

THE EARLY RECOGNITION AND TREATMENT OF SHOCK*

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IN 1745 LeDran (1) described traumatic shock as a state in which there is arterial spasm, capillary stagnation and circulatory insufficiency.

I should like to start with these observations and present a simple concept which seems to offer a workable approach to the better understanding of the mechanism of shock. Next, I should like to demonstrate a series of tests which have proved of value not only in rapidly assessing changes in the peripheral circulatory system but also, at times, in predicting the onset of shock. Finally, I should like to suggest a method of treatment based on this concept and data from several cases in which treatment was guided by these tests.

In 1923 Gustav Ricker (2) published in book form a series of studies relative to the effect of irritative processes on the terminal arterial segment. This segment, consisting of a small artery, arteriole and capillary tree, he considered the functioning unit of the peripheral vascular system, and compared it to the axon, the basic unit in the nervous system, or the nephron, the functioning unit in the urinary system. He stressed the segmental nature of this terminal unit and pointed out the different effects on the arterioles, venules and capillaries, as a result of different degrees of stimulation or irritation. To me, it seems, there is no real difference between a stimulus and an irritant except that the latter is a stimulus which acts too strongly over a short period of time or when of moderate intensity is continued too long, thereby transcending physiological limits.

Professor Horst Oertel (3) of McGill University, to whom I am indebted for this approach to the better understanding of a difficult problem, in carrying on and amplifying the experimental work related to Ricker's concept of inflammation has demonstrated five rather distinct phases in the changes which take place in the peripheral vascular segment under varying degrees of irritation. They are:

1. ISCHEMIA

Under sudden but unsustained local irritation, such as that produced by a sharp crack with a switch on the skin, strong vasoconstriction is apparent in each of the terminal segments. Blood flow ceases and the part

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becomes blanched. Local injury of capillaries will set up not only a reactive hyperemia when the irritant is removed, but through reflex nervous impulses or chemical changes thought to be of the "triple response" nature as described by Lewis (4), inflammatory changes will be seen to follow in the surrounding tissue. With an irritant of this type there is little systemic reaction for the damage done is usually slight. Such slight injury does not cause shock.

2. HYPEREMIA

On the other hand, under mild but prolonged irritation there may be an incipient and transitory vasoconstriction of the whole segment, but the sustained response is that of generalized vasodilation in a manner quite similar to that observed following slight nutritive over-activity of a part or of an organ. Such a state may be seen following a moderate degree of "sunburn." Such a mild irritant, acting for a longer period of time over a much wider area, may have definite systemic effects. There is a definite transudate as a result of the capillary ectasy with upset in water and mineral balance. The cardinal symptoms and signs of inflammation are present and may be explained by the observable phenomena in the peripheral vascular tree. Yet because an irritant of this type is mild, complete restitution to anatomical and functional integrity is the usual finding.

3. PERISTATIC PHASE

Under persistent, stronger irritation there is at first a transitory ischemia, then a period of diminished constrictor irritability, the arterioles and capillaries are dilated, transudation takes place for a while but later *exudation* is marked. The extruded fluid not only tends to diminish effective circulatory volume by virtue of lost fluids but also upsets osmotic balance.

The condition of the peripheral vascular unit seen in this peristatic phase of localized inflammation is observed over a wide area only when there is excessive central stimulation with resultant inhibition of the vasoconstrictive center. Goltz (5), as early as 1863, suggested that any excessive psychic stimuli such as fright, somatic stimuli such as pain, or excessive stimulation along afferent nerves such as caused by a blow to carotid sinus or celiac plexus, may cause inhibition of the vasomotor center and consequent generalized vasodilation, pooling of blood in the periphery and fall of blood pressure. This is the state of a patient in so-called *primary shock*. This is not the subject under discussion at the moment, but it is of great interest to anesthetists for this is exactly the state of affairs found following spinal anesthesia. Anesthetists have learned to prevent the onset of this type of shock incident to spinal anesthesia by preoperative therapy designed to counteract the vasodilatation without affecting the anesthesia. Gesell (6) long ago showed that ani-

mals might survive with very low pressures following spinal section, whereas animals with much higher pressures went rapidly down hill when they were in secondary or surgical shock. In the inflammatory process the peristatic phase is a brief one. So is primary shock a transitory state, for the patient either recovers with restoration of vasomotor tone or the condition passes into a state of true surgical shock.

4. PRESTATIC PHASE

Under stronger irritation, be it in the form of trauma, bacterial toxins, heat, cold, electricity, nerve impulses, or hormones, there is a tendency for the whole segment again to be constricted, but soon the capillaries begin to tire and dilate while the arterioles and venules, being more heavily muscled and not so readily fatigued, remain somewhat constricted. Circulation is slowed, blood begins to pool at the periphery, cyanosis appears, hemoconcentration begins, and circulatory volume begins to decrease.

This is the stage observed in the early stages of surgical shock. This is the phase which must be recognized and must be treated. The blood pressure may remain surprisingly normal for a long period after these changes have begun. All of the compensatory mechanisms are brought into play.

If the irritant is even stronger and more persistent, the arterioles are seen to constrict even more tightly, blood flow is more markedly decreased, white cell diapedesis begins early, and gradually there is complete paralysis of the capillary bed, with loss of red cells into the interstitial tissue, that is, a *hemorrhagic exudate*. This is the picture seen in severe infections, in severe anoxia such as may occur in an obstructed loop of the bowel, or in profound shock.

The blood becomes more viscid with loss of fluid, the rate of flow is diminished, the pulse becomes more rapid with incomplete filling of the heart, the venous pressure disappears and the signs of tissue anoxemia begin to appear. It is this fourth or prestatic phase with which we are concerned when considering surgical shock. It is imperative that this state of the peripheral vascular system be ascertained before collapse is complete. This arteriolar vasoconstriction must be released, capillary tone must be restored, and fluids must be returned to circulation before the changes become irreversible.

5. STATIC PHASE

Finally with extreme or markedly prolonged irritation both the arterioles and venules as well as the capillaries will be seen to be widely dilated, with cessation of peripheral blood movement and cessation of all exudation. Preterminally small arteries will still be seen to be capable of responding and the resulting spasm may result in almost complete occlusion of the lumen. Here the precipitant drop in blood pressure is seen; anoxia resulting from the inadequate blood supply ex-

presses itself in the skin by cold, dusky cyanosis, in the lungs by rapid and shallow respiration, in the muscles by great weakness, in the kidney by anuria and in the building of waste products of metabolism in the blood stream, in the brain by apathy or coma and, finally, death ensues as all tissue respiration ceases.

I shall make no attempt to settle the question of the etiology and mechanism of shock. We know that the cycle of events is a vicious one and at present there is no definite proof that it has its beginning in every case at the same spot in the cycle. Practically all authorities are convinced of the fact that in severe shock there is always present a *reduced blood volume, reduced venous return* to the heart with consequent *diminished cardiac output, peripheral arteriolar and venular vasoconstriction, capillary atony* as a result of either trauma or toxic substances with consequent *decreased capillary blood flow, hemoconcentration, and tissue anoxia*. These changes become irreversible probably because of either irreparable damage to capillaries, great changes in the physico-chemical composition of the fluids bathing the cells or failure of the compensating mechanism to maintain sufficient blood pressure to sustain circulation in the face of peripheral collapse.

There have been many theories concerning shock, among them the theory that shock is due to exhaustion of nerve centers; that a toxin is set free from injured tissues and absorbed by the blood where it causes damage to the capillaries; that there is an excessive amount of CO₂ in the blood stream; that there is a local loss of fluid in the injured areas in traumatic shock sufficient to account for the fall in circulatory volume; that severe sympathetic stimulation either by physical or chemical means is sufficient to bring on the changes described above. For a full discussion of these matters I refer you to more complete monographs [Scudder (7), Moon (8), Harkins (9), and Cannon (10)]. I do not presume to give the complete answer to this question, but I do believe that we can understand the problem better in the light of the changes which take place in the peripheral vascular segment and treat it more effectively with the aid of four simple tests.

I am indebted for much of what is to follow to John Scudder, with whom I have had the privilege to be associated while carrying on clinical and experimental observations related to shock.

These four tests are: (1) determination of the percentage of cells in venous blood by means of a hematocrit; (2) determination of the specific gravity of the whole blood; (3) determination of the specific gravity of the plasma, and (4) calculation of the content of plasmic protein by means of a simple formula.

The merit of these combined tests lies in the speed with which they can be done, the accuracy with which results can be reproduced, the small amount of equipment necessary, and the ease with which the technic may be mastered. The danger lies in attempting to interpret these findings without a clear clinical picture of the patient.

THE HEMATOCRIT

In 1885, Professor Blix presented at Upsala the first "haematokrit." It was modeled after the "laktokrit" used in the dairy industry. Employing this method, Hedin (11), in 1891, reported an average cell volume for adult males to be 48.0 per cent, and for adult females, 43.3 per cent. In the next ten years there were many modifications. Capps (12), in 1903, introduced this work to America.

Haden (13), in 1923, popularized the large hematocrit tube in contradistinction to the capillary type and stressed the importance of using isotonic solutions of the various anticoagulants. The publication of Haden (14), in 1930, is very complete and for further details this article is recommended.

In 1929, Sanford and Magath (15) modified the Haden hematocrit. It is this tube which we prefer because it can be spun in any routine laboratory centrifuge, can be cleaned easily, and, being made of heavy glass, its durability is enhanced.

Anticoagulant.—Heparin is the anticoagulant recommended for hematocrit determinations. It is an active fraction of the naturally occurring anticoagulant which was first isolated in Howell's laboratory

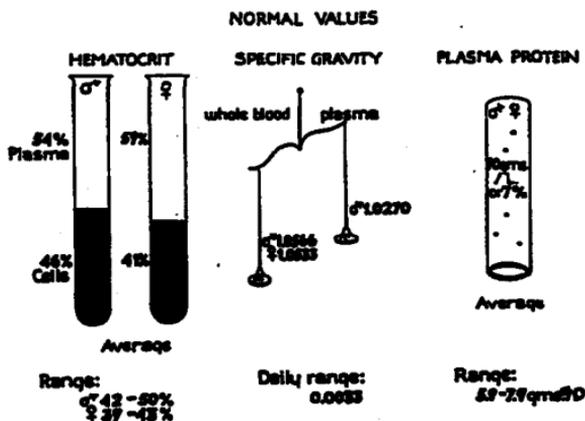


CHART 1. Reproduced from Surg., Gynec. & Obst., "Controlled Fluid Therapy" by Drew, Scudder, and Papps, May, 1940.

by McLean (16) in 1916. The heparin now employed is the sodium salt as prepared in the Connaught Laboratories in Toronto University, Canada. One milligram of the powder is sufficient anticoagulant for the blood in a Sanford-Magath hematocrit tube. (See chart 1.)

Normal Values.—The normal values for cell volume for the male range between 42 and 50 per cent, the average being approximately 46;

those for a female have a range of 39 to 43 per cent, with an average of 41.

SPECIFIC GRAVITY OF BLOOD AND PLASMA

The earliest investigator of blood specific gravity was Robert Boyle (17) who, in 1684, showed that both serum and whole blood were heavier than water. Jurin (18), in 1719, measured their weights more accurately and reported the specific gravity of the blood as 1.053 and that of the serum as 1.030. Sir John Davy (19), in 1839, determined by pycnometry the specific gravity of the whole blood and quoted freely from the earlier work of John Hunter (20), who showed that specific gravity was high in the morning, high in inflammation, and high in dehydration.

Roy (21), in 1884, reported a simplified method of weighing blood. E. Lloyd Jones (22, 23), in 1887, and later in 1891, used this method and published observations which are still of outstanding value for determinations of specific gravity in both health and disease.

Sherrington and Copeman (24) observed that a fall in blood pressure during a long experiment or operation was accompanied by a fall in specific gravity of venous blood; hemorrhage was followed by a rapid fall, while vasoconstriction as seen in shock caused an early rise in the specific gravity of peripheral blood. Rogers (25) showed the value of these tests in treating the severe dehydration of cholera.

In 1924, Barbour and Hamilton (26, 27) presented a means for determining the specific gravity of body fluids which eliminated many disadvantages of the older methods. The principle based on Stokes' law takes advantage of the fact that the time required for a drop of known volume to fall a fixed distance through an immiscible fluid is governed by the density of the drop and other factors, such as temperature, which can be controlled easily. It has been shown that differences of 0.2 of 1 per cent in weight are demonstrable, and that specific gravities may be reproduced with an accuracy of 0.0001.

Guthrie (28), in 1932, reported that, when compared with other methods for evaluation of blood conditions, it stood first from every standpoint.

Normal Values for Specific Gravity.—In the male the average value of peripheral blood is 1.0566 and in the female 1.0533. A swing of 0.0033 occurs daily; the blood is more concentrated in the morning. (See chart 1.)

PROTEINS

In 1927, Atchley and Benedict (29), after a careful study of the electrolytic distribution in a case of severe intestinal obstruction, suggested that a simple determination of the serum protein might be the best aid in following the degree of dehydration and treatment.

In 1929, Moore and Van Slyke (30) showed that there is a constant relationship between the specific gravity of the serum or plasma and the content of protein. For plasma they expressed this relationship by

the formula: $P = 343 (G - 1.0070)$, in which P equals the grams of protein per 100 cubic centimeters of plasma and G equals the specific gravity of the plasma. This work was done on human plasma and the maximum deviation was found to be 0.6 gram per cent.

Weech, Reeves, and Goettsch (31), in 1936, checked the work of Moore and Van Slyke. In their studies specific gravities were determined by pykonometry and nitrogen determinations by the micro-Kjeldahl method. Their formula for plasma was given as $P = 340.1 (G - 1.00687) \pm 0.103$. It is this formula which we have used routinely.

The essence of the relationship is that plasma, completely free of protein, has a specific gravity of about 1.00687. Only rather large changes in the salt content of the blood upset this constant. The factor of 340.1 indicates that for each increase of 1 gram per cent of protein the specific gravity rises $1/340$ or 0.00294; in other words, each increase in the specific gravity of 0.0001 indicates 0.03 gram per cent increase in protein.

By this method the total protein content values are open to question in several types of cases that have come to light so far. They are: gross hemolysis, severe diabetes, hypercholesterolemia, gross lipemia, and excessive bilirubinemia, but for routine, repeated studies of proteins we know of no method quite so simple, and in emergencies none quite so rapid.

INTERPRETATION OF VALUES IN CLINICAL CASES

A fairly definite idea of the history and clinical picture of the patient should always be sought before a final evaluation is made from the data given by the preceding tests. Most important is the trend toward or away from normal as judged by repeated tests, and not the results of a single set of determinations. Certain well defined patterns have recurred many times in following a large series of cases, and these have proved of great aid in the interpretation of the values in any specific case. (See chart 2.)

CLINICAL CASES

Let us consider the findings in a few typical cases of shock, attempt to interpret them, and observe the treatment dictated by the findings.

SHOCK FROM SIMPLE DEHYDRATION

Cases of intestinal obstruction invariably enter the hospital with a history of vomiting and some evidence of dehydration. Some may show clinical signs of shock.

Case 1.—As an example T. K., a female aged 46, P. H. No. 235467, was admitted on February 9, 1939, at 9 p.m. with symptoms and signs of intestinal obstruction as the result of postoperative adhesions. Table 1 gives the results of the suggested tests.

TABLE 1

Date	Hour	Hematocrit (% Cells)	Sp. Gr. Plasma	Proteins (Gm. %)	Remarks
2- 9-39	9:00 p.m.	50.1	1.0307	8.10	On admission.
2-10-39	8:00 a.m.	42.0	1.0255	6.32	After 1800 cc. 5 per cent glucose in saline.
2-11-39	4:45 p.m.	36.6	1.0238	5.75	Immediately following 1800 cc. of saline.
2-14-39	8:15 a.m.	42.4	1.0276	7.06	Miller-Abbot Tube working for 3 days.
2-17-39	8:00 a.m.	44.6	1.0271	6.86	Transfused and explored.

When these findings on admission are compared with the average normal values for women, the hematocrit suggests hemoconcentration of approximately 20 per cent greater than normal. The protein figures are approximately 15 per cent higher than the accepted normal figure, 7.0 Gm. per cent. In this case one may feel justified in assuming that this patient, who had been ill for some time did not have a normal plasma protein when her vomiting attacks began so that the 15 per cent is undoubtedly on the low side. This degree of dehydration can not be classed as severe but it is the type of warning which when heeded prevents collapse later. The second tests on 2-10-39 we interpret to mean: (1) that there was no danger of shock since hemoconcentration had been reduced easily; (2) that peripheral vascular tone was good since a simple saline glucose solution had sufficed to relieve dehydration; (3) that since the hematocrit value had reached normal levels while the protein level had fallen to 6.32 Gm. per cent, the patient must be suffering from a relative degree of hypoproteinemia, which should have been suspected from the clinical history.

The figures on 2-11-39 are of no value since the blood sample was taken at the end of an infusion of 3,000 cc. of saline.

The figures on 2-14-39 show values kept at close to normal in spite of continuous suction by Wangensteen method.

Preoperative values were considered almost ideal. No attempt has been made here to outline the other laboratory procedures or complete details of work up. At operation fibrous bands causing partial obstruction were incised.

Let us consider the findings in another case of mechanical intestinal obstruction of a more severe type.

Case 2.—L. P., male, P. H. No. 419165. (See table 2.)

Two findings are of great significance here. First, in spite of the fact that the hematocrit showed only 53 per cent cells, equivalent to a 5,600,000 red blood count, the proteins indicate an increase in concentration of the fluid portion of the blood of 50 per cent. This is fast ap-

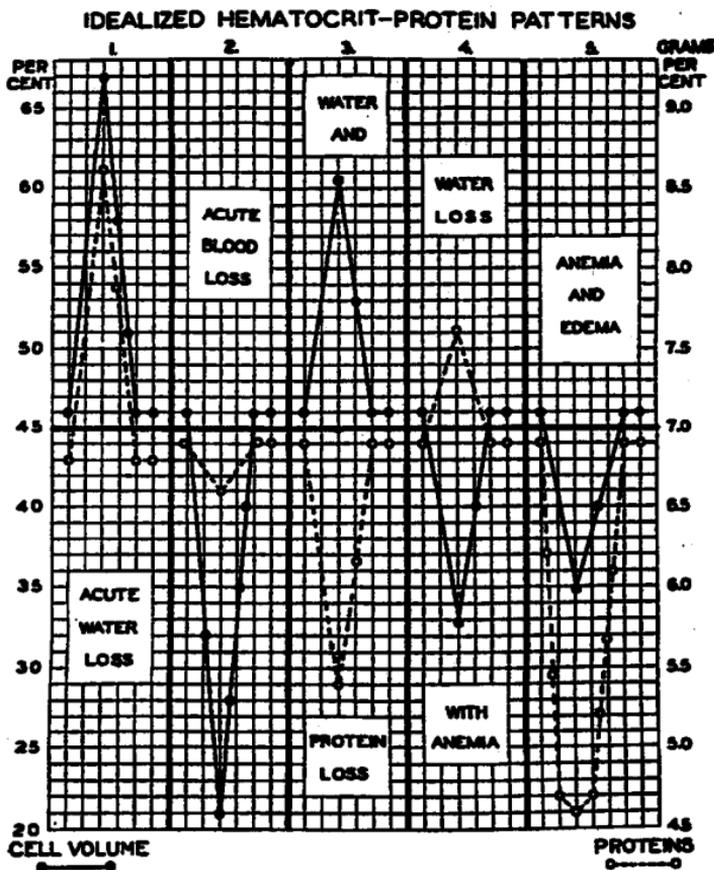


CHART 2. From "Controlled Fluid Therapy," Drew, Scudder, and Papps, *Surg., Gynec. & Obst.* 70: 859-867 (May) 1940.

Column 1. In simple dehydration, whether from lack of fluid intake, diarrhea, excessive sweating, severe vomiting, or shock of traumatic or postoperative origin uncomplicated by hemorrhage, there is a rise in the cell volume, the whole blood and specific gravity of the plasma, and the percentage of plasmic protein.

Column 2. In hemorrhage, either obvious or concealed, there is an immediate fall in the specific gravity of the whole blood and a drop in the cell volume as determined by the hematocrit. The specific gravity of the plasma and protein values calculated from the specific gravity are changed very little when compared with hematocrit changes. Even in severe hemorrhage these values may not be abnormal.

Column 3. In dehydration and protein loss there is a tendency for the hematocrit curve to rise while the protein values continue to fall. Such patterns are typical of severe burns, ruptured peptic ulcers with peritonitis, and even ruptured appendices with large abscesses as the result of a great pouring out into the peritoneal cavity of an exudate rich in protein.

TABLE 2

Date	Hour	Hematocrit (% Cells)	Sp. Gr. Plasma	Proteins (Gm. %)	Remarks
2-17-37	5:10 p.m.	53	1.0379	10.55	Continuous suction and infusion.
	9:40 p.m.	53	1.0379	10.55	
	10:40 p.m.	50	1.0341	9.26	Still dangerous level for operation.
2-18-37	8:00 a.m.	47	1.0238	5.76	Transfusion, then operation.
2-19-37	7:00 a.m.	46	1.0283	7.28	Good water balance; good result.

proaching the limit which dehydration may reach without serious results. This is a real danger sign, one that neither hemoglobin, red count, nor hematocrit alone could give.

The second point is that after four hours, during which time the patient received a continuous infusion of saline at the rate of about 1,000 cc. per hour, the blood studies showed exactly the same values as at the beginning. This can mean but one thing: that the fluid must have run out of the capillary bed as fast as it went in. The vessels must have been in the stage described as the prestatic phase with arteriolar constriction and capillary atony in spite of the fact that blood pressure in this case never reached shock levels. Little has been written concerning the ability of a very sick patient to utilize fluids. It is of great importance, and some sort of test must be used to gain this information.

Studies one hour later showed that by this time some of the fluid had begun to remain in circulation. In addition to fluids, continuous gastric suction was carried out. This change in the right direction continued. Later when the large amounts of fluid which had leaked into the tissues began to return to the circulation, the proteins were too diluted, as indicated by the 5.7 Gm. per cent value, and blood transfusions were resorted to before exploration.

Today we would treat this type of case by administering, in order, 1,000 cc. of normal saline, then 300 cc. of 5 per cent saline in which 20-50 cc. of suprarenal cortical extract had been added and follow it immediately with 500 to 1,000 cc. of plasma. The rationale for this procedure will be discussed a little later under Treatment.

Column 4. In acute changes of water balance in chronic disease, where there already exists an anemia and probably a hypoproteinemia, the hematocrit-protein pattern may appear normal, yet the patient may go into shock from dehydration. The fluid loss in a debilitated person, which is capable of concentrating the constituents of the blood to normal levels, may be sufficient to cause profound shock.

Column 5. Impending edema may be suspected by a gradually falling level of plasma protein. Such water logging of tissues is detrimental in any surgical condition, though of itself seldom causes shock. Latent edema may express itself by poor wound healing and slowed activity of the tissues, especially the gastrointestinal tract when the proteins reach 5.5 Gm. per cent; patent edema appears when proteins fall to a level of 5.0 Gm. per cent. For complete details of technic see a previous publication by Drew, Scudder and Pappas (42).

It has been suggested that there are in truth only two types of shock, one in which the changes are reversible and the other in which the changes are not.

Case 3.—As an illustration of the second type, let me show you the findings in the case of B. D., a woman nine months pregnant, aged 24, who was admitted to the hospital on 10-1-38 with symptoms and signs interpreted as evidence of a severe toxemia of pregnancy requiring immediate emptying of the uterus. Contrary to expectations the improvement was not marked following delivery. The patient continued to complain of severe abdominal pain associated with nausea and vomiting, moderately high fever, scanty urine, but with blood pressures repeatedly within normal range. Blood studies on this patient at 4 a.m. on the day following delivery showed: hematocrit—71.3 per cent cells; sp. gr. plasma—1.0339; plasma proteins—9.19 Gm. per cent. These figures were so startlingly high for a recently pregnant woman that a check was made immediately by determining the specific gravity of the peripheral whole blood taken from the tip of the finger and the venous blood taken from the vein in the antecubital fossa. The results were as follows: specific gravity of finger-tip blood—1.0677; specific gravity of venous blood—1.0657. This finding alone is indicative of a severe degree of peripheral stasis, for as Cannon (10) pointed out following his studies in the last World War, in severe shock the red cell count of blood taken from the finger-tip might show several million more cells per cubic millimeter than a sample of blood taken from the same patient at the same time but from one of the larger veins. So a difference in specific gravity of whole blood from the periphery and that taken from larger veins is an ill omen of very serious portent.

This patient's blood pressure at this time was 100/80 and there were no clinical signs of shock, yet each of these blood findings is pathognomonic of a severe degree of disproportion between the peripheral vascular bed and the circulatory volume.

The clinicians in charge of this case were advised that in the combined experience of Dr. Scudder and myself we had never seen a patient with a hematocrit showing over 67 per cent cells who had failed to go into shock or one who had ever recovered, regardless of the treatment instituted or the cause of the shock.

One liter of saline was started as soon as blood had been drawn for testing, at 4 a.m. In spite of it the blood pressure at 5 a.m. was 0/0. At this time the hypertonic saline and "eschatin" had been obtained and was started. By 6 a.m. the blood pressure had returned to approximately 100/80 and the blood studies showed the following: hematocrit—62.5 per cent cells; sp. gr. whole blood—1.0627; sp. gr. plasma—1.0275; plasma protein—7.01 Gm. per cent. These findings suggested that exploration might be attempted since it was unlikely that the patient would further improve. Five feet of completely gangrenous gut were found. Another series of blood studies was done in the operating room. They

were as follows: hematocrit—66.2 per cent cells; sp. gr. whole blood—1.0677; sp. gr. plasma—1.0267; plasma protein—6.73 Gm. per cent.

The important finding, however, was that the specific gravity of the venous whole blood had returned to 1.0677, a figure equal to the specific gravity of the peripheral whole blood at 4 a.m. This indicated here, as it has indicated in all of our experiences, a rapidly decompensating peripheral vascular tree. A rapid double-barreled ileostomy was done. The patient died soon afterwards. This case never gave the clinical picture of impending collapse that these studies showed an hour before blood pressure fell to zero. Had they been done two or perhaps four hours earlier the changes may well have been picked up in time.

Case 4.—The most striking response to therapy suggested in this discussion was that of B. L., female, aged 35, who went into profound shock on the operating table during a craniotomy for the removal of adhesions which were thought to be the cause of epileptiform seizures. In spite of the use of 4000 cc. of 5 or 10 per cent glucose in saline and 1800 cc. of whole blood over a period of twenty hours postoperatively, the blood pressure had not reached a level of 60 mm. systolic pressure. Twenty-three hours after operation her first blood study showed the following: hematocrit—34.1 per cent cells; sp. gr. plasma—1.0248; plasma protein—6.09.

No pulse was perceptible. No blood pressure had been obtainable for a period of over one-half hour. Because of the tremendous amounts of fluids which had been given the blood studies were of little value except to show that the profound shock was not due to hemorrhage alone nor was it due to an insufficient amount of plasma protein to maintain circulation. With a large syringe, 300 cc. of 5 per cent sodium chloride plus 20 cc. of "eschatin" immediately followed by 300 cc. of blood were given, and within fifteen minutes blood pressure had risen to 98/60 and was sustained at this level or better until the time of her discharge about one month later without further therapy except for a 500 cc. transfusion on each of four consecutive days postoperatively. This is the most unusual response we have seen, but in all of the cases treated to date, with the exception of 2 with severe advanced generalized peritonitis, there has been an increase in the blood pressure and improvement in the clinical picture.

In some of these cases, as in the one described above, the picture of shock again returned and the patients died. In these, undoubtedly, changes had reached an irreversible stage.

TREATMENT OF SHOCK FROM DEHYDRATION

We feel that there are three basic functional derangements in the region of the peripheral vascular segments. These are as follows: (1) arteriolar and venular constriction; (2) capillary paralysis; (3) loss of fluid into the interstitial tissue.

Four things, therefore, have to be done, namely: (1) release arterio-

lar constriction; (2) restore capillary tone; (3) return lost fluid to vascular bed; (4) maintain restored circulatory volume.

The question is naturally raised, "how can these four corrective measures be carried out best?" Experimental evidence is not available to show specifically that any substance can directly relieve the arteriolar spasm. It is known, however, that the severe shock seen following burns, intestinal obstruction, trauma, marked dehydration, and cortical insufficiency is always characterized by a loss in the plasma content of sodium in spite of the hemoconcentration (7). Clinically it is an accepted fact that in mild cases of shock the exhibition of physiologic saline will successfully restore circulatory volume. It seems logical to suggest, therefore, that the first step in the correction of the above named defects should be the introduction of fluid in the form of normal saline. If, however, the capillary bed is atonic and cannot maintain this fluid it seems inadvisable to continue to give large quantities in an isotonic form. It is for this reason that we suggest the introduction of small quantities of hypertonic solutions of sodium chloride. Theoretically it should have three effects: (1) the direct action of the sodium in restoring electrolyte balance; (2) the direct effect of the chloride ion in restoring acid-base equilibrium; (3) the direct effect of its hypertonicity in bringing back into circulation fluids which have already escaped into the interstitial tissues.

There is one obvious danger in introducing any hypertonic fluid into a severely dehydrated patient. This is the danger of drawing into circulation fluid from the cells which is rich in both potassium and magnesium ions, each of which is extremely toxic when brought into the circulation in quantities greater than those normally present in the plasma.

In correcting the second defect, that of capillary atony, experimental and clinical evidence regarding a substance which can restore tone is even more meager. Best and Solandt (43) have suggested pitressin. We feel that the work of Swingle and his associates (32), Rogoff and Stewart (33), Zwemer and Scudder (34) is adequate at least to postulate that an extract of the suprarenal cortex not only plays a part in the redistribution of electrolytes but that it may have a direct action on the capillaries and plays some role in the maintenance of their normal tone. The clinical reports following the use of suprarenal cortical extracts have not been uniformly encouraging. We feel that the results have not been as good as they might have been because the substance has not been used in sufficient quantity. We have never seen any clinical results when 2-5 cc. of suprarenal cortical extracts have been used, but have had excellent clinical results with an initial dose of 10 or 20 cc. repeated at fifteen minute or one-half hour intervals until a substantial rise in blood pressure was obtained. We have seen no deleterious results in these cases which could be directly attributed to the use of "eschatin" (Parke-Davis) in quantities up to 150 cc. within the period of a few hours in severely shocked individuals.

The third defect mentioned, the loss of circulatory volume, is genetically related to, and a result of, the first two. Its correction depends on an adequate supply of fluid in a vascular bed which can keep it in circulation. Even hypertonic fluids will not remain in circulation when the capillary bed is paralyzed.

The fourth step in the treatment consists of introducing into the blood stream some substance with sufficient osmotic power to prevent further leaking. The ideal substance for this purpose is blood. Plasma is equally efficacious. Many other substances have been advocated for the treatment of shock. Rather than discuss them I would rather continue along this single track at present.

SHOCK IN HEMORRHAGE

The shock of hemorrhage is a more readily understandable process than the shock in which the circulatory fluid seems to become "lost" in unseen places. These four tests provide a rapid method of distinguishing this type of shock from those we have just described.

Case 5.—In a typical case, patient G. M., female, aged 28, was admitted with the diagnosis of an acute abdomen. The diagnosis offered some difficulty but the blood studies threw immediate light on the problem and added the final evidence to sustain a diagnosis of ruptured ectopic pregnancy. The blood studies in table 3 showed the following changes during her stay in the hospital:

TABLE 3

Date	Hematocrit (% Cells)	Sp. Gr. Pl.	Proteins (Gm. %)	Remarks
7-17-39	12.5	1.0268	6.76	Before transfusion After 700 cc. of blood and operation.
	18.7	1.0260	6.50	
18	21.2	1.0249	6.12	After 2nd transfusion.
19	23.1	1.0256	6.32	After 3rd transfusion.
20	33.3	1.0255	6.32	After 4th transfusion.
30	43.5	1.0268	6.76	On discharge.

I present this table to point out a rather strikingly constant finding, i.e., the relatively high level at which the plasma proteins appear to be maintained in acute hemorrhage. We have now in our records 9 cases in which bleeding was followed by studies such as these, and in each case, while there was a gradual fall in the hematocrit value, there has been relatively little fall in the protein. The explanation for this is not clear, but we have learned to consider a falling hematocrit with a relatively constant level of protein as indicative of acute hemorrhage.

TREATMENT

The treatment of such cases, when uncomplicated by severe trauma, is obvious. Blood transfusions should be started at once, the source of the bleeding should be sought, hemorrhage should be stopped, and trans-

fusions continued until the red cell count approaches normal levels. In this particular case the patient received 500 cc. of blood before operation, 200 cc. during operation, and 500 cc. on each of three consecutive postoperative days.

When trauma is complicated by hemorrhage the hematocrit protein-patterns are less diagnostic, but the principles outlined for treatment are sound, and the results are good. The base line values often cannot be accurately interpreted, but the course of the patient can be more accurately followed than by any other method we have seen.

SHOCK IN BURNS

One of the most frequent causes of severe shock is that of shock associated with burns. The following table includes studies made on case 6, C. P., male, aged 45, P. H. No. 519132. This case has been reported in some detail by Scudder in his book on "Shock." I present it to point out two things. One, hemoconcentration, which is well known and well recognized; the other, hypoproteinemia, which is still too little thought of when the treatment of burns is considered. Table 4 gives the studies for the first three days on the blood of a severely burned man and will serve to point out these two points:

TABLE 4

Date	Hour	Hematocrit (% Cells)	Sp. Gr. Fl.	Protein (Gm. %)
5-7-37	9:55 p.m.	66.7	1.0235	5.66
	11:50 p.m.	62.7	1.0245	5.99
8	7:35 a.m.	59.8	1.0215	4.96
	12:25 p.m.	53.8	1.0215	4.96
9	8:30 a.m.	52.2	1.0222	5.2
	1:00 p.m.	51.3	1.0223	5.3

Underhill and his associates (35) probably should receive the credit for bringing forcibly to the attention of surgeons the important role of fluid loss in burns. Davidson (36) in 1927, revolutionized the treatment of burns when he introduced the tannic acid method. Aldrich (37), in 1933, showed that most of the so-called toxemia of burns is probably attributable to infection. Only recently have the roles which proteins play been given adequate recognition. Harkins (38), following Davidson at the Henry Ford Hospital, has done much to bring this phase to the attention of the profession. Table 4 gives a fair idea of the levels to which the proteins may fall even before the administration of fluids. It also shows that with fluid therapy the protein level is likely to go below not only the latent edema level of approximately 5.5 grams per cent but also below the true edema level of approximately 5 grams per cent. One cannot conceive of a happier hunting ground for anerobic

bacteria than the soggy, edematous, badly injured tissue beneath a protein coagulum created by tannic acid, silver nitrate or some other coagulating substances. In the treatment of burns, therefore, especially in the treatment of shock, which is so dominantly a feature soon after the accident, it is not only necessary to prevent pain, prevent heat loss, insure adequate oxygen, and prevent further loss of fluids and proteins, but it is imperative that the proteins already lost be restored. The ideal substance for this purpose is plasma or serum either in liquid form or by means of solutions of dried forms. It not only will decrease hemoconcentration by restoring fluid but at the same time will sustain the protein level and circulatory volume. Several formulas (39, 40, 41) have been worked out in an effort to define the amounts of plasma needed in any specific case. The only difficulty with formulas is that they work so well on normal adults with perfectly intact peripheral vascular systems and work so poorly on very ill individuals in whom the circulatory volume, the vascular bed capacity, and the concentration of the blood elements become almost a function of the state of the terminal vascular segments; that is, they become a function of a very decidedly unknown quantity. For instance, in a series of experiments carried out on unwilling colleagues and patients who were not too ill, it appeared that fluid balance in a dehydrated patient might be accurately re-established by giving 50 cc. of normal saline intravenously for every 0.01 gram of plasma protein above the arbitrarily normal value of 7 grams per cent. As an example, a patient who has been vomiting until the plasma proteins register 7.5 grams per cent can be restored to normal very easily by giving him 2,500 cc. of normal saline. The only difficulty is that a patient in profound shock may be given 2,500 cc. of normal saline and blood studies at the end of the infusion may show values higher than at the beginning. This point, too, has not been stressed enough. It is as useless to continue to pour fluids into a vascular system which cannot hold them as it is to feed carbohydrates to a severe diabetic unless each of these procedures is controlled by some method of checking the ability of the individual to handle these substances. So it is with plasma. We have found that the average individual of about 60 kilograms of body weight will require approximately 1 liter of plasma to raise the plasma protein levels 1 gram per cent. This is a very rough figure but a very useful one. In severe shock, in severe infections, and in marked hypoproteinemia, the quantities given must be considerably increased and one must never assume that the injected material has remained in circulation unless the values are actually checked. Treatment, therefore, is similar to that described under dehydration, except that fluids should be given much more carefully and whole blood is less ideal than plasma.

SHOCK IN PERITONITIS

There is a great similarity between the shock of a severe burn and the shock in severe peritonitis. The area of skin is just about equal to

the area of the peritoneum in any given individual. Just as the area of the skin involved in a burn is a real factor in the eventual outcome, so the area of the peritoneum involved is a real factor. When the skin is irritated by a physical agent such as heat there is capillary ectasy and loss of protein-rich fluid to the exterior. When the peritoneum is irritated by bacterial toxins there is also a great loss of protein-rich fluid, as well as the loss of power of absorption. The end result in each case is the same. There is marked hemoconcentration, dehydration and hypoproteinemia. Each of these we know may play some part in the production of shock. As a typical illustration, case No. 7, E. D., female, age 64, P. H. No. 561763, is presented.

This patient was admitted with a diagnosis of carcinoma of the stomach which means that she, like all of the other patients suffering from a similar malady, was anemic and relatively hypoproteinemic on admission. We have no preoperative blood studies, but following gastrectomy there was some leakage in the region of the duodenum, peritonitis and subsequent duodenal fistula. Table 5 presents graphically the changes in her blood picture brought about by the use of blood transfusion, plasma, protein hydrolysates, and intensive vitamin and sulfanilamide therapy, in an attempt to control the irritant, restore fluid balance, remove the edema, and return the gastrointestinal tract to normal activity.

TABLE 5

Date	Hematocrit	Sp. Gr. Pl.	Protein	Remarks
1/19/39	50.4	1.0203	4.56	Marked edema
1/21/39	53.9	1.0210	4.79	
1/23/39	51.8	1.0207	4.66	
1/25/39	44.0	1.0217	4.86	
1/27/39	44.0	1.0226	5.34	Edema gone

Here one notices the same hemoconcentration, though not as marked as in the case of the burn because the initial red cell count undoubtedly was much lower than that of the healthy male who was burned. On the other hand, the change in percentage is probably greater. The protein level is definitely below the edema level and this becomes a doubly important factor in the surgery of the gastrointestinal tract. Soggy wounds will not heal; sutures, if of silk, pull out of the water-logged tissues, and if of catgut, the tensile strength is diminished to the point where rupture is more likely. Peristalsis is slow or disappears entirely leaving a paralytic ileus with its attendant train of complications as the result of the mechanical effects of distention. Only careful and repeated checks as a guide to therapy can salvage some of these difficult cases.

BLOOD STUDIES IN HEAD INJURIES, CHEST SURGERY AND ANESTHESIA

Attempts so far to correlate the results of hematocrit-protein patterns in cases of severe head injuries and in major chest surgery have not been very successful. The effect of raised intracranial pressure on the peripheral vascular tree in our experience has been a very variable one. Attempts to correlate changes in the specific gravity of the cerebrospinal fluid with the degree of damage done to the brain have not yielded usable results. Changes in intrathoracic pressure with its effect upon the large vessels likewise cause systemic upsets which we have not yet been able to measure in terms of hemoconcentration of the blood.

Attempts to establish a relationship between peripheral circulatory changes and the various types of anesthesia have not advanced to the point where they may be stated with authority. In this field we feel that these simple tests offer tools which may be used to great advantage in anesthesia.

No attempt has been made in this discussion to cover shock in all of its many ramifications. But we do believe that with a constant clinical picture of the patient in mind, a working concept of the changes which take place in the physiology of the body under the stress of various degrees of irritation, particularly the changes which take place in the peripheral vascular tree, cases of shock will be more adequately handled. With the aid of such a series of simple tests as we have attempted to outline here, impending troubles may at times be foreseen and prevented altogether.

SUMMARY

(1) Changes in the peripheral vascular tree of a segmental nature as observed by Ricker and Oertel are presented as a basis of better understanding the mechanism of circulatory failure in surgical shock.

(2) On this basis, there are three defects in the peripheral vascular tree which need correction in shock. These are: (a) arteriolar and venular constriction; (b) capillary dilatation; (c) stasis of circulatory fluids in the capillary bed or loss into the tissue.

(3) To correct these defects three steps are recommended: (a) aid in the restoration of the electrolyte balance, acid base equilibrium, normal arteriolar tone and circulatory volume by use of intravenous sodium chloride, at first in isotonic form and then in hypertonic form if there is no response to the former; (b) aid in the restoration of capillary tone by using water soluble suprarenal cortical extract in quantities sufficient to get a response in blood pressure; (c) sustenance of circulation by adequate amounts of blood or plasma.

REFERENCES

1. LeDran, H. F.: A Treatise or Reflections, Drawn from Practice on Gunshot Wounds. Translated from the French, London, 1763.
2. Ricker, Gustav: Pathologie als Naturwissenschaft—Relationenpathologie—für Pathologen, Physiologen, Mediziner und Biologen, Springer—Berlin, 1923.
3. Oertel, Herst: Outlines of Pathology in its Historical, Philosophical and Scientific Foundations, Montreal, Roseaf Pub. Co., 1927.

4. Lewis, T.: *Blood Vessels of the Human Skin and Their Responses*, London, 1837.
5. Golts, F.: *Ueber den Tonus der Gefasse und seine Bedeutung fur die Bluthewegung*, Virchow's Arch. f. path. Anat. 32: 204-222, 1846.
6. Grech, R.: Studies on the Submaxillary Gland. IV. A Comparison of the Effects of Hemorrhage and of Thymus-Abuse in Relation to Secondary Shock. Am. J. Physiol. 47: 482-504, 1919.
7. Scudder, John: *Shock: Blood Studies as a Guide to Therapy*, Philadelphia, J. B. Lippincott Co., 1946.
8. Moss, V. H.: Circulatory Failure of Capillary Origin. J. A. M. A. 114: 1312-1318 (Apr. 6) 1940.
9. Harkins, H. N.: Plasmaproterosis, Plasma Exudation and Traumatic Shock. Science 55: 49, 1927.
10. Cannon, W. B.: *Traumatic Shock*, New York, D. Appleton and Co., 1923.
11. Hedra, S. G.: *Der Haematokrit, ein neuer Apparat zur Untersuchung des Blutes*, Skandinav. Arch. f. Physiol. 9: 134-146, 1901.
12. Capps, J. A.: A Study of Volume Index. Observations Upon the Volume of Erythrocytes in Various Disease Conditions. J. M. Res. 10: 367-401, 1903.
13. Haden, R. L.: The Volume and Hemoglobin Content of the Erythrocytes in Health and Disease. Public Health, 31: 112-123, 1925.
14. *Ibid.*: The Technique of Determination of the Relative Mass, the Individual Cell Volume, and the Volume Index of the Erythrocytes of Man. J. Lab. & Clin. Med. 15: 736-746, 1920.
15. Sanford, A. H., and Magath, T. R.: A New Centrifuge Tube for Volume Index Determinations (Modified Haden Method). J. Lab. & Clin. Med. 18: 172, 1923.
16. McLennan, J.: The Thrombolytic Action of Cephala. Am. J. Physiol. 41: 220-227, 1916.
17. Boyle, Robert: *Memoirs for the Natural History of Human Blood, Especially the Spirit of that Liqueur*, London, R. Smith, 1784.
18. Jurin, J.: *Philosophical Transactions of the Royal Society of London* 5: 226-232, 1719.
19. Davy, Sir John: *Researches, Physiological and Anatomical*, Vol. 2, London, Smith, Elder & Co., 1826.
20. Hunter, John: *A Treatise on the Blood, Inflammation, and Gun-shot Wounds*, London, Sherwood, Gilbert & Piper, 1826.
21. Ray, C. K.: Note on a Method of Measuring Specific Gravity of the Blood for Clinical Use. J. Physiol. Proc. Physiol. Soc. 5: 9-11, 1881-1883.
22. Jones, E. L.: On the Variations in the Specific Gravity of the Blood in Health. J. Physiol. 5: 1-14, 1867.
23. *Ibid.*: Further Observations on the Specific Gravity of the Blood in Health and Disease. J. Physiol. 12: 299-344, 1861.
24. Sherrington, C. S., and Copeman, K. M.: Variations Experimentally Produced in the Specific Gravity of the Blood. J. Physiol. 11: 23-36, 1892.
25. Rogers, L.: *Cholera and Its Treatment*, London, Henry Frowde, Oxford University Press, 1913.
26. Barbour, H. G., and Hamilton, W. F.: Blood Specific Gravity: Its Significance and a New Method for its Determination. Am. J. Physiol. 69: 634-641, 1924.
27. *Ibid.*: The Falling Drop Method for Determining Specific Gravity. J. Biol. Chem. 69: 625-649, 1925.
28. Guthrie, C. C.: An Apparatus for Quickly Measuring the Specific Gravity of Body Fluids. J. Lab. & Clin. Med. 17: 1126-1132, 1922.
29. Aitchley, D. W., and Benedict, E. M.: The Distribution of Electrolytes in Intestinal Obstruction. J. Biol. Chem. 35: 697-702, 1927.
30. Moore, N. S., and Van Slyke, D. D.: The Relationships between Plasma Specific Gravity, Plasma Protein Content and Edema in Nephritis. J. Clin. Investigation 5: 237-250, 1930.
31. Weech, A. A.; Keever, E. H., and Goettlich, E.: The Relationship between Specific Gravity and Protein Content in Plasma, Serum, and Transudate from Dogs. J. Biol. Chem. 123: 167-174, 1934.
32. Swingle, W. W.; Parkins, W. M.; Taylor, A. R., and Hays, H. W.: A Study of Water Intoxication in the Intact and Adrenalectomized Dog and the Influence of Adrenal Cortical Hormone Upon Fluid and Electrolyte Distribution. Am. J. Physiol. 119: 537-566, 1937.
33. Rogoff, J. M., and Stewart, G. N.: Studies on Adrenal Insufficiency in Dogs. II. Blood Studies in Control Animals not Subjected to Treatment. Am. J. Physiol. 78: 711-729, 1928.
34. Zwemer, E. L., and Scudder, J.: Potassium Changes in Experimental Shock. Am. J. Physiol. 119: 427, 1937.
35. Underhill, F. P.; Carrington, G. L.; Kapsinow, R., and Pack, G. T.: Blood Concentration Changes in Extensive Superficial Burns. Arch. Int. Med. 33: 31, 1923.
36. Davidson, E. C., and Matthew, C. W.: Plasma Proteins in Cutaneous Burns. Arch. Surg. 13: 363-374, 1927.
37. Aldrich, H. H.: The Role of Infection in Burns with Especial Reference to Gentian Violet. New England J. Med. 266: 299-307, 1932.
38. Harkins, Henry N.: Recent Advances in the Study and Management of Traumatic Shock. Surgery 9: 231-294 (Feb.) 1941; 9: 447-482 (March) 1941; 9: 607-633 (April) 1941.
39. Eikinton, J. R.; Gilmour, M. T., and Wolf, W. A.: Control of Water and Electrolyte Balance in Surgical Patients. Ann. Surg. 116: 1030-1036 (Dec.) 1939.
40. Eikinton, J. R.: The Systemic Disturbances in Severe Burns and Their Treatment. Bull. Ayer Clin. Lab., Pennsylvania Hosp. 3: 279-282, 1938.
41. Black, D. A. K.: Treatment of Burn Shock with Plasma and Serum. Brit. M. J. 2: 683-687, 1940.
42. Drew, C. R.; Scudder, J., and Papps, J.: Controlled Fluid Therapy, Surg., Gynec. & Obst. 70: 829-867 (May) 1940.
43. Best, C. H., and Tolandt, D. Y.: Studies in Experimental Shock. Canad. M. A. J. 43: 286-299 (Sept.) 1940.