, which may represent a reflex response to lowered arterial pressure. However, it has recently been shown that SNP interferes with the autonomic nervous system. It may possibly inhibit neuronal uptake or enhance leakage of norepinephrine from nerve endings. Long-term treatment, though, may result in norepinephrine
storage granule depletion, thereby reinforcing the
direct vasodilating properties.

Studies of specific organ blood flow with SNP
infusion have shown that the cardiac output to the
brain, heart, lungs, liver, and duodenum is signifi-
cantly increased. No increase was noted in the
stomach, large intestines or skeletal muscles. Blood
flow is decreased to the skin. In general, underper-
fusion of vital organs does not appear to be a major
problem.

Pulmonary artery pressure and pulmonary
vascular resistance has been shown to decrease with
SNP infusion. The decrease occurs if the pressure
has been elevated as in pulmonary hypertension.
It is probably due to a direct effect on pulmonary
vessels. A decrease in pO₂ is sometimes seen. It is
probably a result of homeostatic diversion of blood
flow away from hypoxic areas of the lung. In
healthy patients, pulmonary vascular resistance is
sometimes seen to increase and is a result of lowering
the left atrial pressure from normal to atmos-
pheric or subatmospheric values.¹²

Normally, coronary artery diameter changes
in response to oxygen need. In myocardial disease,
stenosis may prohibit this process. Therefore,
lowering the blood pressure in the patient with
heart disease, even though afterload reduction is
achieved, may result in inadequate pressure to
supply blood to pre-ischemic areas, thereby re-
sulting in cardiac ischemia. Of interest to note is
a finding by Chiariello and associates who reported
that in a study of canines with recent myocardial
infarctions, SNP-induced hypotension resulted in a
decreased transmyocardial blood flow and worsened ischemic areas.¹³ Therefore, at the present
time, differing opinions exist concerning the use
of SNP for afterload reduction in the patient with
coronary artery disease.

In general, the cerebral vasculature is less
responsive than other vasculature to vasoactive sub-
stances due to the cerebral autoregulation discussed
earlier. However, it is important to note that under
experimental conditions, sudden decreases in per-
ipheral arterial pressure have resulted in dramatic
increases in cerebral pressure. Turner and associ-
ates found that with moderate decreases in mean
arterial pressure, intracranial pressure increased.
The increased intracranial pressure is probably
due to an increase in intracranial blood volume.¹⁴

The renal effects of SNP have been carefully
studied. Bastron and Kaloyanides found that when
SNP is directly infused into the renal artery, renal
vascular resistance decreases but there is only a
10% increase in flow. Also, in the intact kidney, a
reduction in arterial pressure from 134 to 69
mmHg resulted in an expected pressure-related
decrease in renal function.¹⁵ Many researchers have
found that hypotension induced by SNP results in
renin release with an increase in the blood level
of angiotensin. This fact could explain some of the
resistance to hypotension noted with SNP usage.
Urine formation may cease at a pressure below
70 mmHg systolic. Stimulation of urine formation
by a diuretic has not been shown to protect the
kidney against ischemia.

When SNP is used to induce hypotension,
three problems often become apparent: tachy-
phylaxis, resistance, and toxicity. The SNP
molecule contains five cyanide groups. Cyanide is
released in its metabolism. Essentially, an electron
is transferred from hemoglobin (Hb) iron (Fe²⁺
to Fe⁺++) to the nitroprusside radical. This trans-
fer may be a result of interaction of the ion with the
sulfhydryl group on the erythrocyte. Nitro-
prusside then rapidly breaks down and releases five
cyanide ions. One of these reacts with Fe⁺⁺⁺
(methemoglobin) to form cyanomethemoglobin.
The remaining four cyanide molecules become
converted to thiocyanate in the liver and kidney
by rhodanase. The availability of vitamin B₁₂ and
thiosulfate are essential for the rhodanase system to
function properly.

It is important to note the fact that thiocya-
nate in high levels is toxic (greater than 10 mg/
100cc). Miosis, toxic psychosis, hyperreflexia, and
convulsions can result from high thiocyanate levels.
Thiocyanate has a half life of one week and is
excreted largely unchanged in feces, saliva, and
urine. Low renal clearance of thiocyanate is due
to its tubular reabsorption. Therefore, with
chronic administration of SNP, high thiocyanate
levels can be found.

Finally, the distinct possibility exists that
liberated cyanide which is not rapidly detoxified
will cause biochemical abnormalities. Cyanide can
bind to tissue cytochrome oxidase and interfere
with electron transport, thereby producing tissue
hypoxia.

Cyanide Toxicity

Even though early in its use it was realized
that SNP released cyanide, the full extent of this
danger was not appreciated. But in 1975, Davies
reported a case in which SNP was used on a 14-
year-old male undergoing mandibular osteotomies.
The patient received 400 mg of SNP over an 80-
minute period. At the termination of the infusion,
mean arterial pressure increased to 75 mmHg but
then fell to 50 mmHg. The patient then experienced bradycardia, acidosis, cardiac arrest and death. The conclusion was that death resulted from cyanide poisoning with resultant acidosis and hypotension. Since that case, many other incidences of cyanide poisoning have been reported in the literature.\textsuperscript{16}

A study by McDowall in 1974 found that when baboons were given whatever dosage of SNP was necessary to lower the mean arterial pressure to 40 mmHg for two hours, half of the baboons died. The mortalities were related to the total dose of SNP used. Circulatory collapse, severe systemic metabolic acidosis, and decreased cerebral oxygen utilization with increased cerebral venous oxygen were seen in the high dosage group.\textsuperscript{17}

Michenfelder and associates studied canines whose mean arterial pressure was lowered to 40 mmHg by SNP for one hour and also found similar results in the high dosage group. Severe interference with oxygen utilization and anaerobic metabolism occurred in dogs treated with SNP doses exceeding 1 mg/kg.\textsuperscript{18}

In clinical and laboratory studies, the occurrence of resistance to SNP has been observed. This phenomenon appears related to toxicity but its mechanism is not completely understood. It begins immediately upon starting the infusion and may be related to an abnormality in the cyanide-thiocyanate metabolic pathway. This seems to be the major disorder in patients who have Leber's optic atrophy and tobacco amblyopia.

Tachyphylaxis to SNP has also been reported in about 30\% of the population. It usually occurs 30-60 min after the start of the infusion. The cause is thought to be due to impaired relaxation of vascular smooth muscle resulting from increased cyanide levels along with acidosis, cellular hypoxia, and/or increased catecholamine production from an increased sympathoadrenal response to induced hypotension.

In general, cyanide release and resultant toxicity is dose dependent and various guidelines have been suggested. It is best to keep the total dose low; therefore, the total maximum dose of SNP administered should not exceed 1 mg/kg. The use of beta blockers, inhalation supplements (halothane, enfurane and isofurane), and the use of other hypotensive agents (trimethaphan and nitroglycerin) have been shown to significantly decrease the dose of SNP needed. Recently, more attention has been given to the dose of SNP used in chronic administration. Based on their work in dogs infused with SNP for 24 hours, Michenfelder and Tinker recommended 0.5 mg/kg/hour or a maximum of 8 $\mu$g/kg/min.\textsuperscript{19}

Detection of impending cyanide toxicity is vital. Measurement of blood cyanide levels is not easily achieved and may be of limited value because released cyanide may rapidly bind to tissue cytochrome oxidase in the absence of significant methemoglobin. The most important indicators of toxicity include a higher dosage requirement to lower the mean arterial pressure or the inability to lower adequately the blood pressure. If the dose requirements increase to 6-8 $\mu$g/kg/min, then arterial blood gases should be checked every hour. It is important to remember that there are no reports of cyanide toxicity when the dose of SNP is kept below 8 $\mu$g/kg/min. The development of metabolic acidosis in these patients should be presumed to be cyanide toxicity.

Treatment for cyanide toxicity obviously includes stopping the infusion at the first sign of tachyphylaxis or resistance. If the base deficit has not worsened beyond -11, usually toxicity can readily be reversed. However, if it is beyond -16, the prognosis is quite poor.

If arterial pressure returns to normal and metabolic acidosis is corrected, nothing further needs to be done. But, if the warning signs have been ignored and persistent metabolic acidosis and hypotension result, then the following steps should be undertaken. Oxygen 100\% should be administered. Thiosulfate IV 150 mg should be given; this dosage should be repeated in 10 minutes. Thiosulfate has no hemodynamic effects and works by converting cyanide to thiocyanate. Sodium bicarbonate should be given to correct the acidosis.

If severe cyanide poisoning has occurred, amyl nitrite and sodium nitrite should be used. Both of these drugs work by converting hemoglobin to methemoglobin. These drugs are vasodilators and can cause severe hypotension. Inhalation of amyl nitrite can be accomplished by breaking an amyl nitrite pearl into the anesthesia system. Sodium nitrite 5 mg/kg can be given slowly IV at a maximum rate of 100 mg/min. Methylene blue should be available in the event that conversion of hemoglobin to methemoglobin becomes excessive. Also, it is important to remember to increase fluid administration to hasten diuresis since thiocyanate is renally excreted.

Vitamin B$_{12}$ (cobalamin) 0.1 mg/kg has been suggested as an effective means of treating cyanide toxicity. B$_{12}$ is believed to work by converting cyanide to cyanocobalamin and it is necessary for the thiocyanate pathway to function. However, as
cobalamin is generally not available and is quite expensive, it is not extensively used at present.

**Trimethaphan**

Ganglionic blockers form the second group of agents used for inducing hypotension. Trimethaphan (Arfonad®) is the most commonly used drug at the present time. Ganglionic blockers work at the level of the sympathetic and parasympathetic ganglia by actually blocking neural transmission. The postganglionic synapse and the liberation, synthesis, and hydrolysis of acetylcholine is not affected.

Trimethaphan is a thiophanium derivative. The hypotensive effect that results has been attributed to several factors. Histamine release occurs along with vasodilation and ganglionic blockade. It has been demonstrated experimentally that histamine release is not a particularly significant factor in causing hypotension, however, it can be quite troublesome. Payne and Larson demonstrated that histamine release by trimethaphan can result in bronchospasm and increased intracranial pressure.20 Mendlowitz showed that it can result in catecholamine release in patients with pheochromocytoma.21

Trimethaphan directly affects vascular smooth muscle. McCubbin and Page found that trimethaphan produced profound vasodilation when injected into the denervated isolated hind leg of a dog.22 Most importantly, trimethaphan works by occupying acetyl receptors of the postganglionic synaptic membrane and by stabilizing this membrane against the action of acetylcholine.

Rowe and colleagues found that when the mean arterial pressure was lowered 35% by trimethaphan, a decrease in cardiac output and an increase in heart rate occurred (a reaction similar to SNP).23 Ganglionic blockers also have been shown to have some direct cardiac effect, consequently a slowing of the heart rate may occur. Though these blockers have been found to cause a precipitant fall in coronary blood flow, myocardial oxygen demand has not decreased. Total peripheral resistance has fallen only slightly. In fact, Crumpton and associates found that in some cases total peripheral resistance actually increased.24 Loss of vascular tone on the venous side has also been seen at times.

Trimethaphan results in a significant decrease in the cerebral metabolic rate. However, several reports have indicated that it may cause neurologic damage and may actually potentiate previous damage. This effect may be totally unrelated to the drug's hemodynamic effect.

Michenfelder and Theye found that trimethaphan results in greater cerebral lactic acidosis.25 Magness concluded that with comparable levels of hypotension, trimethaphan led to alterations in the brain's electrical activity.26 Michenfelder and Theye also observed that halothane and trimethaphan controlled hypotension to a mean arterial pressure of 40-50 mmHg, resulting in a significant decrease in cerebral blood flow. This decrease did not seem to be related to any change in cardiac output.25

The anesthetist should also be aware that trimethaphan results in mydriasis and cycloplegia. Therefore, pupillary reaction to light and pupil size cannot serve as diagnostic indicators.

Although trimethaphan causes renal vasodilation, renal blood flow may decrease. Renal perfusion is usually sufficient to meet metabolic needs, even though glomerular filtration may cease temporarily.

Eckenhoff suggested that a redistribution of pulmonary blood flow may occur during trimethaphan infusion. In fact, dead space may increase up to 80%, if the patient is in the head-up position. Pulmonary artery pressure may also decrease with trimethaphan.27

Trimethaphan should be mixed with D5W, however, normal saline or Ringer's lactate may be used. Trimethaphan has a usage life of 24 hours at room temperature. The infusion rate is usually between 200 μg to 5 mg/min. However, Eckenhoff has recommended a maximum dosage of 100 mg during the first 15 minutes and a total dose of no more than 1 gm in an average 70 kg patient.28

As with SNP, several problems may be encountered with the use of trimethaphan. Tachycardia is frequently seen. This problem is thought to be a compensatory response to the drop in blood pressure. It may be prevented by a beta blocker such as propranolol, 0.05 mg/kg total dose. Warning: Do not use the beta blocker on elderly patients since they are particularly prone to develop bradycardia, and do not give it to patients with a history of asthma, congestive heart failure, or a lowered blood volume.

Tachyphylaxis is another common problem. In a continuous drip technique, often a baseline is reached and it becomes hard to lower the pressure beyond this level. High concentrations of continued administration of trimethaphan may result in a delayed recovery of normal blood pressure at the end of administration. Occasionally a delay of up to two hours in the recovery of normal blood pressure has been reported. This is seen particularly in the elderly patient. Therefore, one should stop
the infusion periodically to assess the return of the blood pressure to preinfusion levels. Position changes should also be used to augment the hypotensive effect of trimethylphane.

Tewfik postulated that trimethylphane is destroyed in vivo as well as in vitro by pseudochondrerase. Trimethylphane should be used cautiously in patients known to have a decreased pseudocholineresterase level (liver disease, cachexia and malnutrition). Up to a three hour delay in the recovery of normal blood pressure has been reported when a succinylcholine drip and a trimethylphane drip were used concomitantly.

**Nitroglycerin**

The third agent used for deliberately inducing hypotension is nitroglycerin. It is a rather new addition to the list of hypotension inducers. During the past few years, it has been administered IV to treat ischemia during surgery in patients with cardiovascular disease. However, it has also been found to be an effective hypotensive agent and may gain more popularity in the near future.

Nitroglycerin (NTG) is absorbed through the skin, mucous membranes, and gastrointestinal tract. It is rapidly metabolized by the liver and its metabolites are weak vasodilators. The water-soluble metabolites are excreted in the urine.

The mode of action of nitroglycerin is not yet fully understood. There are probably multiple modes of action. It has been theorized that there is a specific sulfhydryl group in a nitroglycerin receptor found in smooth muscle and blood vessels. In theory, NTG oxidizes this sulfhydryl group.

Nitroglycerin decreases myocardial oxygen consumption in both conscious and anesthetized patients. With IV administration, the maximal increase in coronary flow was found to occur during the first 10 seconds. With larger doses, the blood pressure also fell but did not reach the maximum level until 20-25 seconds had elapsed. This fall was also associated with a reflex tachycardia. Investigators have revealed that NTG first increases cardiac blood flow and cardiac index, then decreases pulmonary vascular resistance for approximately 20 seconds. This is followed by normal cardiac blood flow and a continued decrease in pulmonary vascular resistance, coronary vascular resistance, and decreased cardiac work.

Chiariello compared NTG and SNP as therapy for ischemic injury in patients with acute myocardial infarction. NTG resulted in improvement of the ST segment, whereas the ST segment was worsened by SNP. With NTG, arterial dilation does not occur until higher dosage levels are employed; therefore, a decrease in preload can be achieved without a reduction in afterload. Consequently, the diastolic pressure is lowered as much with NTG as it is with SNP. As a result, coronary perfusion is probably better.

NTG is a coronary vasodilator that also has systemic effects resulting in a decreased mean arterial pressure. Experimental work has not clearly shown if NTG has a direct inotropic effect on myocardial muscle.

Lack of a commercial preparation of NTG for intravenous use has hampered its utilization for inducing hypotension. However, the drug has just recently become available in IV preparation. As a result, experience with the drug will surely increase.

NTG is not as potent as SNP. The usual starting dose is 1-2 µg/kg/min. Tachycardia is a frequent problem, but again, propranolol can be helpful. As with the other hypotensive agents, patient posture is important in augmenting the drug's effect. NTG has the potential for being a fairly safe agent, however, investigative experience is limited.

**Clinical application**

SNP and NTG are used for patients with ischemic heart disease. Their main value is in controlling preload and afterload, thereby decreasing myocardial work. At present, NTG has been shown to be more effective. Induced hypotension has also been found to be more effective. Induced hypotension also been of value in carotid artery surgery, coarctation of the aorta repair, patent ductus arteriosus (PDA) ligation, hypertensive emergencies, phaeochromocytoma resection, aortic aneurysm repair, postoperative hypertension, repair of intracerebral aneurysm, and operations associated with massive blood loss such as spinal fusions, head and neck dissection and pelvic tumor extirpation.

Recently, controlled hypotension has been used during intubation to control sudden hypertension during laryngoscopy. It is also helpful for operations where any bleeding is significant, such as surgery on the middle ear.

Induced hypotension is used to decrease blood loss and produce a dry operating field to allow for better surgical visualization and accurate delineation of lesions. Most importantly, induced hypotension can drastically reduce the need for transfusions and operating time can be shortened.

Induced hypotension is contraindicated in certain conditions. SNP should not be used in Leber's optic atrophy and tobacco ambylophia. It is relatively contraindicated with severe liver disease, hypothyroidism, malnutrition, vitamin B12 deficiency.
and severe renal disease. Again, these conditions affect the metabolism of cyanide and toxicity may result.

Trimethaphan is relatively contraindicated in patients with low pseudocholinesterase; it should not be used in patients with acute angle glaucoma since pupil dilation may last several hours. Trimethaphan is also best avoided in neurologically compromised patients since along with pupil dilation, it has been shown to interfere with cerebral oxygenation.

NTG is probably the best choice for use in patients with heart disease. In addition, it may prove to be more effective for orthopedic work since it has significant action on the venous circulation.

Induced hypotension is contraindicated in patients with a significant decrease in oxygen transport ability. This occurs with decreased oxygen saturation, lowered fixed cardiac output, anemia, sickle cell disease, polycythemia, arteriosclerosis, and acute cardiac or cerebral disease. Diabetes is not a contraindication if it is well controlled. Patients with arteriosclerosis may have tenuous perfusion of vital organs and the drugs may have a more prolonged effect.

In small children, failure to obtain the hypotensive effect is high; they often respond with tachycardia. The positional influencing of blood pressure is not as great due to a child's small stature. Hypoglycemia may occur in approximately 10% of the children.

All patients undergoing induced hypotension must have continuous arterial pressure monitoring. Positioning is of next concern. The patient should be positioned so that peripheral pooling is encouraged and blood is directed away from the operative site. For example, the reverse Trendelenberg position should be used for head surgery, the sitting position for aneurysm resection, and if the prone position is employed, the abdomen must hang free in order to prevent vena cava obstruction and venous engorgement. If hypotension is induced with the patient in the sitting position, remember that a 2 mmHg gradient/inch in vertical height occurs between the head and where the pressure is actually measured. As a result, pressure is usually measured at the level of the cerebrum.

The patient should be placed on a ventilator because of the increase in dead space and the possibility of shunting. Oxygenation must be at its best and positive end-expiratory pressure (PEEP) can be used to effectively augment a decreased cardiac output along with improving ventilation. The pCO₂ should be kept low in the 30s.

Hypotension must be induced slowly over a 10 minute period. Widening of the arteriovenous oxygen difference (AVO₂) occurs during these first 10 minutes and cerebral oxygen may critically decrease if blood pressure is rapidly dropped. Agents should be administered through an infusion pump. They should be started at a slow rate to determine patient sensitivity.

SNP should be administered at a beginning rate of 0.1 µg/kg/min and at a rate no greater than 8 µg/kg/min or a total dose of 1 mg/kg. Trimethaphan is started at a dose of between 1-20 µg/kg/min. It can be administered by continuous drip technique or intermittent injections of .025-.050 mg/kg. NTG should be started at a rate of .5 µg/kg/min. The onset of action of SNP is 30 seconds, with a duration of 2-4 minutes; its half-life is one hour. Both NTG and trimethaphan have an onset of 1-2 minutes with a duration of 8-10 minutes.

One effective way of establishing the desired pressure level without swings is the method of "targeting." After it has been established that the patient is not overly sensitive to the agent, the infusion rate is increased to the drug's maximal rate. Next, just as the pressure begins to fall, the infusion is slowed to a minimum. As the pressure begins to increase again, the infusion rate is increased to almost the first level. The rate is then slowed but not as much as initially. This process is continued until the desired level is reached.

Agents such as enfurane, halothane, or isoflurane can be used to potentiate the effect of the three agents discussed. Bedford found that enfurane significantly potentiates the hypotensive effect of SNP in a dose-related fashion. With morphine, the effects of SNP are essentially not different from those in the awake state.

Frequently, one encounters a patient who responds to attempts to lower the blood pressure with reflex tachycardia. Propranolol is useful in this situation. It should be given in increments; the total dosage needed is usually smaller if the drug is given before the infusion has begun.

Finally, it is important to remember that blood volume must be maintained. In many cases, a CVP line or a pulmonary artery catheter may be indicated. If the patient's blood pressure drops too far, vasoactive substances should be avoided. The anesthetist should stop the infusion, change the patient's position, increase fluid administration, discontinue PEEP, and discontinue nitrous oxide and inhalation agents. As a last resort, a small dose of an alpha agent may be given to the patient.

In most cases, the agent should be gradually
discontinued as the surgeon starts to close in order to make apparent any areas of bleeding that have not been controlled. With aortic surgery, infusion should be discontinued five minutes before the clamp is removed. With a spinal fusion, infusion should be continued until the fascia is closed.

Conclusion
At present, there is no evidence to show that postoperative hemorrhage occurs any more often with induced hypotension if hemostasis is established and the blood pressure returns slowly to normal. Although not a panacea, if the preceding information is understood and the guidelines are followed, controlled hypotension is a relatively safe technique which has been shown to have a useful place in many operative procedures.

REFERENCES

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