ANESTHESIOLOGY

The Journal of

THE AMERICAN SOCIETY OF ANESTHESIOLOGISTS, INC.

Volume 16 **JANUARY, 1955** **Number 1**

CONTROLLED HYPOTENSION * †

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CONTROLLED hypotension is the deliberate lowering of blood pressure to decrease the danger of certain operations, to diminish blood loss during surgical intervention, and to facilitate and expedite surgical procedures which may be much prolonged in the presence of extensive bleeding.

Hypotension is induced by causing a discrepancy between the circulating blood volume and the capacity of the vascular system. This may be accomplished either by reducing the blood volume by arteriotomy, or by increasing the capacity of the vascular system through vasodilation. The vessels may be dilated by preganglionic sympathetic block (spinal anesthesia) or by the use of a ganglioplegic drug.

Hypotension affects the various structures and organs of the body to different degrees. Those which suffer most are the heart, brain, kidney, and liver. If tissue perfusion in these organs remains adequate, if the blood is well oxygenated, and if the procedure is not prolonged, the structures mentioned are not damaged. The level of the blood pressure, the duration of the hypotension, and the position of the patient are of great importance.

The duration of controlled hypotension varies considerably in different reports. A limit of one hour at 80 mm. of mercury has been recommended for arteriotomy hypotension. Two and a half hours at a pressure of 60 mm. was the longest period of hypotension by hexamethonium bromide in a series by Shackleton (2).

A systolic blood pressure of 60 mm. of mercury, if the blood is well oxygenated, is considered adequate for cellular respiration and metabolism (1). A blood pressure of 40 mm. of mercury is said to be adequate

* Read before the Annual Meeting of the American Society of Anesthesiologists, Inc., Seattle, Washington, October 7, 1953.

† Accepted for publication June 15, 1954.

to transport oxygenated blood to the brain. At pressures below 30 mm. of mercury, capillary flow ceases.

The decision as to what minimal blood pressure can be tolerated by the patient is not simple. One must consider the condition of the blood vessels, the functional capacity of the liver, kidney, and myocardium, the position of the patient during operation, and the length of time required. Zero blood pressure in the previously well oxygenated patient might be safely tolerated for two or three minutes. Any pressure too low to sustain capillary flow is as dangerous as a pressure of zero. Prolonged moderately lowered blood pressure may sustain the vitality of brain and myocardium while causing irreversible damage to the kidneys or capillaries. On the other hand, short periods of severe hypotension may cause cardiac arrest or damage to the brain while inflicting no injury on any other organ.

Blood pressure is mentioned as the most important consideration, which it is not. Of greatest significance is the oxygenation of the tissues, in which perfusion is more important than, although partly dependent upon, blood pressure. However, as no ready means for accurate measurement of tissue perfusion is available, blood pressure must be relied upon as a guide in conducting controlled hypotension. The electro-encephalogram may give evidence of safe oxygenation of the brain, and the electrocardiogram of the heart. No instrument of precision can tell us when in a sluggish blood stream a margination of platelets begins to lay the foundation for a thrombus or embolus.

INDICATIONS

The indication for the use of controlled hypotension by any method should be clear. It should not be employed under any circumstances in which it may not be expected to diminish the risk of operation and improve the chances of the patient for a successful operation and a good recovery. Among the indications are prolonged, bloody operations such as pelvic evisceration; intracranial operations for olfactory groove meningioma, hemangioma, or aneurysm; and patent ductus arteriosus. The choice of the appropriate method of inducing hypotension depends on the site of operation and the condition of the patient. A patient who is in middle age and who has moderate hypertension can reasonably be expected to respond to the ganglioplegic agents, and they should be tried as they provide the simplest method of producing hypotension. Spinal anesthesia may be a good choice in situations in which it can provide both hypotension and anesthesia for surgical intervention. Arteriotomy, although the most cumbersome method, has several clear indications. It is useful in normotensive patients who may fail to respond to the other methods. It is especially well suited to operations for the removal of olfactory groove meningiomas. These tumors, although lying in contact with the cerebrum,

derive their blood supply from the external carotid artery which shares in the generalized vasoconstriction that follows arteriotomy. Meanwhile, the cerebral circulation is little impaired as it, together with that of the myocardium, is maintained at the expense of the rest of the body. Arteriotomy is useful for providing brief periods (one to two minutes) of deep hypotension (20 to 40 mm. of mercury) to provide a dry field for the accurate placement of a clip on a torn intracranial aneurysm, the bleeding from which may otherwise completely obscure the field.

COMPLICATIONS

In the survey of controlled hypotension in Great Britain which was recently conducted at Yale University Medical School (11), some of the complications, in the order of their frequency, were: (1) delayed postoperative recovery; (2) reactionary hemorrhage; (3) difficulty with vision; (4) anuria; (5) oliguria; (6) cerebral thrombosis; (7) coronary thrombosis, and (8) cardiac arrest. A careful study of this list reveals that the chief dangers attending hypotension are the result of anoxia, thrombosis, and postoperative hemorrhage. Anoxia may cause such complications as cerebral damage, cardiac arrest, and anuria. Thrombosis resulting from the slowing of the blood flow may occur in the coronary or cerebral vessels or in the larger veins, with the danger of subsequent pulmonary embolism. Postoperative hemorrhage may result from inadequate hemostasis while the blood pressure is low, as cut vessels imperfectly sealed may bleed again when the pressure returns to normal.

CONTRAINDICATIONS

Contraindications to induced hypotension by any method include severe, advanced coronary disease, angina pectoris, and marked impairment of renal function.

ANESTHESIA

Various methods of anesthesia are used during controlled hypotension. Intravenous sodium pentothal® as the chief anesthetic agent and endotracheal nitrous oxide-oxygen mixtures or oxygen alone has proven satisfactory. Less anesthesia is needed during hypotension. Morphine and the barbiturates used as preoperative agents contribute in some degree to hypotension.

METHODS OF PRODUCING HYPOTENSION

Arteriotomy

Arteriotomy was the first method reported to produce planned hypotension for surgical procedures (3). In this method blood is drawn

from the radial artery into a series of bottles containing A.C.D. solution (fig. 1). The bloodletting is not started until the need for hypotension is present. Blood is withdrawn, with frequent checks of the blood pressure, until a systolic reading of 80 mm. of mercury is reached. Higher minimal levels must be preserved in patients in the older age groups. No patients fail to respond to this method of producing hypotension.

As soon as the hypotension is no longer needed, the blood is returned by arterial infusion. The blood pressure is thus raised to near

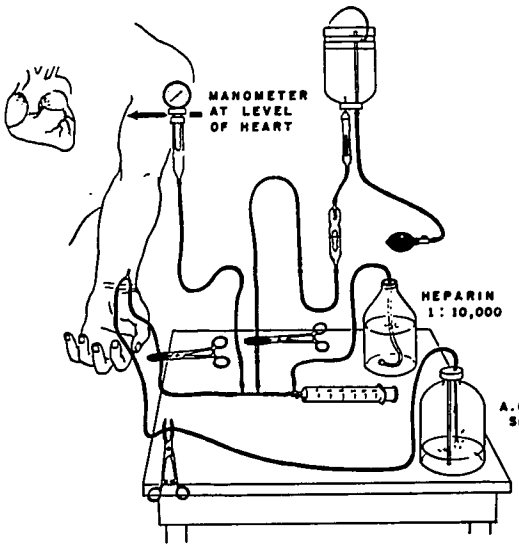

FIG. 1. Apparatus for inducing hypotension by arteriotomy. Blood flows from the artery into a flask containing A.C.D. solution, and is returned as needed under pressure. Heparin, 0.01%, is used to keep the system free from clots. Arterial blood pressure is read on a manometer placed on the level of the heart.

but below the pre-arteriotomy level. If this occurs before all the blood has been returned to the patient, one unit may be sent to the blood bank and given later by the intravenous route.

This method has been used chiefly during operations upon highly vascular intracranial lesions. A survey of 43 meningiomas removed with the aid of controlled hypotension showed a mortality rate of 9.3 per cent as compared to a mortality rate of 17 per cent in 47 cases without controlled hypotension. It is assumed that the reduction in

mortality rate is partly attributable to the use of controlled hypotension in facilitating and shortening the operative procedure.

In the 140 cases in our series, no gangrene or circulatory disturbances appeared even though the radial artery, in many instances, was sacrificed. Several instances of gangrene of the hand following arterial transfusion have been reported. This may result from the use of chilled blood which causes severe vasospasm. Arterial spasm does not result from the injection of the patient's own blood which is oxygenated and is nearly at body temperature.

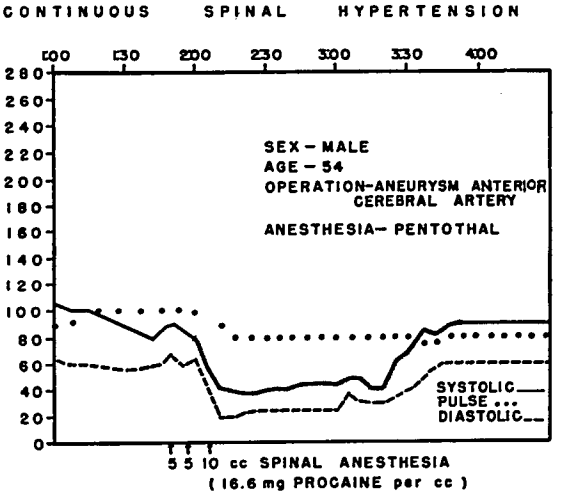

FIG. 2. Continuous spinal anesthesia used to induce controlled hypotension. Injections of 5, 5, and 10 cc. of a solution containing 16.6 mg. of procaine per cc. caused a drop in systolic blood pressure from 80 to 40 mm. of mercury. This level persisted for an hour and ten minutes.

Spinal Anesthesia

Spinal anesthesia produces a preganglionic sympathetic block. It should be sufficiently high to give a total sympathetic block but not necessarily a total spinal anesthesia. This means that its level should be above the first thoracic segment. It may be difficult to determine the level of the block if the patient is under general anesthesia, but cessation of diaphragmatic action indicates that the level has reached the midcervical region. The use of sympathetic block by spinal anesthesia to control the activity of the adrenal glands in hyperthyroidism

was suggested by Crile in 1938 (4) and has recently been described by Knight (5). It was subsequently used by Gillies in Edinburgh for the purpose of providing a bloodless operating field (6). As originally used by Gillies, 150 to 200 mg. of procaine dissolved in 3 or 4 cc. of spinal fluid was injected into the third lumbar interspace, after which the patient was placed in steep Trendelenburg position. Continuous spinal anesthesia with an indwelling spinal catheter provides a controllable means of producing sympathetic block (fig. 2).

Ganglioplegia

Normal transmission in a ganglion is accomplished by the release of acetylcholine by the nerve terminals of the preganglionic nerve and the excitation of the ganglion cell by the acetylcholine so released (7).

Paralysis of transmission can be accomplished by three mechanisms: (1) interference with the release of acetylcholine; (2) prevention of action of acetylcholine on the ganglion cell by agents such as curare, tetraethylammonium chloride or hexamethonium, which compete for receptor groups in the ganglion, and (3) depolarization of the ganglion cell which results from the application of nicotine or acetylcholine.

Hexamethonium is a specific ganglion-blocking agent of low toxicity. It causes no stimulation of nerve terminations or of muscle, exerts no neuromuscular blocking action, has no atropine-like action, does not liberate histamine, and has no anticholinesterase activity. The different ganglia are sensitive to hexamethonium in the following order: (1) parasympathetic ganglia to salivary glands; (2) the superior cervical ganglion; (3) the vasomotor ganglia; (4) visceral ganglia, and (5) vagal ganglia in the heart.

Hexamethonium in man lowers the blood pressure to a level comparable with that produced by tetraethylammonium chloride. It also causes warming of the limbs and an increase in the digital blood flow, depression of sweating, paralysis of the bladder, and ileus of the small intestine. Sensitivity of the blood vessel wall to epinephrine is retained. The lowering of blood pressure and the retention of sensitivity to epinehrine are most important in the present discussion.

Ganglion block following the intravenous administration of hexamethonium takes place in from one to four minutes (7, 8). Hypertensive subjects are more sensitive than normotensive ones, and 20 per cent of subjects (chiefly robust young adults) are not affected by the drug (8). Patients who are awake have a less marked drop in blood pressure. The initial dose may be as little as 5 mg. but is usually 20 or 25 mg., and several such injections at intervals of three or four minutes may be necessary to bring about the ganglionic block.

Patients subjected to hypotension by means of hexamethonium seem to be resistant to shock. This fact was mentioned by Magill on his recent trip to this country and has been noted by many others.

The sympathetic block permits less anesthetic agent to be used, perhaps by blocking the sympathetic-adrenal activity.

Arfonad,® a thiophanium derivative, has proved to be of value in producing controlled hypotension. This drug apparently has a more marked effect upon the musculature of the arterioles than upon the ganglia (9). One of the great advantages of this drug is the quick onset and short duration of its action so that a solution may be given by continuous drip, the blood pressure rising or falling with increasing

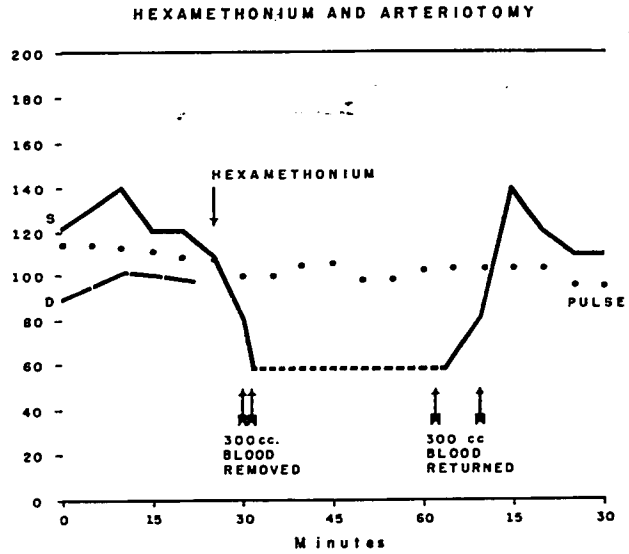

FIG. 3. The administration of hexamethonium (20 mg.) followed by the withdrawal of 300 cc. of blood from the radial artery provided a highly controllable hypotension.

or decreasing rate of administration. Normotensive young patients are less responsive to arfonad as well as to hexamethonium (10). When the need for hypotension arises, a solution of arfonad containing 0.5 mg. per cubic centimeter is given intravenously at a rate which delivers 1 to 1.5 mg. per minute (10). The desired level of blood pressure is maintained by adjusting the rate of flow of the solution. When the drug is discontinued, the blood pressure returns to normal within five to fifteen minutes.

Arteriotomy may be combined with ganglion block to produce a highly controllable hypotension. Ganglionic block increases and fixes the capacity of the vascular bed which is then no longer able to adapt itself to changes in blood volume. Accordingly, changes in blood volume result in considerable changes in blood pressure. This is illustrated in figure 3. In this patient, hexamethonium (20 mg.) was administered as indicated and caused a drop in systolic blood pressure from 110 to 80 mm. of mercury. At this point the withdrawal of 300 cc. of blood from the radial artery lowered the pressure to 60 mm., where it remained until an arterial transfusion of 300 cc. of blood was given thirty-four minutes later. The blood pressure promptly re-

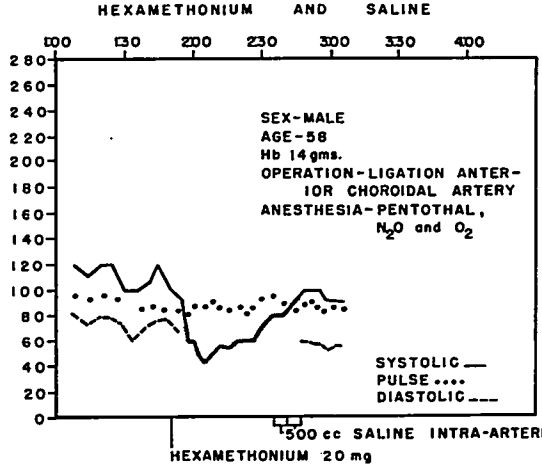

FIG. 4. Five hundred cc. of physiological saline solution were injected intraarterially to raise the blood pressure from a hypotensive to a normal value.

turned to the pre-arteriotomy level, and continued to rise as the effect of the hexamethonium disappeared.

When the operation is finished, the blood pressure may be allowed to rise slowly to a normal level, or it may be restored to normal at once. Some surgeons prefer a slow return of normal blood pressure, believing that this permits the clots which are forming in the cut blood vessel ends to become firm so as to afford effective hemostasis. A slow rise of blood pressure would be safe when the operative site can be exposed to pressure bandages, as following operation for lymphedema of the lower extremity.

If it is desired that the blood pressure be raised to a normal level rapidly, this can be done (following arteriotomy) by restoring blood volume, or (following sympathetic block) by reducing the capacity of the vascular bed. Blood volume may be restored by the reinjection, arterially, of the withdrawn blood. Saline solution may be injected rapidly intraarterially to produce a temporary rise in blood pressure (fig. 4). Vasopressors may be used to decrease the capacity of the vascular tree following hexamethonium hypotension, and discontinuing the arfonad drip accomplishes the same purpose.

DISCUSSION

It may seem, and it may be true, that hypotension with vasodilation is safer than hypotension with vasoconstriction. Every animal organism which suffers hemorrhage, however, responds by preserving as well as possible the blood supply to the vital areas while temporarily denying it to other regions. If in hypotension by vasodilation all tissues are supplied equally without regard for the greater needs of some, this method may not be safer than hypotension with vasoconstriction.

Whatever the method by which controlled hypotension is achieved, its duration should be as short as possible. The method should not be started at the beginning of the surgical procedure but only when the real need for a bloodless field arises. The method should not be used for prolonged operations.

Controlled hypotension should not be administered by the same individual who is responsible for the anesthesia. The management of controlled hypotension demands full time supervision by one or more individuals, and the safety of the patient demands that no compromise be made with careful second to second observation and control of the blood pressure.

The head of the patient should be level with or below the heart. If the head must be higher than the heart it should be remembered that the blood pressure in the head is lower than that in the heart or in the upper extremity by the weight of a column of blood which measures the vertical distance between the two.

The lungs should be inflated with an oxygen-rich atmosphere (by artificial means if necessary) throughout the procedure.

It should be remembered that patients under controlled hypotension respond better than usual to vasopressor drugs, and these can be used with caution when needed to elevate a dangerously low pressure.

During hypotension less anesthesia is required, and anesthesia that is safe at normal blood pressures may be dangerous at lower levels.

The patient must be watched carefully after operation until a safe, stable blood pressure level has returned.

SUMMARY

Controlled hypotension is helpful, when indicated, in reducing bleeding, shortening operating time, and contributing to the safety of the operation.

Controlled hypotension may be induced by arteriotomy, by spinal anesthesia, and by ganglioplegia.

The dangers of controlled hypotension can be lessened by adequate oxygenation, by careful control of blood pressure, and by limiting its use to short periods.

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