CONTROLLED HYPOTENSION*

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Hypotension has long been considered synonymous with shock, and hence its occurrence during surgical procedures is looked upon with fear or apprehension. However, blood pressure readings below normal need not be associated with shock. In recent years arterial hypotension has been utilized in attempts to reduce the loss of blood during operations. By inducing hypotension, it has been possible to perform certain operations more easily, more quickly, and with less risk, and to undertake others that would be impossible without this technique.

If it is true that a fall of blood pressure on one hand means shock, and on the other can be induced intentionally with little danger to the patient, it seems that there must be a fundamental difference between these two types of hypotension.

It will therefore be necessary to consider now some points concerning the factors that maintain blood pressure and to discuss the mechanisms that come into play when hypotension supervenes either because of shock or in consequence of deliberate action on the part of the physician.

PHYSIOLOGY OF BLOOD PRESSURE

Arterial blood pressure is maintained through a number of factors, the chief ones of which are: (1) cardiac output; (2) peripheral resistance; (3) amount of blood in the arteries; (4) blood viscosity; (5) elasticity of the arterial walls. Of these the first four factors contribute in regulating systolic blood pressure, while the last factor is chiefly instrumental in the maintenance of diastolic pressure. Any change in any one of these factors, sufficiently great or sustained to overcome the compensatory powers of the organism, will effect a rise or fall of blood pressure.

In circumstances that produce shock, such as for instance hemorrhage, the immediate reaction is a constriction of the arterioles, or more precisely of the metarteriolar sphincter mechanism. This represents an attempt at compensation which tends to maintain the blood pressure at its previous level. Trying to maintain the circulating volume at an adequate level, fluid

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is next shifted from the interstitial spaces into the blood stream, thus increasing the total plasma volume. When this takes place, one talks of “compensated” or better “incipient” shock. However, if hemorrhage continues without adequate replacement or if anoxic or stagnant hypoxia is superimposed, then arteriolar and capillary dilatation and stasis will develop. The consequence of this is a reduction of venous return and a fall of cardiac output with subsequent failure of compensation, hypotension, and the development of “frank” shock. If shock is not promptly corrected, the hypoxia increases until finally the integrity of the capillary wall is lost with such irreparable hypoxic damage as to make the shock “irreversible.” The phenomenon of capillary stasis is demonstrated clinically by the increase of capillary refill time. The mechanism of hypotension as described pertains to cases of so-called “oligemic shock.”

Another mechanism by which hypotension may be produced is one in which primary dilatation of the arteriolar bed occurs. Thus, by augmenting grossly the vascular bed and by decreasing peripheral resistance, a fall in arterial blood pressure ensues. In this kind of hypotension, capillary circulation should remain adequate, as can be demonstrated by very prompt refill time. Hence, venous return remains satisfactory and cardiac output is only moderately reduced. This is the mechanism acting in the rather badly termed “neurogenic shock,” and is encountered clinically, for example, during spinal anesthesia.

It is, therefore, the adequacy or inadequacy of capillary circulation that determines whether or not the blood pressure fall is or is not a true shock state.

From the foregoing it is seen that hypotension of the first type associated with tissue hypoxia and leading to tissue changes cannot be tolerated for very long, and must be corrected by all the means at our disposal. Hypotension of the second type, on the other hand, has few deleterious effects, provided capillary circulation remains adequate and sufficient oxygenation of the blood is maintained. If these two prerequisites are followed, no damage will result to such vital organs as the brain, heart, kidneys and adrenals. This has been demonstrated both clinically and experimentally. Admittedly, filtration of urine probably ceases if the systolic pressure in the renal arteries falls below 75 mm. Hg (although this may be too high a value according to the latest investigative work). None the less, the nephron remains undamaged with pressures probably as low as 45–50 mm. Hg and may be even less, so that formation of urine is resumed when the filtration pressure is again reached. Let it be emphasized that this applies only with good capillary circulation and adequate oxygenation. With regard to the coronary arteries, even in individuals with coronary insufficiency, attacks of angina pectoris do not occur if arterial hypotension is induced by arteriolar dilatation, and if arteriosclerotic changes have not reduced the elasticity of the coronary vessels. If we consider the brain, we are more uncertain, as no one knows the minimum pressure necessary to maintain adequate nourishment of this sensi-
tive and highly specialized organ of high metabolic requirements. The problem of adequate cerebral circulation and oxygenation will be discussed in more detail later.

METHODS OF CONTROLLED HYPOTENSION

Hypotension may be induced by a variety of means but some, such as large doses of barbiturates and deep general anesthesia, are obviously undesirable. Three principal methods have evolved in recent years and these will be considered in detail. They are:

1. Controlled arteriotomy and arterial re-transfusion.
2. Preganglionic block by spinal anesthesia.
3. Ganglionic and postganglionic block by means of pharmacological blocking agents.

1. Controlled Hypotension by Arteriotomy and Re-Transfusion. This procedure consists essentially of withdrawing blood from an artery until a suitable degree of hypotension is reached, and maintaining this hypotensive level by judicious re-infusion and re-bleeding from time to time.\(^5,10,16,19\) The blood withdrawn is prevented by clotting by the usual methods and is returned to the patient at the conclusion of the operation. Additional blood may then also be given if needed. The blood pressure is maintained at a level insuring a relatively bloodless field, but is never allowed to fall below 80 mm. Hg in a normotensive individual. Correspondingly higher levels must be maintained in hypertensive and arteriosclerotic individuals. There is often a slight rise in blood pressure following withdrawal of the first small amount of blood, no doubt caused by a compensatory arteriolar constriction and increase in plasma volume. If bleeding is still troublesome at the operative site, further blood will have to be withdrawn until the desired level of hypotension is reached or good control of bleeding achieved. Should the blood pressure fall below 80 mm. Hg, re-transfusion of small amounts of blood is started immediately until the pressure again reaches 80 mm. Hg. The average duration of hypotension possible with this method is reported to be 3 hours with a maximum of 6 hours. The amount of blood necessarily withdrawn may be as much as 3000 cc. If the pressure is restored to normal at the conclusion of the operation and not all the blood re-transfused, the remainder is administered by slow intravenous drip, if necessary. The pulse must remain slow at all times. Otherwise re-transfusion must be undertaken immediately.

This method of selective hypotension has been used mainly in the past for cranial surgery, and the advantage claimed for it is better visualization of the operative field as it is not obscured by blood, and visualization is further aided by the reduction of the volume of the brain itself. Various apparatuses have been constructed for the withdrawal and re-transfusion of blood, and are described in the literature.\(^5,10,16,22\) A number of fatalities have occurred with the technique and are understandable, as the mechanism of producing this type of hypotension is by arteriolar constriction and carries
with it all the potential inherent dangers of shock. Frank shock is avoided by maintaining the blood pressure at about 80 mm. Hg, but the margin of safety is relatively small. Another danger is possible damage to the artery and even loss of the artery. Failure of the apparatus may occur and the possibility of air embolism is real. It must be remembered that the power of compensation may be extremely poor in dehydrated and hypovolemic patients. High oxygen concentration must of course be maintained throughout the operation and extra blood must be available to maintain the existing state of incipient shock. At the time this technique was developed, nothing better was available. Probably because of its inherent dangers and its dependence upon all the compensatory powers of the body, this method has only a few proponents and is now being superseded by other less hazardous techniques.

2. Controlled Hypotension by So-Called Total Spinal Anesthesia. This method was first described by Griffiths and Gillies in 1948.\textsuperscript{11,12,15} The hypotension is produced by arteriolar dilatation resulting from a preganglionic sympathetic block which paralyzes the vasoconstrictor innervation. It is based on a number of experimental observations which should be reviewed briefly. First, it has been shown that the severity of the fall in blood pressure depends upon the number of spinal segments blocked, and that the fall is relatively greater the more cephalad the segments have been blocked. Hence for maximum effect a block as high as the first thoracic segment is necessary. Blocks at higher levels are undesirable and cause no further fall of blood pressure as no sympathetic vasomotor fibres arise above T1.\textsuperscript{15} It has also been shown that with blocks higher than T1, death may result from respiratory paralysis caused by paralysis of the phrenic nerves. Cardiovascular failure is a secondary phenomenon\textsuperscript{25} that can be prevented by adequate oxygenation. With artificial respiration, the blood pressure can be maintained at 40–60 mm. Hg.\textsuperscript{8} Since the advent of spinal anesthesia, this has been demonstrated in a number of cases when the anesthesia has risen above the desired level. In relatively early times, operations were performed above the diaphragm with spinal anesthesia without apparent untoward effects.\textsuperscript{18,20,21,27,29} In those operations, it was found that the operative wound was dry, and the breathing was of the diaphragmatic type, indicating that no paralysis of the phrenic nerves had occurred. A point these authors stressed was the necessity of the Trendelenburg position to assure adequate blood supply to the brain.\textsuperscript{28}

Griffiths and Gillies revived the concept of utilizing high spinal anesthesia to reduce blood loss during sympathectomies. In so doing, they rely on the concept of “differential spinal anesthesia,”\textsuperscript{24} which is based on the fact that the least myelinated nerve fibres are the first to be blocked by anesthetic substances.\textsuperscript{17} Hence, by using dilute solutions of anesthetic drugs in the subarachnoid space, it is possible to block sympathetic fibres with a minimum of sensory and motor impairment. Greene has applied the term “hypotensive spinal anesthesia” to this technique.\textsuperscript{14} General anesthesia must be used
throughout the operation. The patient is kept in the Trendelenburg position, and as long as capillary circulation remains sufficient and tissue oxygenation adequate, the method is safe. Bradycardia, which often occurred in Gillies' cases, was caused by paralysis of the cardio-accelerator fibres in the upper thoracic segments, and the consequent increase of vagal tone. Cyanosis, they state, was almost invariably caused by inadequate oxygenation, but had to be differentiated from circulatory failure. Respiratory arrest requires artificial ventilation. The breathing is usually slow and largely diaphragmatic. If breathing is spasmodic, supplementary or controlled ventilation is indicated. The original technique described by Gillies for sympathectomy and based on that of Vehrs28 consists of injecting Procaine (150–250 mg. dissolved in 3–4 cc. cerebral spinal fluid) at L2, turning the patient on his back and then into a steep Trendelenburg position. Before the pressure falls to extreme limits, the tilt of the patient is reduced to approximately 20° (Trendelenburg). Oxygen administration is started before extreme hypotension supervenes. Within 10–20 minutes blood pressure readings cannot be obtained at the brachial artery and the arterial pulse at the wrist is not palpable. With this method, anesthesia is found over the entire body, but motor paralysis extends only to the first thoracic segment. The phrenic nerve and cranial nerves are unaffected. Within 20–30 minutes respiratory and circulatory function return to normal, the radial pulse becomes palpable, and blood pressure is low but measurable.

This technique was amended later so that the blood pressure is no longer allowed to become imperceptible. Yet, the method as originally described showed the relative safety of the technique. There was only one death in the series of 84 operations (44 patients) reported. Gillies also showed that at most only slight interference with kidney function was demonstrated in his series of cases. Oxygen tension and oxygen saturation are unchanged; only slight alterations occur in pyruvate and lactate levels, indicating that cell oxidation is not affected during spinal hypotension13 provided adequate pulmonary oxygenation is assured and that the blood volume remains constant.

A more recent technique utilizes either a single injection of Procaine or continuous spinal anesthesia with 0.5 per cent Procaine affecting predominantly the sympathetic component. Any of the other spinal anesthetic agents may be used, but hypobaric solutions are better avoided as their spread cephalad requires elevation of the head, which is undesirable when hypotensive techniques are employed. Anesthesia is maintained by endotracheal nitrous oxide or cyclopropane with ether. Controlled or assisted respiration is used. The patient is in slight Trendelenburg position and blood pressure is controlled in part by elevation or lowering of the legs. The legs thus may be likened to a reservoir of blood available for autotransfusion. A systolic pressure of approximately 50–60 mm. Hg is the aim. Adequate intravenous fluids and medications are given. It remains the anesthetist's choice to use the spinal anesthetic as both hypotensive agent and analgesic agent without other anesthetic supplement (other than oxygen), to use supplementary ni-
trous oxide or sodium pentothal sleep, or to use dilute Procaine for the sympathetic block and general anesthesia for motor and sensory block and maintenance of unconsciousness. The latter is the method of choice, particularly in operations above the diaphragm.

While this method has proven satisfactory and apparently safe in the hands of Gillies and other workers, it too has not achieved widespread acceptance because of its complexity and because it combines the inherent dangers of a spinal anesthetic and those of general anesthesia.

3. Controlled Hypotension by Means of Blocking Agents. In search of an antidote for the muscle relaxant Syncurine® (C10, decamethonium), penta-methonium was studied extensively, and it was for a time considered the antidote for C10. It was seen that its administration was accompanied by a marked fall in blood pressure of occasional serious proportions. This hypotension was found to be caused by its blocking of autonomic ganglia. These observations in due course led to clinical use of the methonium compounds for the treatment of hypotension. In 1950 Enderby suggested the substance may have value in producing controlled hypotension and thus serve as a more practical substitute for Gillies’ method of total spinal anesthesia. In his original paper Enderby pointed out that the methonium drugs act by blocking autonomic ganglia, producing an increase in blood flow by arteriolar dilatation and thus a subsequent fall of arterial pressure.

Again, we must consider some of the basic work. Paton and Zaimis established experimentally the absence of changes in liver and kidneys in animals that received large doses of methonium compounds. Shackleton in 1951 reported that a systolic pressure below 60 mm. Hg maintained for 3½ hours caused no alteration in the function of vital organs. It has been established that renal blood flow remains constant if blood pressure is lowered deliberately by means of ganglionic blocking agents during anesthesia.

Enderby’s technique to obtain a relatively bloodless surgical field is divided into two distinct manoeuvres. The first consists of lowering the blood pressure to 55–65 mm. Hg which he considers the optimum, the other of elevating the site of operation, a manoeuvre to effect what he called “postural ischemia.” Davison has pointed out that reduction of blood pressure per se, if caused by diminished peripheral resistance, presumably does not reduce bleeding but rather the hydrostatic effect of posture is the factor of great importance. He states that with a systolic blood pressure of 200 mm. Hg, a foot down tilt of 15° will alter the normal ratio of blood flow to the head, which is ½, to a ratio of 7/24, an alteration of no appreciable significance. But with a pressure of only 30 mm. Hg, the change will be from the normal of ½ to a striking 1/7 ratio. A point may thus be reached, and we don’t know precisely what it will be for the particular patient, where elevation of the head, to reduce bleeding during a craniotomy, will cause such interference with cerebral circulation that permanent damage results. This is a most important consideration as the advocates of controlled hypotension by methonium compounds claimed that the postural effect of the technique
is an important part in affording a dry field. Postural ischemia may be employed with safety in operations upon the extremities, abdomen, and chest. Conversely in cranial operations, the technique is by no means free of danger. In fact, there are cases recorded in which decerebration, blindness, or other sequelae followed operations upon the head when postural ischemia was employed in obtaining a bloodless field.

Fortunately, in cranial surgery, an absolutely dry field is not generally

![ANESTHESIA RECORD](image)

*Fig. 1. 38-year-old woman. Removal of meningioma from right sphenoid wing. Previous attempt at removal had to be abandoned because of excessive bleeding. Tumor was removed with comparative ease and speed under hypotensive anesthesia.*

Note that systolic pressure was never below 90 mm. Hg, but narrowing of pulse pressure was marked. Pulse rate remained at around 90. Only small and infrequent doses of Bistrium were needed. Effect was promptly reversed by Vasoxyl.
Fig. 2. 42-year-old woman. Exploration and partial occlusion of arteriovenous angioma of right temporal lobe.

Note initial slight drop of pressure after first dose of Bistrium, not adequate for surgical needs. After 125 mg, there was some narrowing of pulse pressure with better operating conditions. One hour after last dose sudden marked hypotension occurred, but no tachycardia or other signs of shock. Marked reaction to Vasoxyl, then stabilization of blood pressure. No effect from further 100 mg. Bistrium.

required by the surgeon, but only a sufficient reduction of bleeding to facilitate control of bleeding points. In those cases we do not attempt to produce a thoroughly dry field. Clinically, this reduction of bleeding is achieved by producing a moderate fall of systolic pressure without producing a corresponding fall of the diastolic pressure. The result is a diminished pulse pressure. Under these circumstances, capillary oozing is decreased markedly, but larger vessels continue to bleed. These can, however, be controlled with
ease. Furthermore, aneurysms and other vascular lesions show less tendency to rupture and bleed. The technique has not only proved safe, but highly satisfactory to the operating surgeon. Less parenteral fluids are needed and the patient does extremely well postoperatively.

A big disadvantage of the methonium compounds is the degree of uncertainty of response of the patients to these drugs. While prompt and, at times, long-lasting falls in blood pressure may result from as little as 12.5 mg. of hexamethonium in some cases, in others doses of 200–300 mg. may have little or no effect.

Should excessive bleeding occur during the administration of methonium,
prompt replacement therapy is imperative, as the vasomotor system is no longer under control. Blood volume must be maintained assiduously lest shock supervene. Needless to say, oxygenation must be adequate at all times, and capillary refill-time prompt. The skin should be warm and pink, denoting good capillary circulation, the superficial veins somewhat dilated—respiration slow—and in all a pattern of a normal physiologic state otherwise.

The pulse rate usually varies but little if excessive hypotension is avoided. In younger individuals there may be a moderate increase in pulse rate, but bradycardia is seen rarely.

Hexamethonium (C6) [Bistrium®] has largely replaced pentamethonium (C5) as it is a more potent blocking agent, and is said to have more parasympathetic blocking powers than C5. It is noteworthy, however, that at times one will give a satisfactory response where the other has failed.

Hypotension induced with the methonium compounds can be reversed promptly by the use of vasopressors, preferably those acting peripherally, such as norepinephrine (Levophed®) and phenylephrine (Neosynephrine®). Methoxamine (Vasoxyl®), however, is useful too. A small dose of these drugs may cause an exaggerated shift of blood pressure; 2–5 mg. of methoxamine generally are adequate, but may be repeated if needed. Hemostasis can be assured if the method of narrowed pulse pressure is employed. Thus reactionary hemorrhage is an insignificant problem. Yet, the blood pressure can be restored to normal readily before operative closure or should the problem at hand at the moment demand it.

It still remains a matter of speculation whether the combination of a methonium compound and an adrenal blocking agent or adrenalytic compound such as Dibenamine is the answer in cases which prove resistant to methoniums alone. To date, we have not put this to a practical test. We have, however, found that control of hypotension is markedly improved if Procaine is infused simultaneously.

This method of controlled hypotension is not a simple one. It requires skill in administration and, above all, sound judgment for its use. It should not be used in arteriosclerotic individuals, nor should it be entrusted to the novice. Slight indiscretions in the conduct of hypotensive anesthesia may mean the difference of life or death to the patient. Above all, it must be indicated definitely by the problems at hand, rather than to save a bottle of blood for transfusion. It must never be employed after severe bleeding has been encountered and the patient is consequently in a state of incipient shock.

We feel that indications for the use of this technique are operations for aneurysms, vascular tumors of the brain and kidney, or upon major blood vessels. We do not feel, however, that this technique is justified in the average operative case. It has inherent dangers which must constantly be borne in mind, regardless of the method by which hypotension is induced. The methonium drugs, we feel, are not the ultimate choice, but we do believe that they are a step in the proper direction toward controlled hypotension.
SUMMARY

Controlled hypotension and the various techniques to achieve it are discussed.

The authors prefer the pharmacological blocking agents, particularly hexamethonium (Bistrium®) to the other methods available, despite the fact that this drug is somewhat unpredictable in its action.

The indications for the use of this technique are outlined and should be adhered to. The contraindications to the use of hypotensive anesthesia are discussed, and the potential hazards of the technique are emphasized. Success and safety can be expected from it only in experienced hands.

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