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Vascular hypotension in spinal anesthesia

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VASCULAR HYPOTENSION

IN

SPINAL ANESTHESIA

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T A B L E O F C O N T E N T S

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F O R E W O R D

Foreword

Dr. Charles Pannett (1934), Professor of Surgery at the University of London, has voiced the prevailing opinion of surgeons at large when he summarizes the problems of spinal anesthesia, "Two uncertainties dominate the situation: the extent of the anesthetic field produced, and the magnitude of the fall in blood pressure." It is the problem of the vascular hypotension encountered in this type of anesthesia that is the concern of this paper. Especial attention is given to the question of the pathogenesis of the phenomenon because of its significance as a basis for the rational clinical use of subarachnoid anesthesia. Throughout, established experimental evidence is felt to be more sound than purely clinical opinion.

The drawbacks of spinal anesthesia, of which hypotension is probably the most grave, have but recently stimulated such vitriolic condemnation as that of Bevan (1933), despite such enthusiastic praise as that of Babcock (1934) and a host of others. Even in the clinic of Bier, first to use spinal anesthesia in Europe, the method is no longer in use (60), while in thousands of clinics its use is gaining constantly. Unquestionably, spinal anesthesia is firmly entrenched as an operative adjunct, because its accompanying advantages of remarkable relaxation, absence of interfering distended loops of bowel, and smooth post-

operative course have attracted great numbers of prominent surgeons to its use.

Within the past few years, however, discerning experimental evidence and clinical observation have placed it upon a more rational basis for true advance. Because much of the recent investigation has been toward the analysis and control of the justly alarming hypotension, the subject is felt to be a timely one. It has not been attempted to advocate any certain theory, technic, or drug, but to present the most authoritative opinion upon these subjects. Except when the reference is from an indirect source, the name of the author, followed by the year of his article, is given.

The historical resume preceding the discussion is a rather general consideration, largely clinical in nature, of the development of spinal anesthesia. The more specific advances pertaining to the question of blood pressure changes are mentioned under the appropriate divisions of the topic.

Through constant usage in the literature, the term "spinal anesthesia" has become so identified with the more correct term of "subarachnoid analgesia" that the latter terminology is rarely encountered. Undoubtedly, the second designation is superior, both to describe its physiologic effect, and to distinguish it from other types of

block about the spine - sacral, caudal, paravertebral, and more recently, the peridural block advocated by Dogliotti (1934). Case (1928) urged the abandonment of the term "spinal anesthesia" because of the stigma of prejudice that has existed in the lay mind against this type of anesthesia, a prejudice that is engendered, he thinks, because of the word "spinal". However, in this monograph, noattempt is made to exclude the looser term since it is so frequently encountered.

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H I S T O R Y

History

From the recent wide-spread use of spinal anesthesia for surgical purposes, and the animated controversy that pervades the current literature on the subject, one is apt to consider it a new development. Actually, however, it is now half a century since its introduction by J. Leonard Corning of New York (1885). Although subarachnoid block is called "Bier's Method" in Germany, Corning anticipated Bier by fully fifteen years.

That Corning was the first to block the spinal cord is evident from his article in the New York Medical Journal Vol. XLII, pg. 483, "Spinal Anesthesia and Local Medication of the Cord". After saying he is presenting a procedure which possesses the merit of novelty, he continues, "Some time since, I began a series of experiments with a view to determining whether the local medication of the cord was within the range of practical achievement. The drug made use of was the hydrochlorate of cocaine.....I decided to inject the anesthetic between the spinous processes of the lower dorsal vertebrae.....I hoped to produce a temporary condition of things analagous in its physiological consequences to the effects observed in transverse myelitis or total section of the cord..... Whether the method will ever find application as a substitute for etherization in genitourinary or other branches of surgery, further

experience alone can show. Be the destiny of the observation what it may, it has seemed to me, on the whole, worth recording."

In 1896 Bier, in Germany, wishing to amputate the foot of a patient unable to take inhalation anesthesia, recalled Corning's observations, and using cocaine, performed the first actual surgery under spinal anesthesia. So enthusiastic was Bier at the success of the analgesia, that he and his assistant, Hildebrandt, administered the anesthetic to each other in order to describe their sensations. Three years later, Bier reported a series of six cases in which he had used spinal anesthesia clinically. Months later, Tuffier, in France, ignorant of Bier's work, performed spinal anesthesia under identical conditions. In 1900, Tuffier and Hallion introduced their diffusion nulle technic, which became the main standard for clinical spinal anesthesia. (7) (60)

There has been some controversy as to who performed the first operation under spinal anesthesia in America. Tait and Calglieri, or Matas. The confusion arose from the fact that although the first named surgeons performed an operation for osteomyelitis on October 26, 1899, they did not report their case until April, 1900, while Matas, as early as December 30, 1899, published his account of a hemorrhoidectomy performed on December 10, 1899.(Matas,1928)

The introduction of Fourneau's stovaine in 1904, and other anesthetic drugs of less toxicity than cocaine, gave a decided impetus to spinal anesthesia. To 1909, Jonnesco and his pupils had operated upon more than 700 patients, and some 5,000 operations in all had been credited by this method. (81)

Especially active in this country were Babcock, Gwathmey, and Morton. Babcock began using spinal anesthesia routinely in 1904, and experimented with light and heavy anesthetizing solutions. In England, Barker, McGavin, Leedham-Green, and Tyrell Gray pioneered in this field.(81)

The technics which became adopted were the diffusion nulle technic of Tuffier, mentioned above; a diffusion progressive technic of Le Filliatre; the general spinal anesthesia technic of Jonnesco; and a diffusion homogene, or injection brusque technic of Delmas. (80)

The World War afforded an excellent opportunity to observe spinal anesthesia in surgery, and very favorable results were reported, such as those mentioned by Crile (1934), where the danger of operative shock was a vital factor.

Pitkin's articles, in 1927 and 1928, on the control of spinal anesthesia renewed interest in the light and heavy anesthetizing solutions long used by Babcock, and in the

use of strychnine, first tried by Gwathmey and Jonnesco, but discarded by the latter after 16 years of use. Koster championed head and neck surgery under the technic advocated by Jonnesco for many years. These articles, together with those of Labat, Sise, and others which appeared the same year, stimulated universal interest. Encouraged, increasing numbers of surgeons adopted spinal anesthesia, until today it is the anesthetic of choice in clinics throughout the world.

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P A T H O G E N E S I S

Pathogenesis

The phenomenon of a sudden fall of blood pressure was among the early symptoms associated with spinal anesthesia. Bier (1899) noted it, and Tuffier and Hallion (1900) mentioned it specifically, and advanced a theory to explain its occurrence. Early observers noted that it was at times very great, but thought it of secondary importance, since the danger of respiratory failure as a result of the diffusion of the drug to the brain overshadowed the gravity of the circulatory disorders. The cardiovascular depression was thought to be one of the cardinal symptoms by which the toxicity of the drug made itself manifest. (49) The observation of its occurrence has been common knowledge since that time, though the mechanism of its production long lay in obscurity.

In 1929 Evans described the blood pressure changes that occurred with a typical spinal anesthetic as follows:

(a) A slight rise during the lumbar puncture and the period of injection. This may last from 5 to 15 minutes, and is due to the puncture and excitment.

(b) Next, a preliminary fall, smaller in extent than the succeeding fall.

(c) Then the main fall in blood pressure which will vary directly with the height and concentration of the anesthetic.

CoTui (1934) has given this picture of the vascular changes: The typical curve consists of a preliminary fall, beginning a few seconds after injection, an intermediate rise within a minute or two, and a secondary fall, which begins in from five to twenty minutes after the injection and whose duration is longer and roughly proportionate to the dose of the novocain.

The magnitude of the hypotension is a variable, dependent upon several factors later considered. Suffice it to say at this time that it may range from only an insignificant fall to so complete a drop that, as Hillman so aptly expressed it "the blood pressure was nothing over zero". Experimentally, Ferguson and North (1932) found an average drop of 56 per cent of the original pressure, using dogs in their observations. Clinically, Hyman (1933) in a study of 3,000 spinal anesthesia records found a drop in 92.4 per cent of the cases that averaged 10.38 mm. of mercury, the magnitude of the drop varying directly with the height of the original systoltic pressure.

Leriche (1928) named the most salient reason for the retarded progress of subarachnoid block when he said "it has been the misfortune of spinal anesthesia not to have interested the physiologist." It is only comparatively recently that experimental evidence has changed spinal anesthesia from an empirical to a rational procedure.

This present period in which the pathologic, physiologic and chemic changes are investigated in the most important era of spinal anesthesia, according to Vehrs (1934).

A conception of the neuro-anatomy and physiology of the blood pressure control together with an understanding of the pharmacological action of the anesthetic drug upon that neuro-anatomy and physiology forms a necessary background for an explanation of the pathogenesis of blood pressure control. Evans (1929) gives this description of the neuro-anatomy involved: Under normal conditions the blood vessels throughout the body are under the influence of tonic constrictor impulses conducted by sympathetic nerves. These impulses have their origin in the medulla where they are controlled by a vasomotor center.

They pass down the cord as far as the dorsal region and leave it through the anterior roots. As the white rami communicates they pass to the ganglia of the sympathetic trunk, one of which extends along each side of the anterior portion of the vertebral column. From these ganglia they are distributed according to their destination.

(a) The nerve fibers supplying the blood vessels for the head and neck leave the cord with the first four thoracic nerves. They ascend the sympathetic trunk to the superior cervical ganglion, from which fibers arise which pass along the carotid artery and its branches to the head.

(b) The fibers supplying the upper extremity leave the cord between the fourth and tenth vertebral segments and pass up the sympathetic trunk to ganglia whose fibers, after leaving the gray rami, join the cervical nerves that form the brachial plexus.

(c) The fibers supplying the lower extremities and perineum leave the cord with the eleventh thoracic to the third lumbar nerve roots. They pass down the sympathetic trunk to ganglia whose fibers enter the lumbar and sacral nerves that form the sacral plexus.

(d) The fibers supplying the viscera leave the cord with the lower seven thoracic and the upper three lumbar nerve roots. They form most of the fibers of the white rami but go without interruption through the ganglia of the sympathetic trunk to the solar plexus and other large intra-abdominal ganglia. From these intra-abdominal ganglia fibers arise which supply the blood vessels of the viscera. These are a part of those fibers which, after leaving the nerve roots, go to form the splanchnic nerves.

The background of the investigations of the anesthetic drug reaches back to Majendie's description of the cerebro-spinal circulation in 1825. In 1859 Nierman isolated the alkaloid of cocoa leaves - cocaine, as it became known - and shortly after, in 1862, Schraff reported its local analgesic properties. Next, Robin Virchow, and von Monokow

described the intricate subarachnoid cerebrospinal circulation. Weed then advanced the description of its embryologic and mature structure, giving the anatomic paths in the brain and cord by which crystalloids were carried to the nerve roots, nerve fibers, and nerve cells by the subarachnoid fluid.(80) (81)

Dixon, Koch, Santessin gave the basis for proof and the laws which govern sensory and motor selectivity for the cocaine series, and further showed a measure of difference of selectivity between the sensory and motor nerves, and the sequence of block by novocaine of the fibers of each system. (80). Gasser and Erlanger (1929) studied tracings obtained by photographing the deflexion of a galvonometer string produced by an electrical impulse passing through nerve fibers. The curve produced by such an impulse is characteristic, and is similar to an electrocardiograph in its wave tracings. Certain waves can be identified as due to motor impulses, others appear to be sensory in nature. These investigators showed that a cocanized nerve produced a tracing in which the motor wave remained intact, but the sensory was obliterated. Ransom and Bishop investigated and classified the nerve action currents, and Evans classified their response. Babcock experimented with both light and heavy novocaine solutions in small amounts. (80)

It should be noted that with a definite knowledge of histology and anatomic descriptions of the intracordal and intracerebral fluid circulation, novocaine fixation was not considered as combining extra- and intracordal block in spinal anesthesia, but was described as simple extracordal nerve root block. Extra- and intracordal novocaine fixation or transection of the cord was described by Vehrs in 1931 and 1933, who also performed chemic quantative analysis of novocainized cisternal fluid around the nerves and centers of the brainstem. CoTui and Standard (1932) corroborated these findings. Thompson (1934) made further chemic studies.

Ferguson and North (1932) measured the fall in blood pressure as a result of severance nerve block or both in segmental block of the sympathetic nerve fibers. (80) Lundy and Essex (1931) have reported the pathologic changes produced by novocaine in the cords of dogs. Davis (1931), Lindemulder (1932), Rosenbloom and Winograd (1931) (1934), Koster and Kasman (1934) made additional studies.

Vehrs (1931) described regional sensory spinal analgesia and general spinal anesthesia through extra- and intracordal block; Grodinsky and Baker (1933) brought forth the first real chemical proof of transection of the nerves and cord in subarachnoid nerve block. Using Beber's novocaine diazo stain, they demonstrated penetration of the cord by the novocaine and that anesthesia may be the result either

of action upon the nerve roots or upon the sensory tracts within the cord and brain. Vehrs (1934) graphically depicted the speed of nerve fixation, and gave the boundaries of sensory and motor block together with the concentrations of novocaine which produce it. He also discussed the chemistry of novocainization and denovocainization of the spinal fluid in regional and general spinal anesthesia.

In the light of these investigations, how, then, does the anesthetic drug act upon the neuro-anatomy previously described to produce vasomotor paresis? Let us first consider the architecture of the cerebrospinal circulation. Vehrs(1934) has described it in this fashion: The cerebrospinal arachnoid system consists of a communicating network of channels, surrounding and permeating the cord and brain. The surrounding spaces are the subdural and arachnoid spaces. The internal spaces are the ventricles, the aqueduct of Fallopius and the central canal of the cord. Virchow and Robin first described these penetrating channels as vascular channels, surrounding the arteries and lined with pia cells. The arachnoid lies between the artery and pia, containing cerebrospinal fluid, communicating with the perineural spaces around each nerve cell and fiber within the brain and cord, and with the subarachnoid spaces around the brain and cord.

Having accepted a proven pattern for the cerebrospinal

subarachnoid circulation around and within the cord, it is easy to follow the effect of novocaine diffusion in that fluid. Physiologic block of all ascending and descending afferent fibers with total paralysis below the point of block, as in the compartment subdural block as performed by Ferguson and North (1932), is just as sufficient proof of the correctness of the anatomic description of the arachnoid by Virchow, Robin, and Weed as in the intraneural and intracordal stain reaction of Grodinsky and Baker (1933), as Vehrs (1934) points out.

Let us next review the attempts that have been made to explain and clarify the vascular hypotensin itself. First, Tuffier and Hallion (1900), noting rise in pressure on stimulation of the splanchnics, advanced the theory that it was due to action on the cord and nerve roots. However, Doenitz (1903) and Klapp (1904), working independently, thought absorption into the circulation to be the causative factor.

Heineke and Laewen (1906) concluded that the drop in blood pressure was due to a direct action upon the nerve centers rather than to absorption of the drug into the circulation. With intravenous injection of cocaine they found only a short, immediate fall of blood pressure, but an immediate, intensive, long-lasting fall in the pressure with subarachnoid injection. Injection below a ligature placed about the upper thoracic cord caused only a slight fall; injection above the ligature caused abrupt, severe fall of

30 to 50 per cent and death.

Gray and Parsons (1911) suggested that the fall might be due to accumulation of blood in the capillaries of the relaxed skeletal muscles, and stressed the intimate relation of blood pressure and costal paralysis, a theory later corroborated by Featherstone (1924). Smith and Porter (1915) following a now old and discarded theory of traumatic shock, found a greater fall in blood pressure when the anesthetic was confined to the thoracic as compared to the lumbar and cervical regions, and hence assumed that the paralysis of the splanchnics, with resulting dilitation and formation of a "splanchnic pool" was the causative factor.

Schilf and Ziegner (1924), using ligatures also confined anesthia to the various regions of the cord. The sharp thoracic fall they also attributed to paralysis of the splanchnics. Babcock (1925) refers to this splanchnic paralysis as the main cause of lowered blood pressure. Bower and Clark (1926) noted, after cervical injection of stovaine, a depression of blood pressure following a depression of respiration, and concluded that the alterations of blood pressure were secondary to a respiratory depression.

Ferguson and North (1932), in the experments previosly mentioned, conclude that the fall of blood pressure cannot be explained on the basis of splanchnic paralysis. Division

of the splanchnics produced only slight alteration of the general blood pressure, and the typical fall of spinal anesthesia could be produced in animals with both splanchnics severed. There was also slowing of the heart. The entire vasomotor system participates, they decided, in a vasodilitation, and the degree of blood pressure depression is in direct ratio to the number of white rami anesthetized. Kremer and Wright)1932) sectioned the splanchnics with similar findings.

Bower, Clark, Wagoner, and Burns (1932), working along the lines of their 1926 experiments, attributed the fall in blood pressure with thoracic and cervical injections to interference with respiration and the loss of sucking action of the chest upon the right side of the heart. Myocardial weakness, and not vasomotor paralysis, then, would be the cause of the hypotension. Seevers and Waters (1932) also spoke of the effect on the heart, with the collection of large amounts of blood in the dilated peripheral vessels leaving less to return to the auricles; hence a diminished output.

Isenberg and Lundy (1932) pointed to resiratory paralysis, and found, in their experience, that if artificial respiration was continued after complete respiratory paralysis, the blood pressure would remain satisfactory. CoTui and Standard (1932) concluded that procaine through direct

action on the medulla produces respiratory and vasomotor paralysis when injected into the cisterna magna, and the fact that paralysis of the respiratory center occurred first to either the supposition that the vasomotor center is ~~either~~ not exposed anatomically to the procaine, or that it is more resistent. attributed

Grodinsky and Baker (1933) found a drop in blood pressure before a depression in respiration. A typical fall in blood pressure occurred despite artificial respiration. They concluded that any theory placing the mechanism of blood pressure fall upon a basis of myocardial weakness, resulting from interference with respiration, was untenable. They admitted that this latter phenomenon occurred, but only in a concomitant relation to blood pressure fall rather than in one of cause and effect. They also granted that, with complete cessation of respiration, there is an additional sharp fall in blood pressure (after a preliminary anoxemic rise) due to cardiac failure, but that this was a terminal phenomenon and not the ordinary fall compatible with safe anesthesia. Since they found no change in total blood volume, they contended that the usual fall in blood pressure must have been due to reduction in peripheral resistance; hence the anesthetic must have affected the vasomotor system, the only accessible parts of which being the vasomotor center in the medulla or the vasomotor fibers within the cord or nerve roots (preganglionic sympathetic fibers).

Along the same lines, Angelesco and Buzoianu (1934) say the primary element determining the spinal anesthetic hypotensive mechanism is the neuro-vegetative system. They say the cause of vascular hypotension during and after spinal anesthesia is vegetative hypo-amphotony, predominately sympathetic, which depends on the anesthesia of the medullated nervous elements forming conseguently an integral part of the anesthesia. Spinal anesthesia not only paralyzes the motor elements controlling muscular contraction, or the sensory elements of the medulla, but also paralyzes in different degrees the function of the vago-sympathetic vegetative medullary centers. They contend that the variability of the hypotension, conditions of intraspinal injection being equal, depends fundamentally upon the variable state of vegetative equilibrium in different patients.

Thompson (1934) emphasizes that the collapse of circulation and resulant bulbar anemia appear to be intimately associated with respiratory paralysis. The deficiency of circulation is the result of an extensive action of the drug on the nerve elements of the filaments of the spinal cord, producing paralysis of the costal respiration. The results of these effects are a loss of vascular tone, and changes in circulatory mechanisms, for which compensation cannot be made by the central nervous system. He advances the following obsevations in support of his contentions:

(1) A comparison of the changes of cerebrospinal fluid

pressure, produced before and after induction of spinal anesthesia by drugs which cause a rise or fall of blood pressure, demonstrated in the animals studied that the function of the entire sympathetic system was abolished by the spinal anesthesia.

(2) Paralysis of the vital centers of respiration and vasomotor control, produced by procaine injected into the ventricles of dogs, is of short duration, and recovery is complete, provided artifical respiration is adequately maintained throughout the period of paralysis. Were the respiratory failure produced solely by paralysis of the centers, recovery would take place far more quickly and in a different manner than is actually the case.

(3) Cisternal fluid obtained at the time of respiratory failure following spinal anesthesia did not contain enough procaine to produce an effect on the centers of an intact animal when injected into the ventricles.

(4) Paralysis of respiration did not occur when a fall of blood pressure did not take place, or was prevented by preliminary administration of ephedrine.

(5) Recovery of respiration was preceded in all instances by improvement in the circulation.

CoTui (1934) explains the typical blood pressure curve, quoted earlier by saying that the effect of the novocaine solution in the immediate vicinity of the injection is to cause paralysis of the spinal nerves which, of course, in-

clude the vasomotor nerves. This accounts for the primary fall. This primary fall varies from 10 to 50 per cent of the normal blood pressure and is apparently affected by the type of basal anesthesia previously administered. The as yet unaffected vasomotor nerves cause a vasoconstriction to compensate for the fall, thus accounting for the intermediate rise. Then, as the drug spreads upward, the hitherto unaffected vasomotor nerves become paralyzed one by one, causing the secondary fall. The first part of this explanation was verified by a study of the volume of oneof the hind legs. Concomitant with the fall in blood pressure there was an increase in volume of the limb, a fact previously observed experimentally, and also noted by Babcock (1934) by observations of the rise in temperature of the extremities during spinal anesthesia. To prove that the intermediate period of recovery was due to compensation of the unaffected spinal nerves, CoTui flooded the whole spinal simultaneously with novocaine solution. No intermediate rise was noted; on the contrary, there was a steady fall. The same effect he produced by injecting a large volume of anesthetizing solution through the usual lumbar tap. The secondary fall mentioned above CoTui found to be more gradual than the primary fall, the duration depending somewhat upon the dose given.

To evaluate this conflicting tangle of evidence is

at best difficult. Obviously, one of two theories must, in general, account for it; either (1) absorption of the drug into the circulation, as first advanced by Doenitz (1903) and Klapp (1904), or (2) direct action on the nerve roots, cord, or medulla, as first suggested by Heineke and Laewen (1906).

The first theory has no experimental evidence to support it, and must be discarded. The second can be accepted fully, in the light of experimental investigation. As to the relative importance of the factors that may result from this direct action, there is still marked disagreement. The following summary is given considering the various resultant factors suggested:

(1) Paralysis selectively of the splanchnics, with the formation of a "splanchnic pool" of the blood. This theory was advanced by Smith and Porter (1915), and was widely accepted as the predominating cause by most clinicians, such as Babcock (1925), Labat (1928), and others. The observations of Ferguson and North (1932), Bower et al (1932), and others of this period, however, dealt a death blow to this explanation. Clinicians had long observed the bloodless condition of the splanchnic viscera, and were quick to abandon their previous stand.

(2) Paralysis of all the vasoconstrictor fibers in the area reached by the anesthetic, with resultant dilitation of the peripheral vessels involved. Gray and Parsons (1911)

first emphasized this factor, and now most observers hold that it is an important factor; Ferguson and North (1932), Seevers and Waters (1932), Grodinsky and Baker (1933), CoTui (1934), Angelesco and Buzianu (1934), Kordenat (1934), and Pannett (1934). Babcock (1934), however, considers the peripheral vasoparesis to be only a minor cause of the hypotension. Ferguson and North (1932) and Bower et al (1932), supported by Grodinsky and Baker (1933), believe one third of the blood pressure change is due to dilitation in the splanchnic area, abdominal wall, and lower extremities, and two thirds to vasodilitation in the head, neck, thorax, and its contents. Pannett (1934) suggest that the great preponderance of the blood accumulation is in the trunk and lower limbs.

(3) Paralysis of the intercostal and phrenic nerves, with a diminished asiratory action of the thorax sending less blood to the heart. Bowerpt al (1932) and Seevers and Waters (1932) think it a vital factor overshadowing other considerations, as does Babcock (1934) who cites the work of Isenberg and Lundy (1932).

(4) Paralysis of the accelerator nerve to the heart, allowing the vagus to restrict heart action. Evans (1929) mentions it as a cause of lowered blood pressure, as do Ferguson and North (1932), Bower et al (1932), and others. Grodinsky and Baker (1933), however, point out the anatomic consideration that the anesthetic would have to reach above the 4th thoracic segment to be an important factor.

(5) Paralysis of the medullary centers. CoTui and Standard (1932), Bower et al (1932), Sise (1932), Grodinsky and Baker (1933), CoTui (1933) (1934), Angelesco and Buzianu (1934), and others admit this effect to be important, but Thompson (1934) denies that it is a factor in the average anesthesia.

Careful investigation and observation has given decided weight to all these factors, save the first mentioned of predominating splanchnic paralysis. While authorities are at variance as to the relative value of the individual factors as a part of the total picture of the resulting hypotension, it is apparent that the answer to this problem is well on the way to solution. It is perhaps unnecessary to reiterate the fundamental precept that was emphasized at the beginning of this paper that an understanding of the pathogensis involved must form a basis for the rational clinical use of subarachnoid anesthesia.

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E F F E C T

Effect

Little experimental work was done specifically on the effects of the vascular hypotension of spinal anesthesia until relatively a few years ago. Seevers and Watters (1932) found that when too large a dose of anesthetic was injected, or when the volume injected was rather large, that the arterial oxygen was reduced, that the venous carbon dioxide was increased, and that the blood pH was decreased-- in other words, a condition of anoxic anoxia resulted.

CoTui (1934) made determinations for arterial oxygen, venous oxygen, and lactic acid from the blood of dogs where the blood pressure was allowed to fall below the critical level. Artificial respiration was started to avoid asphyxia. He demonstrated that in the state of low blood pressure induced by spinal anesthesia, even though the arterial oxygen content may be slightly raised by aritificial respiration, there is a lowered oxygen content of the venous blood. On account of the sluggish circulation due to the low blood pressure, oxygen is not delivered in sufficient amount to the tissues--that is, there is tissue asphyxia. The venous blood, having come into oxygen equilibrium with the tissues, reflects this oxygen want. The oxygen want is also reflected in the tissue metabolism. Normally, glycogen is broken down into lactic acid which is partly reconverted into flycogen, and partially oxidized into carbon di-

oxide and water, both processes necessitating oxygen. Insufficiency of oxygen leads to accumulation of lactic acid in the blood, as demonstrated by CoTui's figures.

The effects of this stagnant anoxia are, of course, fairly well known clinically, and the vomiting, pallor of the skin, feeling of compression about the chest, thirst, air hunger, cold sweats, and a slowing of the pulse and respirations, as reported by Evans (1929), are illuminated by CoTui's findings.

Without entering into the controversy as to the causation of respiratory collapse, bulbar anemia is considered by most authorities to be admittedly one of the great factors in its causation. Practically all the technics of spinal anesthesia give important consideration to the combatting of bulbar anemia. Roeder (1932) says respiratory failure occurs in two ways; a paralysis of motor nerves of respiration, and a paralysis of the vasomotor nerves followed by myocardial and medullary ischemia. Thompson (1934) again emphasizes the importance of bulbar anemia in the causation of respiratory paralysis. As is apparent, both the anoxia of the blood and the diminished volume reaching the brain are important factors.

Seevers and Waters (1932) bring out the contention that the left heart failure they encountered was a definite result of anoxia. Other investigators have also emphasized the

cardiac effects: Bower et al (1932), Kordenat (1934).

The presence of stagnant anoxia, as demonstrated in CoTui's experiments, plus the reduction of cardiac output as found by Burch and Harrison (1930), and the diminished resistance to the effects of hemorrhage as found by Burch, Harrison, and Blalock (1930) are parts of what has been termed neurogenic shock, or the typical cardiovascular collapse of spinal anesthesia. In hematogenous shock it is known that there is a diminution of the total circulating blood volume, with loss of integrity of vessel walls as regards fluids and blood proteins. It becomes apparent that this does not exist in the average case of spinal anesthesia. Grodinsky and Baker (1933) and others have shown that there is constant blood volume during this type of block. If it is assumed that during early spinal anesthesia permeability of the vessel walls is unaltered and the original blood volume remains intravascular, the matter of control by increasing the fluid volume of the blood is, of course, definitely affected. Seevers and Waters (1932) point out that in prolonged anesthesia the anoxia may affect the integrity of the vessel walls, and a condition somewhat simulating hematogenous shock may be superimposed on the neurogenic shock.

Frazier (1934) reports circulatory collapse is encountered somewhat more frequently with spinal anesthesia

than with ether, an incidence of 2 per cent in the former, compared with 1.33 per cent in the latter. Kordenat (1934) reports one death in 139 cases from what he calls cardio-respiratory collapse--probably a better term than cardio-vascular collapse, in view of Thompson's (1934) contentions. Angelesco and Tzovaru (1933), analyzing the fatality in 120,000 spinal anesthesias, attribute 23 to cardiovascular collapse. Their mortality rate was one death to every 3,992 anesthesias. In 85 per cent of their fatal cases they report the apparent cause was respiratory failure.

Burch and Harrison (1930) and Domenech-Alsina (1932) have shown the mechanism whereby conditions of sanguinary depletion, of intoxication or cachexia following their casual diseases are always aggravated by the hypotension due to the analgesia paralyzing the medullary centers. Doyle (1934) includes these conditions in his list of contraindications for spinal anesthesia. He also includes hypotension and myocardial degeneration as conditions in which the fall of blood pressure in spinal anesthesia may precipitate cardiovascular collapse. Horine (1934), in discussing anesthesia in heart disease, does not advise spinal technic in rheumatic, hypertensive, syphlitic, arteriosclerotic, or thyroid heart disease, or in cardiac arrhythmias. It is of interest to note here that the fatal case of cardiorespir-

atory collapse reported by Kordenat (1934) was a hyperthyroid. The other case he reports (not fatal) was in a patient whose electrocardiogram showed definite coronary sclerosis. In passing, it may be also mentioned that Kordenat, quoting the work of Davis (1931), who showed the hemolytic and myelitic action of certain anesthetic drugs, suggests that possibly the intricate mechanism of cardiac enervation may be harmfully affected in high level spinal anesthesia.

Horine (1934) comments on the problem of hypertensive heart disease: "I am well aware that certain surgeons advise spinal anesthesia in hypertensive indivuals. However, it has been proven that the constant accompaniment of an essential hypertension is a generalized arteriolar sclerosis. In fact the arteriolar change probably precedes and is responsible for the elevation of the pressure. Thus in order to prevent cerebral anemia, which would result from the decreased blood supply through narrowed arterioles, the pressure is elevated. Since cerebral anemia is apparently the cause of death in spinal anesthesia it does not seem logical to court possible disaster by employing a method which would produce a sudden and prolonged reduction in blood pressure thus destroying a protective mechanism." In contrast, Hyman (1933) reports that he has used spinal anesthesia in 28 cases at the Wilkin Foundation for the Study of Heart Disease in order to reduce blood pressure in cases of threatened cerebral hemorrhage, and

that he considers it a safe as well as beneficial procedure.

To summarize the effects of the vascular hypotension, there is ample evidence that there is retarded circulation, a point brought out in the previous discussion of the peripheral vasoparesis, intercostal paralysis, and slowing of the heart rate, and supported by specific authority (see preceding section). The resultant stagnant anoxia has has been demonstrated by Seevers and Waters (1932) and Co Tui (1934), although long assumed present by clincians, such as Evans (1929), Roeder (1932), etc. Tissue asphyxiation is present throughout the body, but is especially manifested in the brain as bulbar anemia, and in the heart as myocardial embaressment. Roeder(1932), as practically allsurgeons, believes the bulbar anemia a main factor in causing resiratory depression; Thompson (1934) brings out experimental evidence. Seevers and Waters (1932), Bower et al (1932), Kordenat (1934), and others emphasize the cardiac picture.

Cardiovascular collapse may result, and death may ensue. Frazier (1934), Kordenat (1934), and Angelesco and Tzovaru (1933) bring out this part of the situation. In toxic, cachexic, and cardiac patients, the hypotension aggravates the pathological condition; Burch and Harrison (1930), Domenech-Alsina (1932). Hence, these are contraindications; Doyle (1934), Horine (1934).

* * *

C O N T R O L

Control

Only with a conception of the foregoing ramifications of the cause and effect of the hypotension as a basis, can the matter of its control be approchaed in a scientific manner. The subject readily resolves itself into two divisions; prevention, and treatment. Under the first will be considered those measures that may be taken to prevent the occurrence of an alarming fall of blood pressure; under the second will be considered those measures that may be employed to combat a cardiovascular collapse which may be either actually present or dangerously imminent. Principle, rather than technic, is the cardinal concern in the ensuing discussion.

In order to prevent serious hypotension from occurring during the operation, a number of precautions can be taken, each attending with a greater or lesser degree of efficacy. The rationale of the following will be considered: (1) the choice of an anesthetic drug causing a minimal fall in blood pressure, (2) the use of a basal anesthesia least augmenting the hypotensive action of the anesthetic drug, (3) the limitation of the height of the anesthetic field, (4) the administration preoperatively of a hypertensive or stimulating drug, (5) the administration preoperatively or coincidently with the operation of intravenous fluid, and

(6) the use of the Trendelenburg position.

Marvin (1933) said, in considering spinal anesthetic drugs, "The ideal anesthetic is still being sought, and the day is not far distant when, in my opinion, it will be found." A long series of drugs have been paraded before the surgeon, all tried enthusiastically for a time, but most largely discarded. Marvin, and Doyle (1934), supply the following:

Cocaine, first suggested for surgical use by Koller in 1884 and used by the first pioneers of spinal anesthesia, was early abandoned in most clinics because of its high toxicity, although, as Babcock (1934) points out, it is still the anesthetic of choice at the General Hospital of the City of Mexico.

Stovaine, prepared by Forneau in 1904, and brought into general use by Barker in 1906, has enjoyed great popularity, especially in France. It is powerful and it produces marked muscular relaxation. There are, however, certain disadvantages in that it is more irritating to connective tissues and nerve fibers. Headaches of rather severe intensity are noted after its use. It deteriorates rapidly, and must be kept in special containers.

Tropacocaine hydrochloride has been used quite extensively in the past. It has a toxicity of about one half that of cocaine, but the duration of its action is shorter.

To be effective, it must be used in a fairly concentrated solution. Because of its high toxicity and rather uncertain analgesia, tropacocaine hydrochloride has been gradually discarded, as have apothesine, alypin, beta eucain, and tutocaine. Lazarus, Pick, and Rosenthal (1933) disagree with this opinion of Marvin's. Reviewing 1000 cases operated under tropacocaine hydrochloride, they find it safer and more dependable than other agents employed. They say it is easy to administer, and is free from untoward effects. Cardio-respiratory shock is less apt to occur than with other agents, as are nausea and headache.

Spinocaine, devised by Pitkin (1927), is a combination of procaine hydrochloride, strychine, alcohol, and normal saline. It gained a wave of popularity at first, but of late has been more replaced by procaine hydrochloride. The fact that it is of lighter specific gravity than the spinal fluid caused severalaccidents that could have been avoided if more care and precaution had been used, and had better instruction been given for its installation. The claims for its complete control sound plausible, Marvin and Doyle bothadmit. Pitkin's (1927) main recommendation for the preparation is that it will control hypotension through the action of the strychnine and through the use of the lighter specific gravity to limit the field of anesthesia. Marbury (1930) reported that it was prefer-30 to 10 over Labat's recommended agent in 92 hospitals

of over 100 beds. Stout advocated it in 1929.

Apothesin, Pitkin (1927) says, gives a perfect anesthesia and complete relaxation; tactile sensation is not constantly impaired. Primarily, there is very little vasomoter disturbance. Its absorbability is slow and retarded. Secondarily, or one or two hours after injection, it produces a severe vasomotor disturbance. Cases have been reported without more than a 10 or 15 point drop 40 minutes after injection, and two hours after injection the pressure had dropped to zero. This secondary action does not occur with any other drug but butyn. At times it is impossible to raise the patients head for 24 hours after the injection. Pitkin dismisses both apothesin and butyn as too dangerous to use. Since this report little attempt has been to revive the drug.

Neothesin, however, does not have this delayd action, and has been used with some success by a number of surgeons. Its use is still quite restricted. Marvin (1933) reports that it is less toxic than nupercaine but more toxic than procaine hydrochloride or pantocaine. It caused an average fall in blood pressure of 20 to 30 points, a slowing of the heart, and appreciable respiratory depression.

Nupercaine (percaine), because of its ability to produce long anesthesia, has been widely used. West (1933) says it is the favorite anesthetic for spinal use in Eng-

land. He claims it can be used in very dilute solutions which are less apt to cause a fall in blood pressure due to vasomotor paralysis than stovaine or procaine hydrochloride. Marvin (1933) found it was more toxic than neothesin, procaine hydrochloride, or pantocaine. He also found it caused an average fall of blood pressure of 30 to 50 points, a larger fall than that produced by any of the other three drugs, and that it caused appreciable respiratory depression, and slowing of the heart that was quite marked. Holder (1934) recommends a mixture of nupercaine and novocaine, claiming less pressure drop with maintenance of a constant level giving fewer subjective symptoms during anesthesia, due to a decrease in individual susceptibility to the effects of the nupercaine.

Procaine hydrochloride is the American brand of the same salt that is known in Germany as novocaine and in France as neocaine. Einhorn discovered it, (as novocaine), and Braun introduced it therapeutically in 1905. Pitkin (1927) claimed it (novocaine) affected the vasomotors less than any other drug in use at that time. Labat (1930) recommended it (as neocaine), reporting no deaths from its use since its introduction in 1916. Marvin (1933) found it to be less toxic than nupercaine or neothesin, but more toxic than pantocaine. Doyle (1934) and Babcock (1934) think it the least toxic, however, of all agents, and strongly advocate its use. Marvin found it produced

a 20 to 30 point average fall in pressure, caused only slight slowing of the heart, and had no effect of respiratory depression.

Pantocaine is a comparatively recent drug in the field of spinal anesthesia. Marvin (1933) is one of the few to publish any comprehensive work upon it, although a number of surgeons have enjoyed marked success with its use . Brown (p. c.) has employed it in some 300 operations, and plans a report advocating it after additional observations. Marvin found only a very slight drop in blood pressure averaging below 10 points, no respiratory depression, and no slowing of the heart. He consludes, "Pantocaine offers everything that procaine hydrochloride will accomplish, and has the advantage that it does not lower the blood pressure." Pantocaine, then, may easily be his "ideal anesthetic" for which surgery is seeking.

Even from as superficial a survey as the foregoing, it seems apparent that a judicious choice of anesthetic agent is an important step in the prophylactic control of alarming hypotension. The matter of care in its use, of course, can not be overstressed. Babcock (1934) has said that he would prefer cocaine, used carefully, to procaine hydrochloride (his favorite), used carelessly.

The use of basal anesthesia preceding the subarachnoid technic has been widely used, and was initiated largely

because of its success in inhalation technic. While there is little indication that basal anesthesia actually prevents blood pressure fall, there is evidence that after certain basal anesthetic drugs the hypotension of the spinal anesthetic is augmented.

In 1928, the beginning of the "renaissance", so to speak, of spinal anesthesia, most of the leading clinicians incorporated it as an integral part of their particular technic. Pitkin gave 1/4 grain of morphine sulphate and 1/150 grain of scopolomine, claiming it in no way intensifed the anesthetic, but did allay fear and apprehension. Labat gave 1/6 grain of morphine sulphate and 1/300 grain of scopolomine, making the same claim. Babcock recommended 1/6 grain of morphine and 1/100 grain of hyosine; Koster said he had used 1/4 grain of morphine and 1/150 grain of atropine.for sixteen years.

Doyle (1934) uses one of the barbiturates, nembutal, the night before, and again one hour before, theoperation, following the second dose(4 1/2 grains) with 1/4 grain of morphine sulphate and 1/150 grain of scopolomine after 15 minutes. He contend the preoperative use of the barbiturates hasnot as yet been fully appreciated, and he uncompromisingly recommends them because of his own favorable experience. Citing Tatum, Knoefel and Güttman (quoted by Downs and Eddy), Swanson, and others, he says it has been

established that barbiturates detoxify cocaine and its derivatives. Rhino-laryngologists, he points out, routinely administer a barbiturate preliminary to the use of cocaine or novecaine. He suggests that not a few of the unexplained sudden deaths immediately following subarachnoid block may be due to novocaine poisoning or sensitivity. In addition to this and the quieting effect, he also claims the barbiturates diminish nausea and vomiting due to depression of the vital centers. Though he does not actually say so, this implies that that there would be less danger of vascular depression.

CoTui(1933) presents the antithesis of this view. He just as uncompromisingly condemns the barbiturates. Experimenting on dogs, he found that sodium amytal narcosis, whether light or heavy, produced a marked reduction in the lethal dose of novocaine injected into the cisterna magna; hence they would be contraindicated. In contradistinction to Doyle's last contention, it would follow that there would be greater, rather than lesser, danger of vascular depression. Ragsdale (1934) agrees that the barbiturates are contraindicated; he does administer morphine and scopolomine, however.

Morphine, on the other hand does not share CoTui's condemnation. This investigator, in the same series of experiments, showed that small but effective doses of mor-

phine, morphine-scopopomine, and morphine-avertin medication given prior to cisterna magna injection did not cause a determinable decrease in the minimum lethal dose of the novocaine. Larger doses of these pre-anesthetic drugs, however, did cause appreciable decrease. The inference is easily made. The average dose given clinically is small and probably has no effect, then; smaller doses would be the preferable.

West (1933) brings up a further consideration. He reports that Professor Sebrechts of Bruges, Belgium, in whose clinic spinal anesthesia has been used in more than 31,000 cases, thinks that patients are of two types - one sensitive to spinal anesthesia, and the other resistant. One hour before operation, he gives an injection of morphine and scopolomine. If this injection renders the patient very sleepy, he is regarded as "rachi-sensible", and the dose of anesthetic drug (percaine) reduced, and a subcutaneous injection of ephedrine given. If, on the other hand, the premedication has no calming effect on the patient, he is regarded as "rachi-resistant", and a larger dose of percaine is given, but no ephedrine.

Summing up the evidence, it would appear that the usual morphine combinations of basal anesthesia do not intensify the drop in blood pressure of the spinal anesthetic drug, and may even be beneficial in indicating whether

the patient is sensitive or resistant to the anesthetic. As to the barbiturates, opinion is divided; further work will have to be done before a definite conclusion can be reached.

Experimentation has demonstrated that there are several factors which determine the height of the anesthetic field produced, and, hence, the fallin blood pressure. Consideration specifically of the details of technic of administration, and of the theories of spread of the drug within the subarachnoid space, is advisedly not within the scope of this paper. Babcock (1934) has urged retension of whatever well-developed technic the surgeon may have been using with definite success.

In 1928 the articles of Pitkin, Labat, Koster, and Evans on the control of spinal anesthesia were responsible for reawakened interest in both the operating room and the laboratory. The literature of the ensuing seven years has been filled with attempts to satisfactorily correlate clinical and experimental observations so that the extent of the anesthetic field may be under the full control of the surgeon. When this has been achieved, inhalation anesthesia will have been robbed of one of its chief advantages over subarachnoid block.

Two main schools of technic developed; the Pitkin and the Labat. Stout, Babcock, long an authority on

administration, Sise, and others too numerous to mention have helped to build up a profound respect for technic in the mind of the average surgeon. Among the most illuminating recent contributions dealing with control of the field have been those of Grodinsky and Baker (1933), Pannett (1934), CoTui (1934), Babcock (1934), and Vehrs (1934).

Grodinsky and Baker state that the height of the anesthesia is dependent upon (1) the volume and contration of the solution, (2) the rate of injection, (3) the position of the patient, and, to a lesser degree, (4) the site of injection. Pannett concludes spread of the drug depends on (1) diffusion, (2) gravity, (3) volumetric displacement, and (4) mechanical commotion. CoTui has named three factors; (1) gravitational flow, (2)leveling, (3) molecular diffusion. Babcock and Vehrs have pointed out anatomical considerations of the human spine that must be kept in mind.

Whatever the method or mechanism of control of the field of anesthesia may be, indication for limitation is suggested by the pathogenesis of the complication of vasomotor paralysis. Koster has long advocated spinal anesthesia for head, neck, and thoracic surgery.(1928). He says 'there is no pressure (i.e. blood pressure) too low to stand operation', and 'it does not matter how great the fall in pressure may be'. However, this disregard of the gravity of hypotension is not shared by other surgeons.

Labat (1928) declares that surgery in the region advocated by Koster is unsound from a clinical standpoint. Seevers and Waters (1932) say, "Grave cardiovascular changes occur as a rule in blocks that involve the chest. As the thorax is implicated, two important factors enter into consideration, (1) additional paralysis of vasoconstrictor fibers, and (2) intercostal nerve paralysis." They conclude that rational use of spinal anesthesia implies limitation of the block to exclude major thoracic involvment. Any method dependent for its safety on selective paralysis of sensory as opposed to motor nerves, especially when motor components are phrenic, deserves little consideration. A blood pressure so low as to require palpation of the abdominal aorta to determine whether the heart is still active is hardly compatible with what is ordinarly considered to constitute good anesthesia". Bower et al (1932) conclude, "Safe anesthesia is the preservation of epicritic and protopathic sensation about the level of the sixth rib. Above this cardiac and respiratory embarressment may develop." Maxson (1934) says, "Untoward symptoms can be avoided by holding the upper limit of anesthesia to the costal margin."

Regarding the extent of safe blood pressure drop, Foss and Schwalm (1933), comparing fatalities with ether and with spinal anesthesia, agree with Bower, Clark, and Burns (1933), who say, "The death of a patient whose blood pressure drops more than fifty per cent, or who develops

respiratory embaressment, within twenty minutes following the injection, and who does not react to within twenty-five per cent of the normal before the operation is finished and subsequently devlops secondary shock and dies, is an anesthetic death."

The great balance of evidence, it can be seen, is for limiting the anesthetic field below the thorax, for only in this way can the dangers of vascular disturbance be held to a minimum, other things being equal.

The use of hypertensive drugs prior to the anesthetic to forestall blood pressure fall was first suggested by Gwathmey(1903) and Jonnesco (1909), strychnine being the drug used. Jonnesco abandoned its use, but Pitkin (1927) incorporated it in his "spinocaine". Although the adherents of spinocaine claim it retards blood pressure drop, the profession at large has turned elsewhere for a hypertensive drug. Babcock (1925) - and in all later articles - declares it valueless, after experimenting with it since for many years. The use of caffeineand atropin, largely as heart stimulants, and of pituitrin also have few adherents. Pannett (1934) suggest atropin again, but admits he has no experimental proof. Frazier (1934) dismisses all these drugs as of no use.

The acknoledged peripheral constrictor, epinephrine, was first suggested by Doenitz (1903) and Klapp (1904).

About that time Babcock (1934) began its use, and still regards it as the only stimulant of much value. Used in the anesthetic solution, he says it is not effective, as is true of the other drugs previously tried. Intramuscularly, however, it is an efficient prophylactic. The assertion that the action of adrenalin is too transient to be of value is untrue, he declares. Its period of 15 to 30 minute stimulation is usually longer than the period of intense depression from spinal anesthesia. By careful graduated or continuous use of this drug, the stimulating effect can be prolonged for hours, he points out. Bower et al (1932) found adrenalin did not prevent the associated cardiac dilitation they encountered experimentally in dogs. Grodinsky and Baker (1933) recommend adrenalin, pointing out that its peripheral vasoconstriction should compensate for the vasomotor paralysis at the cord. Frazier (1934) and Kordenat (1934) claim epinephrine is of no value. Abelson (1934) says its use is not essential.

Ephedrine, also a vasoconstrictor acting at the sympathetic myoneural junctions, is the drug most widely used, and has been the talisman of safety for many. Chen (1925) rediscovered ephedrine, and Ockerblad and Dillon (1927) brought it to surgical attention. Chen and Schmidt (1930) brought out that the effectiveness of ephedrine appears to be due to its ability to (a) increase the peripheral resistance by constricting arteriols and (b) increase the

minute volume output of the heart by direct action on the cardiac muscle. Seevers and Wabers (1932) claim that it may actually depress the heart, yet in their conclusions grant that it is sometimes efficacious. Bower et al (1932) give the same results as with epinephrine, but Ferguson and North (1932) strongly advocate it. They gave ephedrine to dogs in doses of 2 mg per kilo of body weight prior to the subarachnoid injection, and noted a rise of 17 mm Hg in the blood pressure and no cataclysmic fall. After 5 minutes there was an average depression of 3.5 mm; at 20 minutes there was an average depression of only 19.5 mm, or 13 per cent, compared with a depression of 51.8 per cent in dogs that had received no ephedrine. The maximum effect comes, they say, when ephedrine is administered about 10 minutes before the anesthetic. They say, as do Grodinsky and Baker (1933), that since vasoparesis takes place at the preganglionic sympathetic fibers, it is possible, using ephedrine, to stimulate the post ganglionic fibers, or myoneural junctions, and produce vasoconstriction and a rise in blood pressure. Angelsco and Buzianu (1934) and Thompson (1934) urge the use of ephedrine.

On the clinical side, Pitkin(1927) injected ephedrine while infiltrating for the puncture. Stout (1929) used much larger doses. Labat (1928) rejected it. Babcock (1934) thinks the use of ephedrine is based largely on "hysteria", and denounes the experimental evidence save

that of Seevers and Waters, already quoted. He claims that ephedrine greatly increases the work of the heart; because it raises the blood pressure and heart rate is no reason the anesthetic is safer. Babcock says no one has reported as low a mortality from spinal anesthesia with ephedrine as he has reported without ephedrine - 10,000 injections between deaths. Concluding, he says, "In my opinion such a potentially dangerous drug should no longer be used routinely". Doyle (1934), however, uses it routinely as do many others, injecting it intramuscularly 10 to 15 minutes before the subarachnoid injection. He says, "Clinically we have found that the initial effect of the drug is to raise the blood pressure 10 to 30 points, and that following the block the pressure falls gradually, in contrast with the sudden drop encountered if such medication has been ommitted." Some authorities, such as Abelson (1934), do not incorporate it in their technic even when no other stimulant is used.

Of the three hypertensive drugs in present use, strychnine, epinephrine, and ephedrine, the first is used only in spinocain, and then supplemented with ephedrine; the second is used by some men but is not a strongly used routine procedure; the third enjoys wide advocacy but has been sharpely attacked. It can hardly be said that the principle of the use of a drug to conteract the hypotension of spinal anesthesia is firmly entrenched

procedure - some clinicians have altogether abandoned its use.

Supplementing the blood volume before the anesthetic has been tried, though never used very extensively. Burch and Harrison (1931) found the injection of rather large amounts of physiological salt solution prior to the spinal anesthetic was quite effective in controlling hypotension. Seevers and Waters (1932) point out that the solution to be effective must be given while the vessels and heart are physiologically intact, that is, either prior to or throughout the anesthesia. Few clinicians or anesthetists report its routine use, however, as a purely prophylactic method.

The sixth measure suggested for preventing a drop in pressure, the Trendelenburg position, is the most universally used of all. Labat (1921) gave the first demonstration of the position in this country as an adjunct to spinal technic at the St. Mary's Hospital of the Mayo Clinic in October, 1920. The writings of Labat, Evans, and Koster, especially those of 1928, popularized the position. Prior to that time, precautions were taken to keep the patient's head elevated for fear the solutions of higher specific gravity than the spinal fluid would gravitate to the medullary centers and there affect them adversely. The rationale urged for the adoption of the Trendelenburg position was the relief by dependent position of the cer-

ebral anemia occaisioned by the fall in blood pressure.

Two variations of the position were used as prophylactic measures - the immediate Trendelenburg, that is, as soon as the anesthetic was administered, and the delayed Trendelenburg, that is, after about ten minutes from the administration. Labat urged the immediate, as did Babcock (1925) and Pitkin (1927) when light solutions were used, saying it was the most important part or his technic. Koster (1928) also used it at once. Stout (1929) used the delayed, advising a wait of ten minutes in the horizontal position to allow the anesthetic to become "fixed". Grodinsky and Baker (1933) also urge this precaution. Evans (1928) reserved the position for the treatment of cardiovascular collapse. Sise (1929) used the position as soon as a small drop in pressure occurred. At the present time, most surgeons employ it to greater or lesser degree. Doyle (1934) routinely uses the immediate position, for example, as does Kordenat (1934).

CoTui (1934) says the first advocates of the position had little experimental basis for their adoption of it. To test whether the position was advisable, he injected novocaine solution through a lumbar site, and found the lethal dose in the Trendelenburg position was only about half that of the horizontal position. He cites the work of Grodinsky and Baker (1933) showing a cephalad spread of

spread of dye in cadavers in the Trendelenburg position as further proof for his contention that the position is actually harmful. Maxson (1934) also agrees that the position is contraindicated. Thompson (1934), however, still advises the position. Further experimentation seems indicated.

It has been pointed out in the foregoing discussion of the prevention of vascular hypotension that there is by no means agreement among authorities as to the most efficacious measures. The fact that there is such controversy indicates healthy interest, and augers well for the future of spinal anesthesia.

After cardiovascular collapse has occurred, or when it seems iminent, numerous procedures have been resorted to, with varying success. Of these the following six now strongly advocated will be discussed; (1) the use of drugs, (2) the use of oxygen, with or without carbon dioxide, (3) the use of artificial respiration, (4) the use of fluid to increase the blood volume, (5) the use of blood transfusions, and (6) the use of the Trendelenburg position.

As to the use of drugs, stimulants such as ammonia and ether have been found to give a rise in pressure on inhalation. Most observers, such as Pannett (1934), mention them, but agree that the rise they give is small and transitory. In shock their central stimulation is at least an aid to recovery, but they can not be depended upon

as a primary measure.

Epinephrine is more commonly used as a means of combatting shock than for preventing it. It may be injected intramuscularly or subcutaneously, given intravenously, usually in saline infusion, or injected directly into the heart. Babcock (1925), as did most of the first users of spinal anesthesia, employed it, giving intravenously a 1 to 1000 solution - 3 minims in a physiological salt solution. Bower et al (1932), however, found it ineffective in preventing cardiac dilitation in their experiments. Roeder (1932) advises its use, as do Grodinsky and Baker (1933). Kordenat (1934) thinks it ineffect. Abelson (1934) advises its use in saline and glucose solution.

Ephedrine also has strong support. CoTui and Standard (1932) say, "When complete paralysis occurs, artificial respiration and the intravenous injection of ephedrine are effective means of resuscitation." Seevers and Waters (1932) and Ferguson and North (1932) recommend it, but show it is less effective after collapse has occurred than before. Grodinsky and Baker (1933), Abelson (1934), Ragsdale(1934), and Kordenat (1934) all advise its use, but Babcock (1934) contends that experience shows it is unreliable when a real emergency occurs. CoTui (1934), experimenting on dogs, injected ephedrine hydrochloride intravenously (2 mg. per kilo body weight) within the first 5 to 10 minutes after

the blood pressure reached shock level. The injection caused the blood pressure to maintain its level of about 100 mm. and over for 1 to 2 hours after the injection, that is, until recovery.

Drugs are used, apparently, by most clinicians, and recommended by most investigators. The amount of good they do is debatable, but they do afford an opportunity to the surgeon to at least make an honest effort to remedy the situation.

The administration of oxygen, or carbon dioxide and oxygen, aids through relieving the respiratory embarressment. Roeder (1932) directs particular attention to this method, saying administration of 5 to 10 per cent carbon dioxide in pure oxygen will assist in maintaining the blood pressure in most instances, and in maintaining the circulation of blood when heart contraction ceases. Seevers and Waters (1932) recommend the inhalation of oxygen even throughout the operation. Certainly the experiments of CoTui (1934) proving the anoxemia of the blood, long assumed, would bear out such a practice. Frazier (1934), Kordenat (1934), and Abelson (1934) recommend its use.

Artificial respiration is in a like category. If respiration ceases, it is at once indicated. Gray and Parsons (1911) first stressed the intimate relationship of blood pressure to costal paralysis. They found a disappearance

of much of the circulatory hypotension when an adequate to and fro type of artificial respiration was established. Seevers and Waters (1932) made similar findings, though Grodinsky and Baker (1933) did not. (The last named consider respiratory embarressment a secondary factor.) Burch and Harrison (1931) reported it was the most effective means of combatting cardiorespiratory failure. CoTui and Standard (1932) urge its use. Isenberg and Lundy(1932), with complete respiratory paralysis, found artificial respiration effective in keeping animals 10 hours with little change in blood pressure or pulse rate. Clinically, Pitkin (1928), Babcock (1928), (1934), Evans (1928), and Kordenat (1934) especially advise it.

Obviously, if respiration has ceased, or is about to cease, some measure must be taken to restore aeriation of the blood and resumption of the circulation. Artificial respiration and the administration of carbon dioxide and oxygen afford excellent means of accomplishing these ends.

Raising the fluid content of the blood by saline intravenously is a method adopted because its repeated trial in other types of shock. It may be noted that in a normal circulation it is at best difficult to increase the volume of the circulation of the blood, since the solution passes so quickly into the tissues. Although the shock here is largely neurogenic, the suggestion of Seevers and Waters

(1932), that the permeability of the vessel walls may be altered by the time collapse occurs, should be borne in mind. CoTui (1934) found the blood pressure in shock dropped to its former level as soon as saline was discontinued. To be effective, then, it must be continued until the patient is well recovered, though it has been suggested that cardiac stasis may result from too great a volume. Babcock (1934) and Abelson (1934) use intravenous fluid, incorporating adrenalin. Kordenat (1934) also considers it an efficacious method.

Blood transfusion accomplishes the same purpose, probably more effectively as it is better retained intravascularly. It has been recommended by some clinicians, but the obvious difficulty of having a donner ready for instant use, and the delay and expense (to the patient) are marked disadvantages. CoTui (1934) found immediate drop of pressure when transfusion was discontinued. As blood transfusion can not be continuous, as saline can be, it is a rather poor way of combatting the shock.

Some readily available solution, such as physiological saline, or glucose, is apparently the best agreed method of treating cardiovascular shock by increasing blood volume. It is, however, effective only while being administered.

The Trendelenburg position has long been extolled as a means of treating the vascular collapse, and is con-

sidered by many to be imperatively indicated. The surgeons who popularized it - Labat, Evans, and Koster - have reported excellent results from its use. Evans (1928) places the patient in this position only when shock occurs, but then advises it at once; the others increase the position as signs of collapse appear. This latter procedure is followed by practically all who use it as a prophylactic measure. Sise (1932), Grodinsky and Baker (1933), Doyle (1934), and Abelson (1934) allare emphatic in advising the use of the position. On the experimental side, Lundy and Essex (1931) tested the position and reported it was of little value. Seevers and Waters (1932), though little trial was made of it, recommend it. CoTui (1934) again brings up the contention that there is very little experimental proof for the efficacy of the position in remedying the shock. Fifteen minutes after the develoment of shock, he placed the dog in the Trendelenburg position. The lowering of the head caused a rise of about 20 mm. of blood pressure lasting for less than a minute and falling again to its previous level. This was, he said, to be anticipated, as the raising of the distal part of the body had the effect of driving the blood accumulating in the distal veins toward the heart, thereby increasing for the moment its output. But, says CoTui, there is no lasting improvement in the circulation. The use of the head down position in other forms of shock is useful because this transient improve-

ment causes an improvement in the medullary centers which is reflected in an increased tone of the circulation, which, in turn, improves the centers further, thus breaking the vicious cycle. But, in order that this improvement may occur, the nervous pathways to the circulatory system, namely, the vasomotor nerves, must be intact. In spinal anesthesia these nerves are paralyzed and the measure therefore futile. Among clinicians, Maxson (1934) is one of the few that agrees with CoTui that the Trendelenburg position is a procedure of no merit shock. Pannett (1934), although he does not follow CoTui's line of reasoning, suggests that the Trendelenburg position is inefficient, and that raising the abdomen and legs is a better procedure to follow.

Of the methods used to combat shock, there is the most disagreement on the matter of the use of drugs and the use of the Trendelenburg position. This disagreement will no doubt stimulate further experimentation and observation, and it can be predicted that within a few years this problem, together with the other controversial problems of spinal anesthesia, will be solved to the satisfaction of surgeons and laboratory workers as well.

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S U M M A R Y

A N D

C O N C L U S I O N S

Summary and Conclusions

Spinal anesthesia - or, more properly, subarachnoid analgesia - is by no means an established and undebated procedure, despite its wide spread use. While firmly entrenched as a surgical adjunct, there is still a definite note of controversy running through the literature. Especially is this so of the vital problem of the cause, effect, and control of the alarming vascular hypotension that accompanies the use of this type of block. The problem has been the concern of surgeons since the inception of spinal anesthesia; fortunately, of late years, it has also drawn the attention of the physiologist, the pathologist, and the chemist, and now the important process of correlation experimental and clinical evidence is taking place.

By the citation of competent authority, the history, pathogenesis, effect, and control of the vascular hypotension have been developed in the foregoing discussion. The summation here given indicates the gist of the paper.

History: Spinal anesthesia is a procedure now half a century old. It owes its discovery to Corning, of New York, and its introduction to clinical surgery to Bier, of Germany. Interest has waxed and waned in turn, until 1927 and 1928, when the articles of Pitkin, Babcock, Labat, and Koster occaisioned popular interest, and instigated

a renaissance of spinal anesthesia. Since then its use has been constantly growing, until today it is a universal surgical procedure.

Pathogenesis:

Experimentation has quite definitely shown that the anesthetic drug acts directly on the nerve roots, tracts, and medulla; an extra- and intracordal block. Five factors have been suggested as causing the hypotension because of this action:

(1) Paralysis selectively of the splanchnics, with a formation of a "splanchnic pool" of the blood.- an explanation not substantiated by experimentation.

(2) Paralysis of the vasoconstrictors fibers of the segments reached by the anesthetic, with resultant dilitation of the peripheral vessels involved.- an explanation well established as a factor of prime importance.

(3) Paralysis of the intercostal (and phrenic nerves, at times), with a diminished aspiratory action of the thorax sending less blood to the heart - an explanation also well proven as an important factor.

(4) Paralysis of the accelerator nerve to the heart, allowing the vagus to restrict heart action - a factor well established, but of importance largely ~~only~~ in high blocks.

(5) Paralysis of the medullary centers - a factor established as thoroughly possible, but also of importance largely in high blocks.

Authorities disagree as to the relative value of these four factors in the causation of the hypotension. The weight of evidence would indicate that the second and third named are the predominating influences in the average anesthesia. In any event the action is apparently cumulative; that is, the higher the block the greater the effect.

Effect: As a result of the vascular tension, there is a diminished circulation and a stagnant anoxia, causing tissue asphyxiation throughout the body, a condition manifested especially in the brain as bulbar anemia and in the heart as myocardial embarressment. The bulbar anemia adversely affects the respiratory center - one of the factors in respiratory depression - and the vasomotor center, thus setting up a vicious cycle. As the condition is augmented, cardiovascular collapse may result, and even death. The cardiovascular collapse here encountered is a type of neurogenic shock, a condition differing from hemotogenous shock in that the circulating blood volume remains intravascular. Concomitant with the stagnant anoxia, in this type of shock there is reduction in cardiac output, and diminished resistance to the effects of hemorrhage.

In the sanguinary depleted, the toxic, the cachexic. and the cardiac patient, the hypotension of the anesthesia aggravates the pathological condition; hence these are are contraindications to administration. Possibly in the selected cases, hypertension may be benefited, however.

Control:

The problem of the control of the hypotension readily resolves itself into two divisions; prevention, and treatment. In order to prevent the occurrence of hypotension during the operation, the following points are considered, chiefly from a standpoint of rationale:

(1) The choice of an anesthetic drug causing a minimal fall in blood pressure. Cocaine, stovaine, tropacocaine hydrochloride, Pitkin's spinocain, apothesin, neothesin, nupercaine, procaine hydrochloride, and pantocaine are considered. Of these, procaine hydrochloride, most widely used of the drugs, and pantocaine seem to be the least toxic, and to have the least effect on the blood pressure. Spinocaine, nupercaine - alone or combined with novocaine- and tropacocaine hydrochloride have considerable adherents who claim minimal vascular effects for their particular agent.

(2) The use of basal anesthesia. While preliminary narcosis apparently does not prevent blood pressure fall, certain narcotics seem to influence a further fall. Morphine sulphate with scopolomine and with other adjuncts are widely used and seem to have no derogatory evidence against them experimentally. As to the barbiturates, some claim they detoxify the anesthetic drug and depress the medullary centers; hence they are indicated. Others claim they render the medullary centers more susceptible to detrimental effects of the anesthetic agent; hence they are contrain-

dicated. Further experimental and clinical observation is advisable.

(3) The limitation of the height of the anesthetic field. Considerable experimentation has pointed out several factors that influence the field height - limitation of the field is one of the prime concerns of every technic. However it is done, the great preponderance of evidence is for limitation at the thorax or mid-thorax, since the higher the anesthetic paralysis, the greater the fall in blood pressure. Operations above this level hold too much danger of cardiovascular and respiratory collapse.

(4) The administration preoperatively of stimulating or hypertensive drugs. Caffeine, atropin, and pituitrin have proved of little value. Strychnine is incorporated in spinocaine, but has little other use. Its beneficial effect is questionable. Epinephrine and ephedrine both should be of value as they act on the postganglionic fibers (the myoneural junctions) to offset the paralysis of the preganglionic vasomotor fibers. Epinephrine has been the longest used; some extoll its action, others condemn its effects as too transitory. Ephedrine has perhaps more adherents, and more experimental evidence to support its use. Many clinicians use it routinely, claiming excellent results. The question is raised by one surgeon whether mortality statistics bear out its use - he claims they do not, and that it should be abandoned as a dangerous drug.

(5) The administration preoperatively or coincidently with the operation of intravenous fluid. This has been found to be efficacious, but must be used before the operation while the heart and vessels are physiologically normal, or must be given continuously throughout the operation. It is not been widely advocated clinically as a routine procedure.

(6) The use of the Trendelenberg position. Since made popular by Labat and Koster it has been a part of practically all technics as a measure to combat cerebral anemia. Some surgeons use the immediate Trendenburg, using it as soon as the anesthetic is injected; others use the delayed Trendelenburg, waiting until the drug becomes "fixed". Recent investigation brands the Trendelenburg position as actually harmful, endangering the patient.

Treatment of present or iminent cardiovascular collapse is discussed under these six proceures, rationale again being the chief consideration:

(1) The use of stimulating drugs. Ammonia or ether inhalation gives a transitory rise; it is of value only as a supplementary procedure. Epinephrine may be given intrmuscularly, subcutaneously, intravenously, or intracardially. Usually it is administered intravenously in normal saline as a vehicle. Results are reported as excellent. Ephedrine is more often used, and is usually given intravenously. Experimental and clinical evidence show it to be of great

value, though one prominent surgeon contends it fails too often in a crisis.

(2) The inhalation of oxygen, with or without carbon dioxide. This is highly recommended as a rational procedure to combat anoxemia and respiratory dépression, thus maintaining blood pressure. It is strongly advocated experimentally, widely used, and highly effective.

(3) The use of artificial respiration. If respiration ceases, it is obviously imperative. Investigators claim it will eliminate most of the hypotension. It is a part of practically all regimes of cardiovascular shock treatment. Aeriation of the blood and resumption of more nearly adequate circulation result.

(4) The use of fluid to increase the blood volume. This measure is almost always used in this type of shock, saline or saline and glucose being employed. Experiment shows it must be continuous to be of any value, as the blood pressure drops when it is discontinued.

(5) The use of blood transfusion. Though volume would be better retained by this method, the difficulty of arranging for it, the delay occaisoned, and the expense involved, together with the fact continuous administration is impossible, dismiss this measure as impractical ordinarily.

(6) The use of the Trendelenburg position. This is the most highly recommended emergency treatment of all, and though extolled clinically is condemned experimentally as useless.

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