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A STUDY OF SHOCK IN BATTLE CASUALTIES

MEASUREMENTS OF THE BLOOD VOLUME CHANGES OCCURRING IN RESPONSE TO THERAPY

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THE PATHOGENESIS OF TRAUMATIC SHOCK is generally recognized to be a reduction of the circulating blood volume. An essential feature of modern shock treatment is the correction of this deficiency by the transfusion of injectable protein-containing fluids. Recognizing the need for prompt transfusion therapy in the care of battle casualties, the United States Army Medical Corps has consistently made available to all medical units adequate supplies of human plasma. The efficacy of plasma transfusions in the treatment of traumatic shock has been firmly established through wide experience with its use during the present war; there is no question but that its provision to the armed forces has been responsible for the survival of countless battle casualties, and has effected an unprecedented improvement in the prognosis of serious war wounds.

Early in the war the hope was entertained that the transfusion of plasma alone would prove to be effective therapy for the vast majority of patients suffering from traumatic shock, and it was presumed that whole blood would enjoy a relatively restricted use, indications for its employment being restricted to a small percentage of extremely severe cases. However, limitations in the effectiveness of plasma as a sole replacement medium have since become apparent. It was the experience of many surgeons operating at the front in the African and Sicilian campaigns, that a considerable proportion of patients in severe shock failed to respond adequately to plasma transfusions, death occurring preoperatively or in the course of operation.[1] This type of case appeared to respond more favorably to the transfusion of whole blood in addition to plasma.

Throughout the Normandy campaign, in contrast to the earlier situation, large amounts of refrigerated whole blood were supplied to the Field and Evacuation Hospitals. The relative quantities of whole blood used during this period were considerably in excess of the anticipated requirements. A statistical survey of Field Hospitals in July, 1944, at the time of the intense fighting in the vicinity of St. Lo, indicated that the total amounts of whole blood and plasma administered to nontransportable casualties through the first

postoperative day averaged 1,250 cc. of whole blood and 750 cc. of plasma per patient. These cases had received an average of 550 cc. of plasma in the Battalion Aid Station or Clearing Station prior to their admission to the hospital; the final ratio of whole blood to plasma given, therefore, averaged 1:1. The unexpectedly high proportion of whole blood required raised the question as to whether its preferential use by the field surgeons was dictated on the basis of sound indications or, possibly, on false impressions.

A preliminary study was carried out by the authors during July, 1944, on 55 nontransportable patients treated in Field Hospitals. This study was restricted to serial determinations of the hemoglobin concentration and arterial pressures, with relation to the clinical condition and course, in response to therapy. The data obtained indicated that the magnitude of the blood loss sustained by patients exhibiting signs of severe shock was substantially greater than had been generally appreciated. A striking anemia was commonly present at the conclusion of therapy, despite massive whole blood transfusions. It was obvious from the results that whole blood was not being utilized to excess; indeed, the data suggested that possibly even more should be administered for optimum therapeutic results than was the customary practice.

A second investigation was then planned, the purpose of which was to accumulate more detailed and precise data pertaining to the pathologic physiology of traumatic shock with especial reference to the therapeutic problems involved. This study was carried out on a series of severely wounded casualties treated in a Field Hospital during the campaign on the German border in September, 1944. In addition to clinical observations, measurements were made of the plasma volume, hematocrit reading and plasma protein concentration, before and after therapy and, in some instances, pre- and postoperatively. This program of investigation was devised in the hope of providing definitive answers to the following questions:

1. The degree of blood volume deficit associated with shock, and the extent to which clinical signs can be correlated with varying grades of oligemia.
2. The degree of spontaneous hemodilution occurring following extensive hemorrhage.
3. The relative importance of whole blood and plasma loss, and the total blood loss resulting from various types of war wounds.
4. The magnitude of blood loss attendant on various surgical procedures.
5. Relative requirements for whole blood and plasma in shock therapy, and the effect of transfusions on the blood volume.
6. Causes of therapeutic failure in the treatment of traumatic shock.

TYPE OF PATIENTS AND PLAN OF STUDY

All patients reported in these series belong to the group of "nontransportable" battle casualties: patients who, because of the location or severity of their wounds, require prompt definitive treatment in a Field Hospital. One group, comprising 57 such cases, was subdivided as follows: 21 patients

with penetrating wounds of the abdomen; 15 with penetrating chest wounds; seven with combined chest and abdominal wounds; nine with extremity wounds alone; and five with extremity wounds combined with penetrating wounds of the chest or abdomen. On this group, determinations of the plasma volume, hematocrit reading and plasma protein concentration were made. The arterial blood pressures and pulse rates were measured at frequent intervals, and the clinical course was carefully described in each case.

Less detailed laboratory investigation was conducted on a series of 55 additional patients. In this group, the hemoglobin concentration was determined before and after shock therapy, the arterial pressure, pulse rate and clinical manifestations being carefully followed throughout. This group is subdivided as follows: There were eight patients with penetrating abdominal wounds, 13 with penetrating chest wounds, eight with combined chest and abdominal wounds, seven with extremity wounds alone, and 21 with extremity wounds combined with penetrating wounds of the abdomen or chest.

Seventy-three per cent of the casualties in these series were due to shell fragment wounds, 24 per cent were caused by gunshot wounds, and 3 per cent by the explosion of mines. The majority of cases were seen within six hours following injury. The patients selected for study either presented clinical evidences of shock, or had wounds of such severity that a considerable blood loss was deemed probable. Most had received preliminary shock treatment in the form of plasma transfusion before admission to the Field Hospital.

LABORATORY METHODS

The plasma volumes were determined by the dye method of Gibson and Evans,[2] adapted to the Klett photo-electric colorimeter. Plasma protein concentrations were calculated on the basis of specific gravity, using the copper sulfate method of Phillips, Van Slyke, *et al.*[3] Hematocrit readings were obtained after rapid centrifuging of oxalated blood samples in 4-cc. hematocrit tubes. The acid-hematin method was employed for the estimation of hemoglobin concentrations, using the Sahli-Hellige hemoglobinometer. All determinations were made exclusively on venous blood, obtained without stasis. The femoral vein was selected for venepuncture in all cases of shock.

Certain modifications of technical procedure were necessary in order to adapt these methods to the limited facilities available in a Field Hospital, and to render the tests practicable in the face of urgent therapeutic requirements. Determination of the plasma volume involved the taking of serial samples of venous blood over a period of 40 minutes. Inasmuch as a delay of 40 minutes in instituting transfusion therapy was unwarranted in many instances, the following routine was adopted:

Immediately upon admission of the patient to the shock ward, 5 cc. of venous blood were removed to serve as the dye-free sample and for the hematocrit reading, following which the dye was promptly injected. If severe shock was present a plasma transfusion was then initiated and continued during the 20-minute period required for the intravascular mixing of the dye. The amount of plasma administered during this period varied between 250 and 500 cc. During the succeeding 20-minute interval, when serial specimens were taken for determination of the disappearance curve of the plasma-dye concentration,

the transfusion was discontinued. Calculation of the initial plasma volume entailed a correction for the amount of plasma administered during the mixing period.

Blood samples were introduced into a 4-cc. hematocrit tube containing 0.2 cc. of a solution of sodium chloride in a concentration of 0.85 Gm. per cent, ammonium oxalate, 1.2 Gm. per cent, and potassium oxalate, 0.8 Gm. per cent. This solution causes no swelling or shrinkage of the red cells, and, after correcting for the 0.2 cc. increase in plasma volume due to the anticoagulant solution, the same hematocrit and specific gravity readings are obtained as with the use of dried mixed oxalate, recommended by Phillips, Van Slyke, *et al.* The advantages in using the solution of mixed oxalate in isotonic saline are, that it is unnecessary to engage in the time-consuming process of drying an aqueous oxalate solution in the tubes to prepare them for use; and, most important for the determination of plasma-dye concentration, no hemolysis is caused by the anticoagulant solution, whereas it is unavoidable in the presence of the dried mixture.

The tubes containing the blood and anticoagulant solution were placed in a portable electric angle centrifuge (Gomco Surgical Mfg. Co.) and rotated at high speed for one-half hour. Maximal packing of the cells was obtained by this procedure, and, contrary to expectations, little difficulty was encountered in reading the cellular volume since the upper level of the cell layer tends to assume a horizontal position if the tube is allowed to stand vertically for a few minutes. The hematocrit reading having been obtained, the supernatant plasma was pipetted off for the determination of plasma protein and dye concentrations. This procedure utilized the minimum of equipment, and the preparation of glassware was reduced to a point that was quite practical under the conditions imposed.

As a standard for comparison between the results reported in this investigation and the expected "normal" values for hematocrit reading and plasma protein concentration, the figures reported by Phillips, Van Slyke, *et al.*,[3] were used. On the basis of their study of 20 normal men, the average normal hematocrit reading is considered to be 46.9; the average normal plasma protein concentration is accepted as 6.63 Gm. per cent. The data obtained by Gibson and Evans[4] on 49 normal males was used to compute the expected normal plasma volume in each case reported in this communication. It should be pointed out that there is a considerable individual variation in plasma volume, irrespective of surface area. Hence, the percentage reduction in blood volume calculated for any given individual on the basis of the "normal" value, predicted from the surface area, may be in considerable error. However, a sufficiently large number of cases have been studied in this series to lend validity to such a comparison.

The hematocrit reading is utilized in calculating the total blood volume and total red cell volume from the plasma volume. This calculation is based on the assumption that the proportion of cells to plasma is the same in vessels of all caliber, an assumption that is probably incorrect. There is considerable evidence to suggest that in normal individuals the cell-plasma ratio is lower in the small vessels.[5, 6] This circumstance leads to an estimated error of approximately 20 per cent in calculating red cell volumes on the basis of plasma volume and hematocrit reading. To further complicate the situation, there is evidence that in shock the cell-plasma ratio in the small vessels is actually increased over that in the large vessels, owing to erythrostasis.[7] At any rate, caution must be exercised when comparison is made between the values accepted as normal for the total blood volume and total red cell volume, and those computed from the plasma volume and hematocrit reading of a patient suffering from shock. The absolute error inherent in the estimation of total blood volume in shock cases is, however, not of great significance; the red cell volume is so reduced that even a very considerable percentage error results in but a small error in the total volume. Assuming a 20 per cent error in computing a red cell volume of 800 cc., the resultant miscalculation amounts to only 160 cc. in the total blood volume. However, in order to reduce the inaccuracies inherent in comparing the total blood volume calculated for patients in shock with

TABLE I

INITIAL DATA ON FIFTY BATTLE CASUALTIES ADMITTED TO A FIELD HOSPITAL

Case No.	Diagnosis and Outcome*	Hours Since Injury	Previous Transfusions		Arterial Pressure	Pulse	Plasma Protein	Hemat.	Blood Volume		
			Plasma Cc.	Blood Cc.	Mm. Hg.	Rate	Gm. %		Plasma Cc.	Total Cc.	Deficit %
1	Gunshot wd. perforating rectum, colon and small bowel. Died 12 hrs. postop.	3	500	0	65/40	104	6.3	41.5	2230	3810	30
2	Shell fragment wds. of abdomen; lacerations of colon and kidney. Died 30 hrs postop.	5	1150	1250	60/40	124	5.3	32.4	2440	3610	37
3	Gunshot wd. through rt. chest; hemothorax; compound fracture of femur. Survived.	4	500	0	100/60	116	5.7	36.5	2430	3830	27
4	Gunshot wd. of rt. chest, sucking. Survived.	4	250	0	80/60	108	6.0	41.7	1790	3070	33
5	Shell fragment wds., multiple, both thighs. Survived.	3	1150	0	100/60	136	6.1	29.5	1880	2660	42
6	Mine wds. penetrating abdomens; multiple intestinal perforations. Survived.	3	750	0	130/70	104	6.6	38.4	2740	4440	6
7	Gunshot wd. penetrating rt. chest. Survived.	4	0	0	85/60	92	6.5	48.1	2730	5260	9
8	Shell fragment wd. through rt. chest. Died 12 hrs. postop.	2	0	0	80/40	140	6.0	46.4	1860	3470	31
9	Gunshot wds., with compound fractures of humerus, mandible and zygoma. Survived.	2	0	0	70/40	130	5.1	38.5	2130	3450	37
10	Shell fragment wds. perforating lung, diaphragm and liver; multiple wds. of thigh and buttock. Died immediately postop.	6	1000	500	50/40	140	5.9	29.4	1910	2700	46
11	Shell fragment wds. perforating duodenum, colon, liver and gallbladder. Died 0.5 hrs. postop.	4	350	0	55/45	140	6.5	32.1	1660	2450	48
12	Shell fragment wds. with traumatic amputation of leg; perforation of cecum. Survived.	4	1150	500	70/35	140	5.9	27.6	1660	2340	52
13	Shell fragment wd. penetrating left chest. Survived.	3	0	0	120/70	112	6.3	47.0	2830	5340	11
14	Gunshot wd. through abdomen; multiple perforations, colon and small bowel; compound fracture of ilium. Died 48 hrs. postop.	5	500	0	60/40	124	5.8	32.8	2170	3230	30
15	Shell fragment wd. through lt. chest; extensive laceration lt. upper lobe. Died 5 hrs. postop.	2	750	0	75/20	112	5.9	32.9	1790	2670	47
16	Shell fragment wd., with perforation of duodenum and inferior ven cava. Died 0.5 hrs. postop.	2	250	0	85/40	128	6.4	31.8	2160	3160	42
17	Mine wds. penetrating abdomen; multiple small perforations and mesenteric lacerations. Survived.	3	500	0	85/50	160	6.5	36.5	1630	2560	48
18	Gunshot wd. through axilla, severing brachial artery and vein. Survived.	3	750	0	70/40	124	5.9	27.4	2200	3030	46

TABLE I—(*Continued*)

INITIAL DATA ON FIFTY BATTLE CASUALTIES ADMITTED TO A FIELD HOSPITAL

Case No.	Diagnosis and Outcome*	Hours Since Injury	Previous Transfusions: Plasma Cc.	Previous Transfusions: Blood Cc.	Arterial Pressure Mm. Hg.	Pulse Rate	Plasma Protein Gm. %	Hemat.	Blood Volume: Plasma Cc.	Blood Volume: Total Cc.	Blood Volume: Deficit %
19	Shell fragment wd., with compound fracture of femur; urethral transection. Survived.	5	500	0	80/55	128	6.2	33.7	2230	3420	44
20	Gunshot wd. penetrating rt. chest, sucking. Survived.	2	500	0	70/50	132	6.0	28.6	2130	2990	47
21	Shell fragment wd. penetrating abdomen; liver lacerated. Survived.	5	250	0	100/70	80	7.3	39.6	2580	4270	16
22	Shell fragment wd. penetrating lt. chest; hemothorax. Survived.	2	0	0	50/0	140	6.0	44.2	2140	3840	27
23	Shell fragment wds. penetrating abdomen; lacerations of liver and kidney; compound fracture of femur. Survived.	5	250	0	40/30	128	6.9	35.4	1830	2840	41
24	Shell fragment wd., sucking, rt. chest; hemothorax; perforation, diaphragm and liver. Survived.	3	750	0	65/25	140	5.6	27.5	1920	2550	46
25	Shell fragment wd. penetrating abdomen; multiple small bowel perforations. Survived.	2	0	0	100/60	96	6.9	47.3	2840	5380	4
26	Gunshot wd. penetrating rt. chest; hemothorax. Survived.	1	0	0	120/80	116	6.4	43.8	2080	3710	15
27	Shell fragment wd. penetrating abdomen; liver laceration. Survived.	3	0	0	130/80	180	6.5	49.1	2670	5250	3
28	Gunshot wd. of thigh, lacerating femoral artery and vein. Died 5 hrs. after admission.	8	1400	500	50/0	120	5.2	16.3	2390	2860	46
29	Shell fragment wd. through chest and abdomen; hemothorax; lacerations of diaphragm, spleen and kidney. Survived.	5	1000	0	95/50	144	6.1	28.4	2180	3050	32
30	Shell fragment wd., abdominal, with perforation of colon and evisceration. Survived.	4	250	0	95/60	140	6.5	44.0	2520	4500	9
31	Shell fragment wds., with compound fractures of humerus, scapula and clavicle. Survived.	3	500	0	100/65	110	6.0	38.1	2490	4030	23
32	Shell fragment wd. penetrating rt. chest; hemothorax. Survived.	2	250	0	120/75	88	7.0	48.2	2430	4700	9
33	Shell fragment wd. penetrating abdomen; no visceral perforations. Survived.	3	250	0	110/70	88	6.4	44.0	2580	4600	13
34	Shell fragment wds. penetrating abdomen; multiple perforations of colon and small bowel; wds. of arm, face and scalp. Died 14 hrs. postop.	2	500	0	140/90	96	6.6	45.5	2050	3760	24

TABLE I—(*Continued*)

INITIAL DATA ON FIFTY BATTLE CASUALTIES ADMITTED TO A FIELD HOSPITAL

Case No.	Diagnosis and Outcome*	Hours Since Injury	Previous Transfusions: Plasma Cc.	Previous Transfusions: Blood Cc.	Arterial Pressure Mm. Hg.	Pulse Rate	Plasma Protein Gm. %	Hemat.	Blood Volume: Plasma Cc.	Blood Volume: Total Cc.	Blood Volume: Deficit %
35	Gunshot wd. through abdomen, perforating colon. Survived.	2	500	0	120/80	96	6.5	46.3	2050	3820	24
36	Shell fragment wd. penetrating abdomen; multiple perforations of bladder and small bowel. Comp. fracture of coccyx. Survived.	3	0	0	110/70	80	6.5	46.0	2000	3700	22
37	Shell fragment wd. of lt. chest, sucking. Survived.	1	0	0	90/70	120	6.3	36.0	1940	3040	25
38	Gunshot wd. through lt. flank with laceration, lt. kidney. Survived.	4	0	0	80/65	76	6.4	38.2	1900	3040	35
39	Shell fragment wd. penetrating abdomen, with multiple perforations of small bowel and colon. Died 12 hrs. postop.	5	1000	0	50/40	80	5.4	26.4	1850	2520	51
40	Shell fragment wd. penetrating lt. chest; hemothorax. Survived.	7	500	0	65/50	108	6.9	37.0	2270	3610	26
41	Shell fragment wd. penetrating abdomen; laceration of spleen. Survived.	3	0	0	170/90	80	6.2	49.0	3040	5950	2
42	Shell fragment wd. penetrating lt. chest; lacerations of diaphragm and liver; hemothorax. Survived.	5	0	0	140/70	108	6.1	41.5	2140	3660	25
43	Shell fragment wds., multiple, arm and thigh. Survived.	3	0	0	100/70	120	6.2	40.2	2710	4550	5
44	Shell fragment wds. penetrating abdomen; multiple perforations, small bowel, colon and bladder. Died 8 hrs. postop.	2	0	0	90/80	104	6.0	53.2	1760	3760	22
45	Gunshot wd. through rt. chest; hemothorax. Survived.	?	500	0	90/70	132	6.1	39.8	2170	3600	24
46	Shell fragment wd. penetrating chest; lacerations of diaphragm and liver; hemothorax. Survived.	1	0	0	65/40	112	5.9	34.1	2040	3100	32
47	Shell fragment wds. penetrating abdomen and buttock; multiple perforations of small bowel; compound fracture, rt. ilium. Died 12 hrs. postop.	2	500	0	0/0	140	5.8	37.0	1840	2920	39
48	Mine wds., multiple, with compound fractures of rt. femur, rt. and lt. tibia and fibula, and rt. radium. Died 5 hrs. after admission.	6	750	0	60/0	100	5.4	24.2	1810	2390	51
49	Shell fragment wd. penetrating thorax; cord transection, level T-V. Survived.	5	500	0	70/50	80	5.7	39.2	2880	4740	0
50	Shell fragment wd. penetrating thorax; cord transection, level T-II. Survived.	3	1250	0	85/60	88	6.2	34.2	4200	6390	18% excess

"normal" values, 9 per cent has been arbitrarily subtracted from the values reported by Gibson and Evans for normal males. Using their figures, altered in this fashion to compensate for the error in red cell volume, it is considered that the total blood volumes determined for patients in severe shock stand valid comparison with the volumes estimated to be normal for these individuals.

RESULTS

I. CLINICAL MANIFESTATIONS OF BLOOD VOLUME DEFICIENCY

Detailed clinical and laboratory data, obtained on 50 battle casualties upon their admission to the Field Hospital, are recorded in Table I. This series includes all patients whose blood volumes were determined at the time of hospital entry. From the figures obtained a correlation was attempted between the arterial pressure and pulse rate, on the one hand, and the percentage deficit in total blood volume on the other.

The Arterial Pressure.—Figure 1 illustrates the relation between the systolic arterial pressure and the blood volume deficit in 48 patients with war wounds and varying degrees of shock. It is apparent that all cases with a systolic arterial pressure below 85 mm. of mercury had a diminution in blood volume of more than 25 per cent. All cases with a systolic arterial pressure exceeding 100 mm. of mercury showed a deficit in blood volume of less than 25 per cent. Thus, it may be stated that, whereas, the absence of hypotension does not preclude the presence of a considerable degree of oligemia, a systolic pressure persisting at a level below 85 mm. of mercury is definite evidence of a very grave deficiency in blood volume.

Blood volume determinations were made in 23 patients whose systolic pressures were below 85 mm. of mercury; the average blood volume deficit in these cases was 40 per cent. It should be pointed out that all cases examined were first seen several hours after their injuries were incurred, so that hypotension on the basis of syncope, peripheral vascular collapse or "neurogenic shock" due to temporary vasometer influences, did not play an important rôle. None of the cases included in Figure 1 had sustained injuries to the central nervous system. Two cases with signs of spinal cord transection in the upper thoracic region (Cases 49 and 50) showed definite hypotension in the absence of significant blood volume deficiency, probably as the result of sympathetic paralysis.

The Pulse Rate.—The correlation between pulse rate and diminution in blood volume is not striking (Fig. 2.) Rates exceeding 130 per minute were generally associated with a marked decrease in blood volume; on the other hand, several cases with severe oligemia exhibited no tachycardia whatever.

Other clinical signs commonly associated with shock, such as pallor of the skin, coldness of the extremities and mental changes, proved to be unreliable indices of blood volume deficiency. Cold extremities and pallor were present almost universally on arrival of the wounded patients in the hospital, due, to some extent at least, to the influence of pain and exposure to cold.

II. ALTERATIONS IN HEMATOCRIT READING, HEMOGLOBIN CONCENTRATION AND PLASMA PROTEIN CONCENTRATION ASSOCIATED WITH SHOCK

Determination of either the hemoglobin concentration or the hematocrit

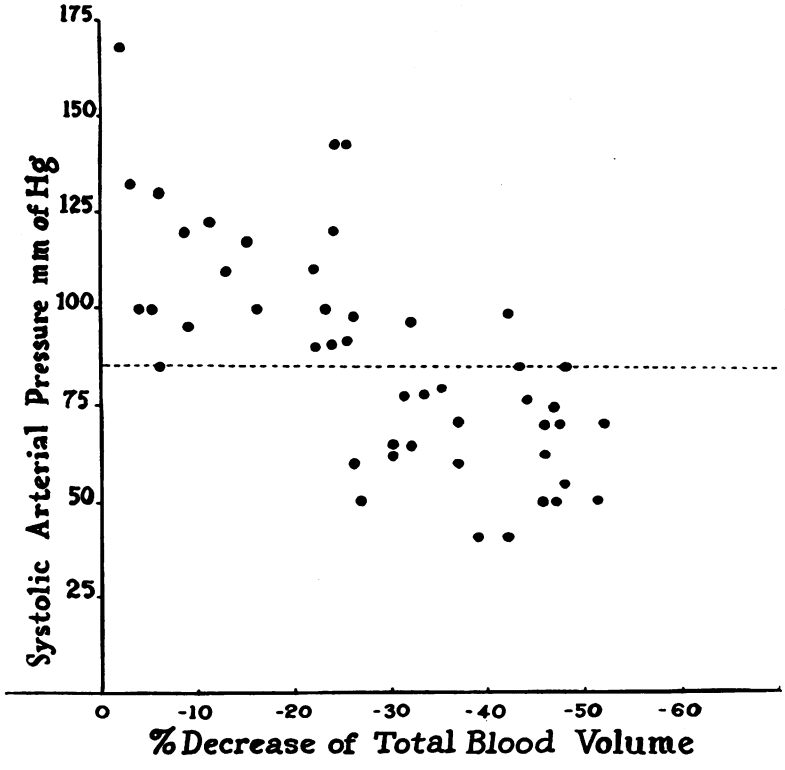

FIG. 1.—The relationship between systolic arterial pressure and blood volume deficit in 48 seriously wounded battle casualties before hospital therapy.

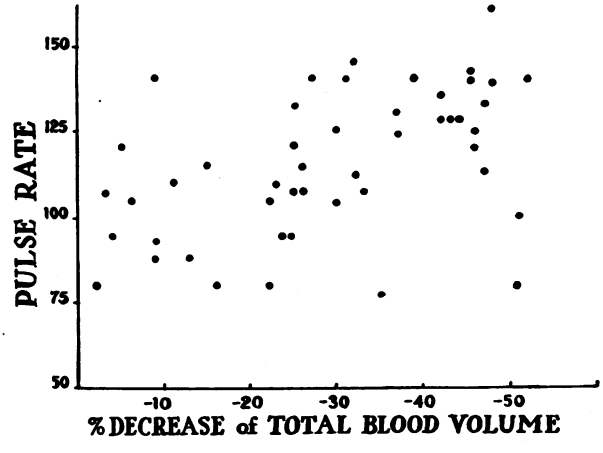

FIG. 2.—The relationship between pulse rate and blood volume deficit.

Data was obtained from the same group of 48 patients represented in Figure 1. No consistent correlation between pulse rate and degree of oligemia is observed.

reading were performed in 94 patients with severe war wounds. The results are plotted in Figure 3.

Anemia, indicating some degree of hemodilution, was found in the great majority of cases. Definite erythroconcentration was encountered in but one instance (Case 44, Table I). Almost all patients received in severe shock, *i.e.*, whose arterial pressures were less than 85 mm. of mercury, had some degree of anemia. The amount of plasma administered to the patient prior

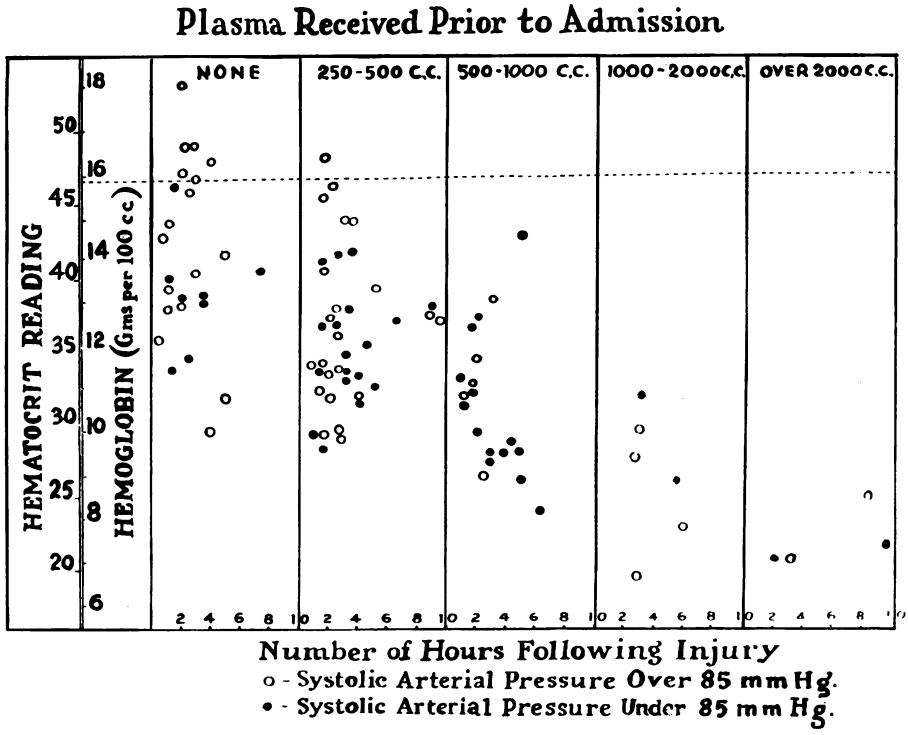

FIG. 3.—The degree of anemia observed in 94 casualties on admission to a field hospital. The dotted line represents the approximate average hemoglobin concentration and hematocrit reading for normal adult males of this age-group. Spontaneous hemodilution of moderate degree occurred in the majority of the cases who had bled severely. It is evident that marked anemia is produced by the injection of plasma in large quantities.

to hospital admission was a potent factor in those who had received this material, unsupplemented by whole blood, in volumes exceeding 1,000 cc. There was no definite correlation between the degree of anemia and the length of the time-interval following injury, or the type of wound incurred.

The plasma protein concentration was measured in 50 cases at the time of hospital admission (Table I). The values ranged between 5.1 and 7.3 Gm. per cent. A concentration below 5.5 Gm. per cent was encountered in only five instances. There was no consistent correlation between the degree of hypoproteinemia and the degree of shock. The results indicate that in the majority of cases spontaneous hemodilution with protein-free fluid had occurred in the interval between injury and hospitalization, but that the degree of hemodilution was not great. The maximum volume of such fluid calcu-

lated to have entered the circulating blood was 450 cc., and only in rare instances does it appear to have exceeded 200 cc.

III. RELATIVE LOSSES OF PLASMA AND RED CELLS, AND THE ESTIMATED TOTAL BLOOD LOSS ASSOCIATED WITH VARIOUS TYPES OF WOUNDS

The relative losses of red cells and plasma can be estimated from the ratio of the hematocrit reading and the plasma protein concentration. If whole blood is lost from the vascular system and hemodilution with protein-free fluid occurs, the hematocrit reading and protein concentration decrease proportionately. If plasma alone is lost, or if the plasma loss is disproportionately high, the ratio of plasma protein concentration to hematocrit reading is low. This relationship is illustrated in Figure 4.

Few cases showed evidence of pure, or markedly disproportionate, plasma

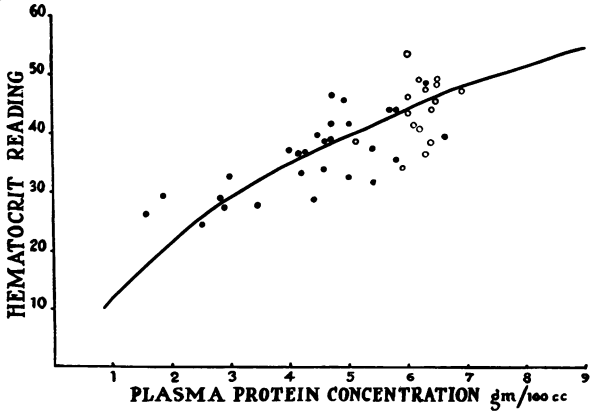

FIG. 4.—The relative loss of plasma and red cells incurred by 44 battle casualties.

The curved line represents the ratio between hematocrit reading and plasma protein concentration with progressive dilution of normal blood by protein-free fluid. Solid dots represent patients who had received plasma, their plasma protein values having been corrected for the injected protein; circles denote patients who had received no transfusion therapy. Points above the line indicate a disproportionate loss of plasma; those below the line indicate either plasma protein regeneration or erythro-concentration in the capillary bed.

loss. Case 44 (see Table I) is the most striking instance in which this phenomenon apparently occurred. This particular patient was admitted with an hematocrit reading of 53.2, and a plasma protein concentration of 6.0 Gm. per cent, having received no transfusions prior to entry. At operation he was found to have multiple perforations of the bowel and bladder; the peritoneal cavity was filled with urine and feces. Similar findings were obtained in Cases 34 and 35; both of these patients, likewise, had penetrating wounds of the abdomen with multiple perforations of the colon.

Inasmuch as the majority of cases had received plasma before admission to the hospital, the blood volume deficit determined at that time does not represent the total amount of blood lost. Knowing the volume of plasma received prior to admission, the extent of the hemorrhage can be estimated with reasonable accuracy from the calculated deficit in total circulating protein.

TABLE II

CHANGES IN BLOOD VOLUME EFFECTED BY TRANSFUSION THERAPY

Case Type* (No.)	Hours After Entry	Volume Transfused			Arterial Press.	Plasma Protein Conc.	Hemat.	Blood Volume		Increase in Red Cell Vol.		Increase in Plasma Protein		Estimated Blood Loss During Therapy
		Plasma Cc.	Blood Cc.	Diluent† Cc.	Mm.Hg.	Gm. %		Plasma Cc.	Total Cc.	Expected Cc.	Found Cc.	Expected Gm.	Found Gm.	Cc.
Abd.	0				65/40	6.3	41.5	2230	3810					
(1)	2.5	250	2500	2500	150/80	6.0	41.6	3660	6270	1250	1030	105	80	600
Abd.	0				60/40	5.3	32.4	2440	3610					
(2)	3.5	250	2000	2000	110/84	5.3	36.0	4000	6250	1000	1080	87	83	0
Chest	0				98/60	5.7	36.5	2430	3830					
(3)	3.5	0	1500	1500	140/66	5.5	37.9	3570	5740	750	770	53	58	0
Ext.	0				70/44	5.1	38.5	2130	3450					
(9)	8.5	250	2000	2000	138/75	5.3	36.7	3450	5450	1000	670	105	75	900
Ext.-Chest	0				50/40	5.9	29.4	1910	2700					
(10)	5.5	500	2750	1250	90/60	6.4	34.9	3270	5010	1375	950	131	97	1000
Abd.-Ext.	0				55/45	6.5	32.1	1660	2450					
(11)	5	400	2000	2000	124/70	5.6	35.5	2750	4260	1000	720	98	46	1100
Ext.	0				70/35	5.9	27.6	1660	2340					
(12)	6	350	1800	600	126/78	6.2	32.6	3200	4750	900	870	87	100	0
Abd.	0				62/38	5.8	32.8	2170	3230					
(14)	3	250	2000	2000	100/50	5.8	36.5	3680	5800	1000	1060	87	87	0
Abd.-Ext.	0				85/40	6.4	31.8	2160	3160					
(16)	3	500	2000	2000	140/50	6.5	34.0	3800	5750	1000	890	105	108	0
Ext.	0				70/42	5.9	27.4	2200	3030					
(18)	5	500	1500	1500	148/84	5.8	31.0	2870	4160	750	460	87	36	1100
Ext.	0				78/54	6.2	33.7	2230	3420					
(19)	4	450	1500	1500	138/78	5.5	31.0	3380	4900	750	330	81	48	1000
Abd.-Chest	0				70/50	6.0	28.6	2130	2990					
(20)	5	500	2000	2000	112/72	6.1	33.5	3710	5580	1000	1010	105	98	0
Abd.	0				100/70	7.3	39.6	2580	4270					
(21)	6	250	1000	1000	122/70	7.3	40.2	3380	5650	500	580	53	58	0
Abd.	0				40/30	6.9	35.4	1830	2840					

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TABLE II (*Continued*)

CHANGES IN BLOOD VOLUME EFFECTED BY TRANSFUSION THERAPY

Case Type* (No.)	Hours After Entry	Volume Transfused			Arterial Press.	Plasma Protein Conc.	Hemat.	Blood Volume		Increase in Red Cell Vol.		Increase in Plasma Protein		Estimated. Blood Loss During Therapy
		Plasma Cc.	Blood Cc.	Diluent† Cc.	Mm.Hg.	Gm. %		Plasma Cc.	Total Cc.	Expected Cc.	Found Cc.	Expected Gm.	Found Gm.	Cc
(23)	6.5	250	2000	2000	110/75	6.2	38.0	3420	5510	1000	1080	88	86	0
Chest-Abd.	0				96/48	6.1	28.4	2180	3050					
(29)	4	0	2000	2000	128/88	5.8	32.2	3200	4720	1000	650	70	50	700
Ext.	0				100/65	6.0	38.1	2490	4030					
(31)	4	250	2300	2300	126/70	6.1	36.0	3520	5500	1150	560	98	65	1100
Chest	0				90/70	6.3	36.0	1940	3040					
(37)	3	0	1000	1000	150/105	5.9	36.6	2820	4450	500	530	35	43	0
Chest-Abd.	0				80/66	6.4	38.2	1900	3040					
(38)	2	250	1150	550	120/76	6.2	36.5	3040	4800	570	600	57	67	0
Abd.	0				50/40	5.4	26.4	1850	2520					
(39)	3	250	2500	2500	156/86	5.9	39.2	3270	5300	1250	1350	105	93	0
Chest	0				65/50	6.9	37.0	2270	3610					
(40)	4	500	1350	450	110/58	6.8	36.8	3270	5170	675	570	82	65	350
Chest	0				65/40	5.9	34.1	2040	3100					
(46)	4	0	2000	2000	138/100	6.3	37.5	3160	5050	1000	830	70	80	0
Abd.	0				0/0	5.8	37.0	1840	2920					520
(47)	9	500	2500	2500	80/60	6.1	43.0	3270	5730	1250	1380	122	91	(plasma)
Ext.	0				60/0	5.4	24.2	1810	2390					
(48)	4	0	2350	1450	102/20	4.9	32.6	3380	5010	1170	1050	82	68	400

* Location of the major wound: (Abd.—abdominal: Ext.—extremity.

† Glucose—citrate—saline solution used as red blood cell preservative.

This deficit, in the 23 cases of severe shock whose blood volumes were measured at the time of admission, averaged 63 per cent. The blood volume deficiency in the majority of these patients represented a loss of plasma and red cells in approximately equal proportions; therefore, the protein deficit determined in this group can be assumed to represent an average blood loss of 63 per cent of the original total blood volume, or approximately 3,000 cc. Six patients (Cases 2, 5, 10, 12, 28 and 39) had sustained an estimated blood loss of over 80 per cent of their normal volumes before admission to the Field Hospital, life having been sustained by plasma transfusions exceeding 1,000 cc. in volume, supplemented in three cases by transfusions of whole blood.

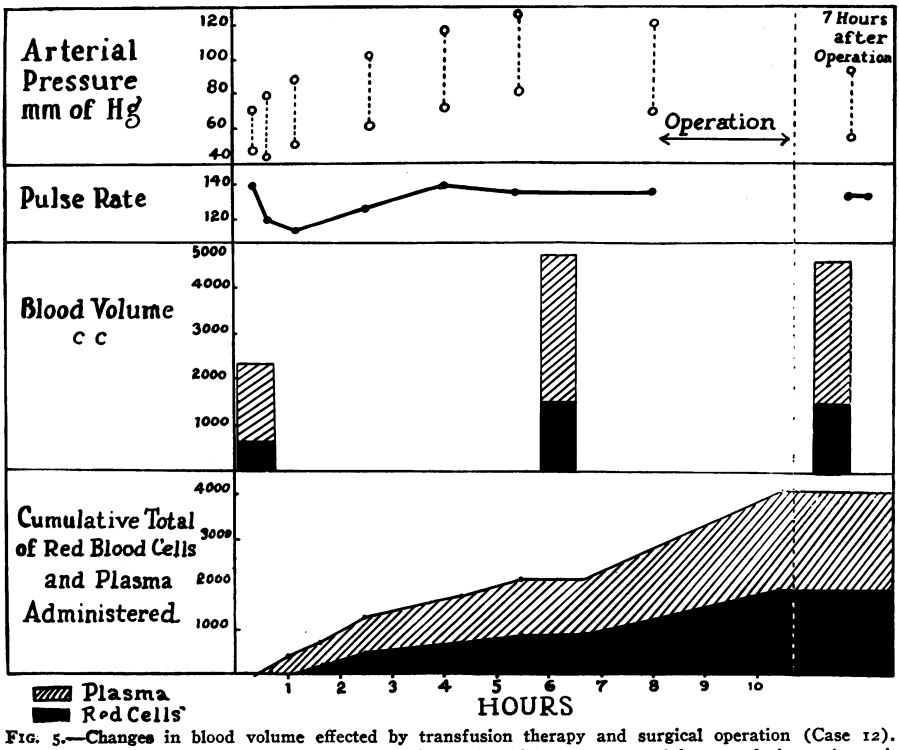

FIG. 5.—Changes in blood volume effected by transfusion therapy and surgical operation (Case 12). This patient was admitted in severe oligemic shock which was corrected by transfusion. An estimated loss of 2,600 cc. of blood occurred during operation, which included repair of a cecal laceration and débridement of peripheral wounds.

The most excessive blood loss occurred in the patients with extremity wounds, only one of whom—a patient with multiple small soft-tissue shrapnel wounds—had bled less than 40 per cent of his estimated total blood volume. Six patients with extremity wounds, complicated by perforating wounds of the abdomen or chest, lost an average of 70 per cent of their blood volume; seven cases with extremity wounds alone lost 60 per cent. The average total hemorrhage occurring between the time of injury and admission to the hospital was least in the group with perforating chest wounds, uncomplicated by abdominal or extremity wounds. This group comprised 12 patients who

were studied from this point of view; their average loss was estimated to be 35 per cent. Nineteen patients with abdominal wounds alone lost an average of 40 per cent, and the hemorrhage in four cases with combined abdominal and chest wounds averaged 50 per cent of their expected normal total blood volume.

IV. BLOOD LOSSES DUE TO SURGICAL PROCEDURES

The degree of hemorrhage complicating various operative procedures in traumatic surgery varies widely depending upon the extent and type of operation performed, as well as on the care that the surgeon can afford to devote to hemostasis. It was thought to be of interest to measure the loss occurring during the surgical repair of various types of war wounds, as carried out under Field Hospital conditions. Accordingly, blood volumes were determined pre- and postoperatively in ten cases (Table III), and the volume of blood given during operation was ascertained. Five of the operations involved celiotomy, with repair of bowel perforations; in one case (see Fig. 5) the operation included débridement of multiple extremity wounds. The series includes three open thoracotomies with repair of diaphragmatic and hepatic lacerations, one amputation of an arm combined with thoracotomy, and one débridement of multiple wounds of thigh and foot.

The average blood loss in the five celiotomies was 2,200 cc.; in the three thoracotomies, 600 cc. The blood loss in the case with amputation of an arm and thoracotomy was estimated to be 3,200 cc. It is apparent from even this small series of cases that the blood loss complicating extensive débridements, and the repair of perforating abdominal wounds is frequently of such magnitude as to require vigorous replacement therapy during operation.

V. RESPONSE TO THERAPY

Fifty-five cases of severe shock were treated by the authors. The majority of these patients responded to preoperative transfusion therapy by exhibiting a satisfactory rise in arterial pressure. Only three cases, representing 5 per cent of the cases studied, failed to respond in this fashion. The average volume of whole blood and plasma administered prior to operation was 2,650 cc. The ratio of whole blood to plasma was 2.3 to 1.0, this ratio being determined to a large extent by the availability of whole blood; thus, in the series of cases studied during the campaign in Germany, after large quantities of whole blood had been made available, the ratio of the whole blood and plasma used in the hospital for preoperative preparation of these battle casualties approached six to one. The average total volume of plasma and blood required to produce an elevation of arterial pressure from below 85 to above 100 mm. of mercury was 1,250 cc. No consistent alteration in pulse rate was observed in response to transfusion therapy.

Serial determinations of the plasma volume, total circulating protein and hematocrit reading were performed in the course of transfusion therapy in 23 cases (Table II). Predicted increases in red cell volume and total circulating protein are based on data derived from testing numerous samples of the plasma and stored blood used in treatment; the plasma protein content

per 250-cc. unit of dried plasma, and that contained in 500 cc. of undiluted whole blood, averaged approximately 17.5 Gm., the average hematocrit reading of the stored blood, correction having been made for the added preservative-diluent solution, was approximately 50.

Twelve cases showed an increase in red cell volume and total circulating protein that corresponded very closely with the values expected on the basis of the amounts transfused. There were 11 patients, however, in whom it is apparent that blood loss must have persisted during the course of shock therapy. The individual losses in these cases ranged from 350 to 1,100 cc., or between approximately 20 and 50 per cent of the blood and plasma transfused. Such losses occurred with greatest regularity in patients with extremity wounds, seven out of a total of ten such patients suffering a loss which averaged 40 per cent of the blood and plasma received. Two of six abdominal cases continued to bleed after admission, their losses averaging approximately 600 cc., or 20 per cent of the volume transfused; in one of these (Case 47), several hours after the patient had incurred multiple perforations of the small bowel, the material lost during therapy appears to have consisted exclusively of plasma.

There was no obvious relation between the phenomenon of continued hemorrhage and the degree of oligemia present at the time therapy was begun. Neither the initial blood pressure nor the pulse rate proved helpful in the diagnosis or prediction of continued hemorrhage; thus, of those patients who continued to bleed during therapy, 80 per cent had been in shock at the time of their admission, whereas signs of shock were present in 70 per cent of those whose bleeding had ceased. Persistence of hemorrhage, likewise, appeared to bear no relation to the amount of blood and plasma administered prior to admission, the average amounts received by the persistent bleeders and the others having been practically identical.

Almost all of the blood employed in the treatment of these cases was diluted with an equal volume of glucose-sodium citrate-saline preservative (Alsever's solution). Patients requiring the transfusion of large amounts of blood were, therefore, obliged to receive, in addition, large volumes of crystalloid solution, the amounts of which are recorded in Table II. The effect of this therapy, with respect to the degree of hemodilution produced, may be gauged by observing the resultant changes in the plasma protein concentration; the latter, together with the plasma volume and hematocrit reading, was measured in all cases within 30 minutes, and in most cases within ten minutes following the conclusion of the transfusion. As is evident from inspection of Table II, surprisingly little accentuation of hypoproteinemia was produced by the injection of large volumes of dilute blood, the plasma protein concentration of which averaged approximately 2.3 Gm. per cent. The circulating plasma protein concentration after transfusion was less than 5.5 Gm. per cent in only three patients (Cases 2, 9, and 48), and in each of these cases the concentration was less than 5.5 before transfusion. In no instance was the hematocrit reading substantially reduced, although that of

most of the blood given was approximately 25; the occurrence of any reduction whatever was almost invariably associated with continuance of hemorrhage during the transfusion. It may be concluded, therefore, that retention of the blood-diluent solution, even when injected rapidly in quantities exceeding 2,000 cc., is not of sufficient duration or magnitude to promote significant hemodilution in the recipient.

VI. ANALYSIS OF THERAPEUTIC FAILURES

Table IV summarizes the mortality statistics for the entire series of 112 battle casualties observed by the authors. All deaths are recorded which occurred preoperatively, during operation and within 24 hours postoperatively. A few deaths occurred later than the first postoperative day, but it is not

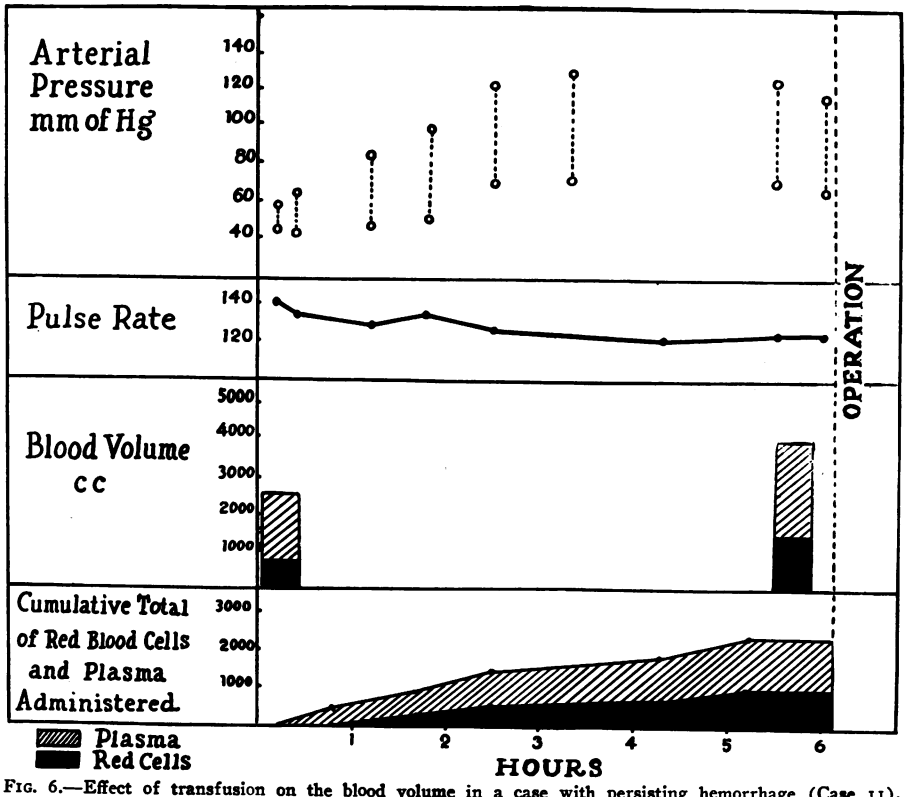

FIG. 6.—Effect of transfusion on the blood volume in a case with persisting hemorrhage (Case 11). This patient, with perforations of duodenum and colon, compound fracture of humerus, and thigh wounds, received 2,400 cc. of blood and plasma, of which 1,100 cc. is estimated to have been lost during therapy.

considered that they were attributable to failure of shock therapy or preoperative preparation of the patient. The mortality incidence in 55 cases admitted with systolic arterial pressures over 85 mm. of mercury was 11 per cent, representing six cases in this group; of these six patients, five died as a result of penetrating abdominal wounds with intestinal perforation. Of the 57 patients admitted in severe shock, *i.e.*, with arterial pressures less than 85 mm. of mercury, there were 18 deaths, a mortality incidence of 32 per cent.

It is of considerable interest to analyze the factors apparently responsible for therapeutic failure in the cases which failed to survive. For the purposes of this analysis, only those patients who had received careful laboratory investigation, as well as clinical study, are discussed. Of the 57 cases in which blood volume measurements were made, 13 deaths occurred within the first postoperative day. Eight of these 13 patients (Cases 1, 11, 16, 34, 39, 44, 47 and 57) died as a result of penetrating wounds of the abdomen; one died without operation, two died during or immediately following surgery, and five approximately 12 hours postoperatively. The initial response to shock therapy was good in all cases. Excepting one case, the amount of blood transfused prior to operation appeared adequate to restore the blood volume to normal. In one patient (see Fig. 6) some hemorrhage obviously occurred during therapy, and blood volume was decreased at the time of operation

Two patients (Cases 11 and 16) died on the operating table. The wounds, in one case, included perforation of the inferior vena cava and transection of the duodenum; in the other, there were extensive lacerations of the liver, duodenum and transverse colon. These deaths were considered to be due to excessive, uncontrollable blood loss during operation.

The six remaining fatalities are attributable to peritonitis. Two of these cases are of particular interest in that, despite adequate shock therapy, there occurred a secondary fall in arterial pressure before surgical intervention was possible.

Case 57 (Fig. 7) was admitted to the hospital five hours after receiving a gunshot wound penetrating the right lower abdomen. A moderate degree of shock had responded satisfactorily to the previous transfusion of 1,500 cc. of blood and plasma. Four hours after admission, however, despite an additional transfusion of 1,300 cc. of whole blood, the systolic arterial pressure dropped to an average level of 60 mm., and diastolic to 40 mm. of mercury. One hour later the blood volume was determined and found to be normal, in view of which no more blood or plasma was given.

The patient gradually developed an ashen cyanosis. The skin became cold, dry and mottled in appearance; blanching, which lasted for several seconds, could be produced by momentary pressure at any point. The abdomen was tense and exquisitely tender. The chest was normal on physical and roentgenologic examination. Restlessness became increasingly marked, but the patient complained of no pain or discomfort and remained entirely lucid. During his sixth hour in the hospital, the arterial pressure ceased to be obtainable. The femoral pulse, still palpable, became irregular, the rate averaging 130 beats per minute. The blood volume was again measured; the results were substantially the same as those obtained three hours previously, indicating that no further intra-abdominal hemorrhage had occurred during this interval.

Nine hours after entry the patient died. Postmortem examination revealed extensive lacerations of the cecum and ascending colon, and multiple perforations of the ileum; the abdominal cavity was filled with blood and intestinal contents. It is apparent, in this case, that the terminal fall in arterial pressure, culminating in severe shock and death, was unrelated to a diminution of blood volume, but was due to massive peritoneal contamination.

Case 47 (Fig. 8) illustrates a good initial response to shock therapy, with a secondary fall in arterial pressure in spite of a sustained normal blood volume. The findings at operation included multiple perforations of the rectum, colon and small bowel with generalized peritonitis, and a compound fracture of the ileum. The postoperative course

TABLE III

BLOOD VOLUME CHANGES RESULTING FROM MAJOR OPERATIVE PROCEDURES IN THE TREATMENT OF BATTLE CASUALTIES

Case No.	Operative Procedure	Transfused During Operation			Plasma Protein Conc.		Blood Volume		Estimated Blood Loss During Operation		
		Blood Cc.	Plasma Cc.	Time	Gm. %	Hemat.	Plasma Cc.	Total Cc.	Red Cells Cc.	Plasma Cc.	Total Cc.
1	Celiotomy; 2 ft. of jejunum resected; colostomy; multiple perforations of small bowel and rectum repaired.	1500	250	preop.	6.0	41.6	3660	6270	680	2070	2750
				postop.	5.1	44.0	3420	6100			
12	Celiotomy; cecum repaired; débridement of wds., rt. flank and rt. leg.	2000	0	preop.	6.2	32.6	3200	4750			
				postop.	5.8	34.4	2940	4490	1000	1630	2630
44	Celiotomy; colostomy; perforations of small bowel and bladder repaired.	1500	750	preop.	6.0	53.2	1760	3760			
				postop.	4.9	31.2	2490	3620	1620	1650	3270
34	Celiotomy; 18 inches of jejunum resected; portion of colon exteriorized.	1500	0	preop.	6.6	45.5	2050	3760			
				postop.	5.9	45.4	2220	4060	620	950	1570
51	Celiotomy; portion of ileum resected; multiple perforations of jejunum repaired; portion of descending colon exteriorized.	540	0	preop.	6.6	44.9	2600	4700			
				postop.	6.3	49.9	2260	4500	130	760	890
52	Thorocotomy; laceration of rt. lung repaired; hemothorax drained. Rt. arm amputated.	1550	0	preop.	5.7	32.8	3310	4920			
				postop.	5.4	30.7	2530	3650	1270	1930	3200
53	Thorocotomy; rib resection; foreign body removed from hilus, right lower lobe; hemothorax drained.	0	0	preop.	6.3	42.0	2930	5050			
				postop.	6.2	41.8	2780	4770	130	210	340
54	Thorocotomy; 3000 cc. of blood evacuated from rt. chest; wd. of liver sutured; diaphragm repaired.	1000	0	preop.	5.6	38.7	3380	5510			
				postop.	5.2	35.2	3750	5800	580	540	1120
55	Thorocotomy; penetrating wd. of diaphragm sutured.	0	0	preop.	...	42.3	3240	5620			
				postop.	6.9	43.7	2830	5020	190	....	440
56	Débridement of penetrating wds. of lt. thigh and foot.	500	250	preop.	5.7	33.8	3380	5100			
				postop.	5.8	30.9	3240	4680	570	700	1270

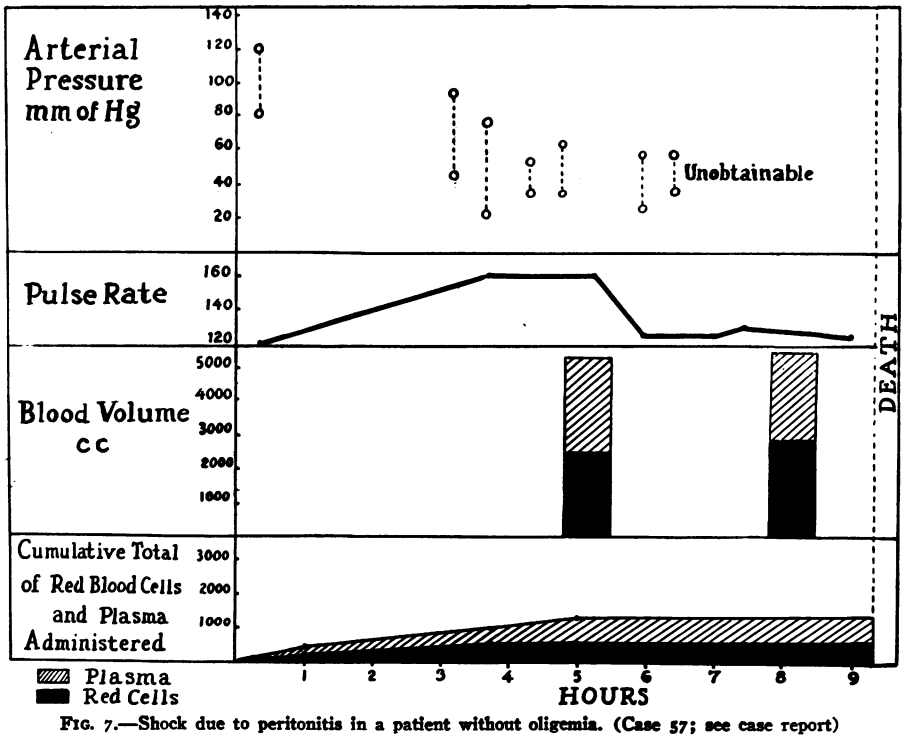

FIG. 7.—Shock due to peritonitis in a patient without oligemia. (Case 57; see case report)

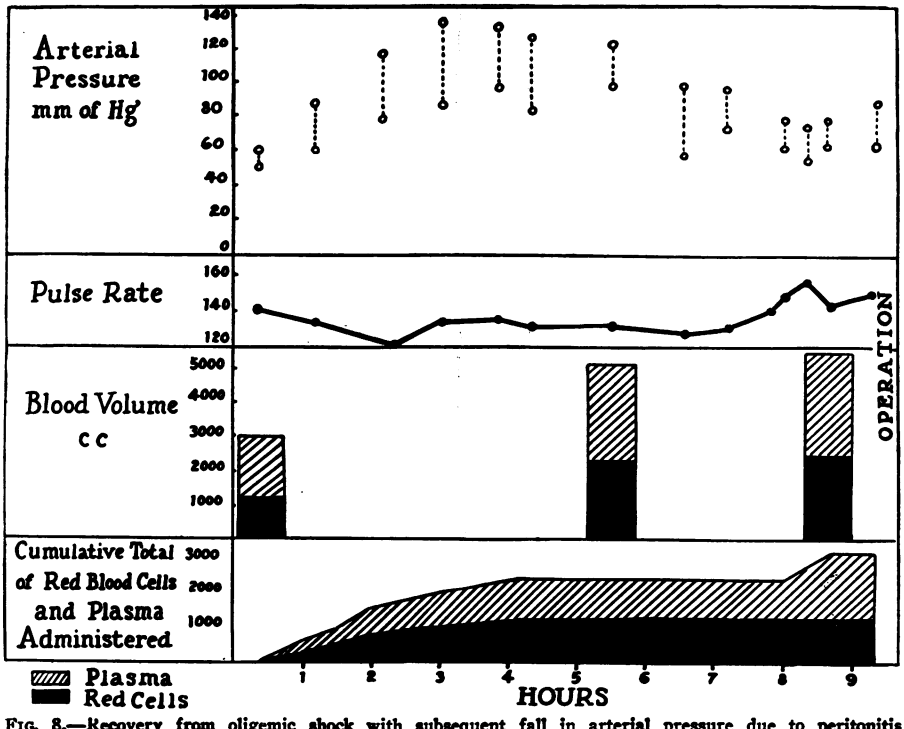

FIG. 8.—Recovery from oligemic shock with subsequent fall in arterial pressure due to peritonitis (Case 47).

Patient was admitted in severe shock, with penetrating abdominal wounds. Correction of the initial oligemia was followed by satisfactory rise in arterial pressure, which, however, was unsustained despite a normal and stable blood volume.

was marked by persistent hypotension and progressively severe shock, terminating in death 11 hours after operation.

The four remaining fatalities due to abdominal wounds also died in shock approximately 12 hours postoperatively. The recurring signs of shock in these patients, in contrast to Case 47, first developed after operation. This group is well exemplified by Case 1 (Fig. 9), a patient admitted in severe shock following a gunshot wound of the right buttock. Response to transfusion therapy was excellent, both with respect to clinical signs and blood volume.

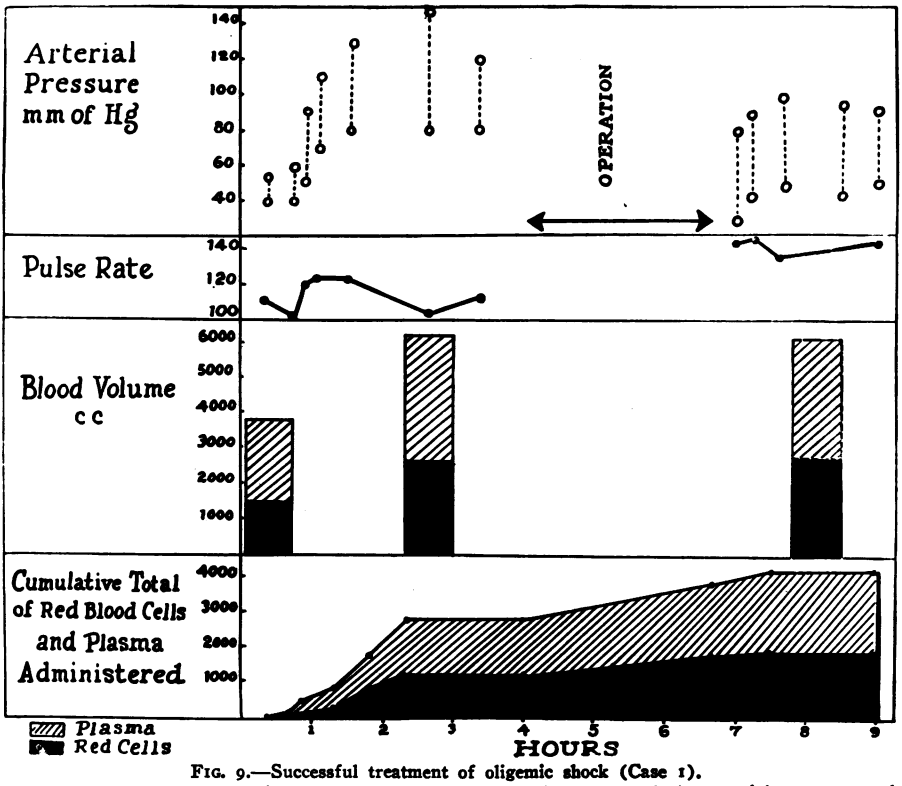

FIG. 9.—Successful treatment of oligemic shock (Case 1).

Adequate response to initial shock therapy is indicated by return of the arterial pressure and blood volume to normal. Operation, nine hours after injury, revealed multiple intestinal perforations and massive peritoneal contamination with feces. The blood volume was satisfactorily maintained, despite which there subsequently developed signs of progressively severe shock due to peritonitis.

Operation was completed six hours following admission, nine hours after injury; the abdomen was discovered to be filled with blood and feces in consequence of multiple tears and perforations involving the rectum, colon and small bowel. Immediately following operation the patient's condition was satisfactory, and a blood volume determination performed at that time yielded normal values. Twelve hours later, however, death ensued, apparently as the result of overwhelming peritoneal infection.

Blood volume studies were done on three patients with fatal wounds of the chest (Cases 8, 10, and 15). Extensive damage to lung tissue was present in all three cases. One patient died without operative intervention,

one died immediately following completion of open thoracotomy, and the other died approximately 12 hours postoperatively. Dyspnea and cyanosis, due to lack of functioning lung tissue, consistently dominated the clinical picture. The response to transfusion therapy was disappointing, the arterial pressure tending to remain moderately depressed despite a normal blood volume. The patient who died prior to operation developed terminal pulmonary edema, and death in all three cases appeared to be the result of pulmonary damage with consequent inadequate blood oxygenation, and not due primarily to circulatory failure.

The two patients who died as a result of extremity wounds presented features of unusual interest.

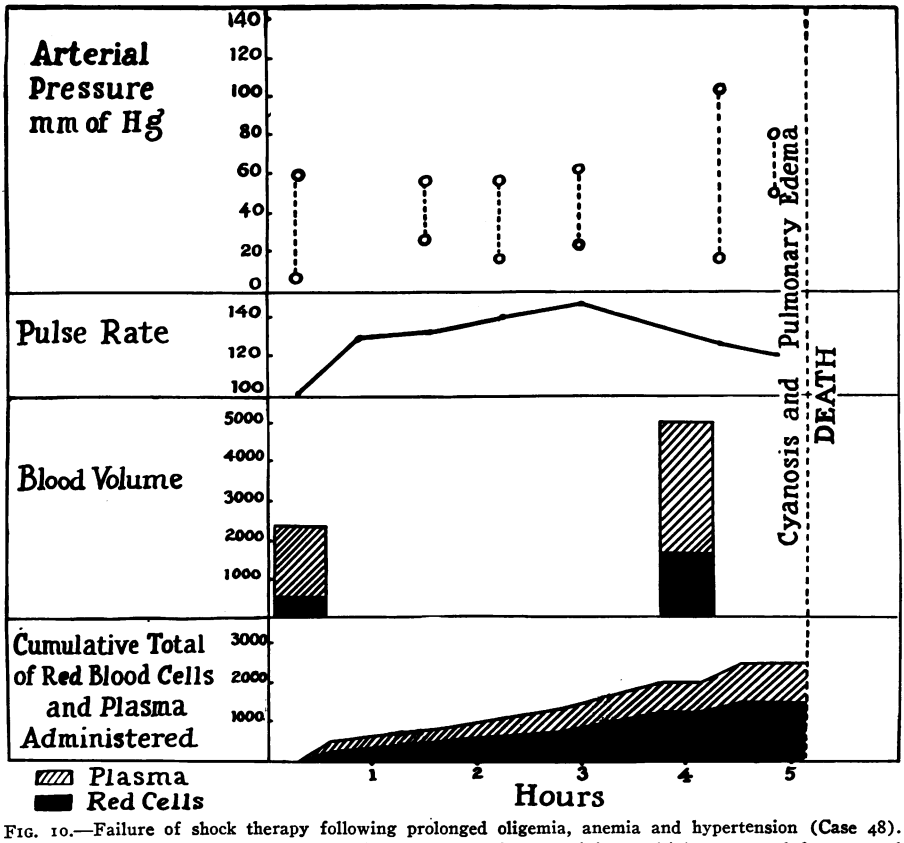

FIG. 10.—Failure of shock therapy following prolonged oligemia, anemia and hypertension (Case 48). The patient was admitted to the hospital six hours after sustaining multiple compound fractures of both legs. Correction of the oligemia not only failed to alleviate shock, but precipitated signs of venous hypertension and pulmonary edema.

Case 28 was admitted with a through-and-through gunshot wound of the thigh, incurred seven hours previously. Despite having received 1,900 cc. of blood and plasma before entry he was in severe shock, manifested by coma, pallor and coldness of the skin, and a systolic arterial pressure of 50 mm. of mercury. Blood volume studies indicated not only a marked oligemia, but also a severe anemia, the red cell volume totaling approximately 500 cc. Following the transfusion of 900 cc. of whole blood the patient became relatively lucid; the skin became warm and acquired a pink hue,

with a slightly cyanotic tinge. However, there was no substantial rise in arterial pressure; the maximum level was 75 mm. of mercury systolic and 35 mm. diastolic, only briefly attained after 2,000 cc. of blood had been received. Thereupon, inasmuch as the diameter of the thigh appeared to be increasing slightly, a tourniquet was placed above the wound and an additional transfusion of 2,000 cc. of blood was given. In the course of this transfusion the arterial pressure continued to fall, the sensorium again became clouded, cyanosis increased and the neck veins became distended. Five hours after admission death supervened, preceded by the development of frank pulmonary edema. Postmortem examination revealed a transection of the femoral artery and a massive hematoma in the thigh; the femur was not fractured, and there was no evidence of gas bacillus infection.

Case 48 (Fig. 10) was admitted with multiple mine wounds of both legs, including compound fractures of one femur and of both bones of both lower legs. He was received into the hospital six hours after injury. The initial laboratory studies indicated a

TABLE IV

MORTALITY INCIDENCE IN 112 BATTLE CASUALTIES

Type of Wound	No. Survived	No. Dead*	Per Cent Mortality
Admission Systolic Arterial Pressure over 85 Mm. of Hg.			
Abdominal	15	4	21
Chest	12	0	0
Chest and abdominal	8	0	0
Extremity	4	0	0
Extremity and chest	6	1	14
Extremity and abdominal	4	1	20
Total	49	6	11
Admission Systolic Arterial Pressure under 85 Mm. of Hg.			
Abdominal	6	4	40
Chest	11	5	31
Chest and abdominal	5	2	29
Extremity	7	5	41
Extremity and chest	5	0	0
Extremity and abdominal	5	2	29
Total	39	18	32

* Includes deaths occurring preoperatively, during operation, and within 24 hours after operation.

severe oligemia and anemia; the total red cell volume was approximately 600 cc. Despite adequate replacement therapy, as indicated by a return of the blood volume to normal levels, the patient never recovered from shock. There developed a livid cyanosis, neck vein distention and, terminally, frank pulmonary edema, death occurring five hours after admission.

The above cases are similar, in that both patients had been in shock for an extended period of time before effective replacement therapy could be instituted. Both had received large quantities of plasma prior to admission, and entered with severe anemia in addition to marked oligemia. These patients failed to respond to adequate shock treatment, although in neither case could this failure be attributed to lack of adequate transfusion therapy or to the presence of infection. The sequence of events suggests that failure of shock therapy in these cases is related to irreversible changes in the cardiovascular system resulting from prolonged tissue anoxia. Persistence of their arterial hypotension, with associated signs of peripheral venular stasis and, with

increase of the blood volume to normal, the appearance of progressive venous hypertension and pulmonary edema, are possibly all attributable to myocardial insufficiency.

DISCUSSION

The present study indicates that the shock syndrome, developing in battle casualties within a few hours after injury, is essentially a reflection of a diminished blood volume attributable to hemorrhage. The average blood volume deficit was 40 per cent in the patients who were received in severe shock. A similar degree of oligemia associated with traumatic shock has been reported by Evans.[8] The great majority of patients presented no evidence of excessive plasma loss, relative to the loss of red cells; a few abdominal cases were encountered in whom a disproportionate loss of plasma had occurred, seemingly in consequence of peritoneal exudation.

Most of the patients reported in this study had received plasma before admission to the Field Hospital. Many cases, having been transfused with large amounts of plasma, were admitted in severe shock which was obviously due to continued hemorrhage. In consequence of the dilution of their blood with the transfused plasma, these patients suffered a marked reduction in the oxygen capacity of the circulating blood in addition to a diminution of blood volume, a combination of deficiencies that is extremely deleterious. Oligemia was not accompanied by profound anemia in those cases which had not received plasma, from which it may be deduced that spontaneous hemodilution, at least during the first few hours after hemorrhage, plays a very minor rôle in restoration of the blood volume.

Ideal shock therapy, and the proper preparation of shock cases for surgery, entail restoration of the blood volume to approximately normal levels, and the maintenance of an adequate hemoglobin concentration in the blood. The amounts of blood and plasma required to correct the oligemia vary from case to case, and sound clinical judgment must be exercised if the therapeutic requirements are to be met properly. Blood volume measurements are obviously not practical as a routine laboratory procedure. Most clinical signs, including the rate and character of the pulse, the skin temperature and the degree of pallor, were found to be unreliable indices of oligemia. The presence of anemia, unless plasma had been received prior to admission, was found to be indicative of marked oligemia, but the progress of spontaneous hemodilution is so slow and variable that the hemoglobin determination proved of little value as a guide to transfusion therapy in the treatment of casualties received within a few hours after injury. Two criteria, however, were found to be exceedingly helpful in estimating the degree of blood volume deficiency, the first of which is the character of the wound. Certain types of wounds, such as traumatic amputations, compound fractures of large bones, severance of major blood vessels, chest wounds with signs of hemothorax and lacerations of abdominal viscera with hemoperitoneum, are almost invariably accompanied by marked oligemia. The second criterion of transfusion requirement is

the level of the arterial blood pressure. Excepting in patients with central nervous system injuries, a definite correlation was found to exist between the systolic pressure and the degree of oligemia. Patients with systolic pressures below 85 mm. of mercury were consistently found to have a blood volume deficit exceeding 25 per cent, while those with pressures greater than 100 mm. of mercury always presented less than a 25 per cent deficiency.

The following general plan of transfusion therapy was followed by the authors in treating oligemic shock and preparing casualties for surgery: Patients received with normal arterial pressures, but with severe wounds suggesting a significant degree of blood loss, were given 1,000 cc. of blood preoperatively; those patients admitted with a low arterial pressure attributable, as far as could be detected, to blood loss alone, received 2,000 cc. of blood preoperatively, or, if an adequate response was not attained, 1,000 cc. beyond that amount required to restore the systolic arterial pressure to approximately 100 mm. of mercury. Blood volume determinations at the completion of shock therapy applied in this fashion, indicated that the oligemia had been accurately corrected in most instances. Patients with perforating wounds of the chest were treated somewhat more conservatively: unless they were obliged to undergo a major operation under general anesthesia, preoperative transfusions were halted when the systolic arterial pressure had risen to approximately 100 mm. of mercury, in order to avoid precipitating further intrapulmonary hemorrhage.

During major surgical procedures, particularly in abdominal and extremity cases, further transfusion was usually required to maintain the blood volume. The degree of operative blood loss was often considerable, in some cases amounting to between 2,000 and 3,000 cc. The amount of transfusion required must obviously be calculated on the basis of the estimated blood loss incident to the surgical procedure and, more particularly, the course of the arterial pressure during operation.

The question as to the proper rôle of plasma in shock therapy is a very important one. Plasma unquestionably serves as an adequate substitute for whole blood in the restoration of a reduced blood volume. It is, therefore, an invaluable therapeutic agent in emergency shock therapy under circumstances in which whole blood is not immediately available, and in the treatment of mild or moderate oligemia as a means of conserving whole blood. However, it must be emphasized that the unrestricted use of plasma inevitably leads to anemia, when employed in the presence of oligemia; the greater the degree of oligemia, the greater is the dilution effect of transfused plasma on the remaining red cells. The use of more than 1,000 cc. of plasma in the treatment of severe oligemic shock results in a very profound anemia, which often cannot be materially improved by whole blood transfusions without dangerously overloading the circulation. It is particularly desirable to avoid this complication in patients with massive wounds. Such patients usually face the added ordeal of a prolonged general anesthesia within a few hours following injury, and the additional loss of blood during operation may be ex-

cessively great. The presence of severe anemia, with marked diminution of the oxygen-carrying power of the blood, renders these patients especially prone to develop irreversible shock, in consequence of prolonged tissue anoxia. Anemia is, likewise, a dangerous complication in patients with penetrating wounds of the chest, already suffering from anoxemia as a result of a reduction in the amount of functioning lung tissue; not only is there a lowering of the oxygen capacity of the blood but its oxygenation is deficient.

Excessive transfusion therapy should be avoided in the treatment of shock and the preoperative preparation of wounded patients. No case should receive more blood or plasma than is required to restore the blood volume to normal. Most individuals, to be sure, suffer no ill effects from transfusions which elevate the blood volume several hundred cubic centimeters in excess of normal; on the other hand, patients with any type of wound may have hemorrhage induced or enhanced by this procedure. Chest cases, with penetrating wounds of the lung, are particularly endangered by overloading of the circulation. Too vigorous replacement therapy in these patients often leads to increased dyspnea and cyanosis due to pulmonary congestion, edema and hemorrhage, complications that may prove fatal. It has been our experience that these patients respond best to slow transfusions of whole blood, the volume of which does not exceed that amount required to restore and maintain the arterial blood pressure at a safe level.

It often requires the finest clinical judgment to ascertain at what point transfusion should be stopped in the treatment of a patient in shock. Failure of the arterial pressure to rise as expected, in response to apparently adequate shock therapy, may be due to persistent oligemia on the basis of continued concealed bleeding; on the other hand, there may be other factors perpetuating or aggravating the shock, irrespective of a normal blood volume. Possible factors include infection, such as peritonitis, or a gas bacillus infection; prolonged tissue anoxia, due to oligemia and hypotension, especially when aggravated by anemia; pulmonary damage with resultant impairment of blood oxygenation, or anoxic anoxia; and, finally, failure of vasoconstriction due to lesions involving the central nervous system. As soon as it becomes evident that oligemia is no longer the factor responsible for the state of shock, further transfusions should be regarded as of no avail, and this therapy abandoned forthwith. One of the earliest indications that the replacement therapy has been more than adequate, or has been prosecuted too vigorously, is the development of neck-vein distention; on the appearance of this sign, transfusion must promptly be halted if pulmonary edema is to be averted.

SUMMARY AND CONCLUSIONS

One hundred and twelve battle casualties admitted to a Field Hospital with serious abdominal, chest or extremity wounds have been studied by the authors. Fifty per cent of these patients were in severe shock. Detailed clinical observations were made in all cases, and serial determinations of either the hemoglobin concentration or hematocrit reading were performed. Measure-

ments of the plasma volume and plasma protein concentration, as well as hematocrit reading, were completed in 57 cases; in 33 cases multiple blood volume determinations were made, either in the course of transfusion therapy, or before and after operation.

The arterial blood pressure was found to provide the most reliable clinical index of blood volume deficiency. All patients with initial systolic pressures below 85 mm. of mercury, excluding cases with spinal cord transection, were found to have marked oligemia, the deficit averaging 40 per cent of the expected normal blood volume; all cases with this degree of hypotension had a diminution in blood volume that exceeded 25 per cent.

Blood volume and plasma protein measurements indicated that some degree of spontaneous hemodilution with low protein fluid often occurred in cases suffering from oligemic shock; the amount of this dilution, however, was small, rarely exceeding 200 cc. It is concluded that a normal hematocrit reading, or the demonstration of a mild anemia within a few hours after injury is no indication that a severe blood loss has not occurred. Severe anemia was produced by the adminisration of plasma to patients with marked oligemia.

The majority of patients presented no evidence of an excessive loss of plasma in proportion to red cells; in a few cases with severe abdominal wounds there was demonstrated a disproportionate plasma loss, which resulted in a mild degree of erythroconcentration. The average total blood loss estimated to have occurred in cases of severe shock before admission to the hospital was 63 per cent. Hemorrhage appeared to have been most severe in patients with extremity wounds, and least severe in patients with uncomplicated chest wounds.

Blood volume measurements were performed pre- and postoperatively in ten cases, in order to ascertain the degree of blood loss occurring in the course of various surgical procedures. The average loss in three cases subjected to open thoracotomy was 600 cc.; five patients requiring extensive abdominal surgery lost an average of 2,200 cc. of blood.

Serial determinations of the blood volume indicated that hemorrhage occurred during the course of transfusion therapy in 11 out of 23 patients studied. This complication was encountered most commonly in patients with severe extremity wounds, a majority of these cases suffering a loss which averaged 40 per cent of the blood and plasma transfused.

Plasma protein measurements before and after the injection of blood diluted with equal volumes of preservative solution indicate that retention of the latter in the blood stream is transient, and of insufficient degree to produce significant hemodilution.

The mortality incidence in all cases admitted in severe shock was 32 per cent; of those whose arterial pressure on admission exceeded 85 mm. of mercury, 11 per cent died within a similar period, which included the first postoperative day. The majority of deaths were attributable to penetrating abdominal wounds.

Cases are described in whom the clinical signs of shock were unrelieved by therapy, despite complete restoration of the blood volume to normal. The factors operative in the production of "irreversible shock" included severe infection, lesions involving the central nervous system, anoxic anoxia due to pulmonary damage, and long-persisting combination of anemia, oligemia and hypotension, with terminal signs of myocardial insufficiency.

Therapeutic indications for the use of whole blood and plasma are cited, and criteria for evaluating the requisite amount of transfusion therapy are discussed.

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