THE PERIPHERAL BLOOD FLOW IN SURGICAL SHOCK

The Reduction in Circulation through the Hand Resulting from Pain, Fear, Cold, and Asphyxia, with Quantitative Measurements of the Volume Flow of Blood in Clinical Cases of Surgical Shock

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Patients in surgical shock present clinical evidence of a diminished peripheral circulation. The extremities are cold, the pulse is feeble, and the veins are empty of blood. An increase in the peripheral vascular resistance in experimental shock has been demonstrated by Erlanger, Gesell and Gasser (1). Quantitative measurements, however, on the reduction in circulation in human cases of shock have not been made. These studies were therefore undertaken to learn the extent of impairment in the distribution of blood to the peripheral tissues. In addition, the effect of traumatic stimuli on the volume flow of blood in normal individuals was studied under controlled conditions.

METHODS

The subjects were patients and medical students at the Massachusetts General Hospital. The volume flow of blood through the hand at controlled temperatures was measured by the plethysmographic method previously described (2). In the observations on surgical shock the blood flow was determined with the hand at different temperatures. Then, at a constant temperature, the reactive hyperemia was measured 10 seconds after release of a tourniquet which had occluded the arterial inflow for 5 minutes. Samples of arterial and venous blood were taken when feasible for oxygen content, oxygen capacity and carbon dioxide content. The oxygen content, oxygen capacity and carbon dioxide content were determined in duplicate by the method of Van Slyke and Neill (3). Studies were carried out in the laboratory, in the operating amphitheatre, and on the wards. Notes were taken on the room temperature, clinical condition of the patient, and any incidental stimuli.

The reactions of patients and students to the traumatic stimuli—cold, fear, pain and asphyxia—were studied.

When the effect of cold was studied, the subject lay scantily clad on a bed for one-half hour with the temperature of the hand stabilized at 30° C. The window was then opened and the room temperature allowed to fall to between 15° and 18° C. After a short period of cold, the window was closed and the room temperature allowed to rise.

Fear was produced by suggesting to the patient some painful or repulsive procedure which was to be carried out. The subject was unaware that his reactions were being noted.

Pain was precipitated, with the consent of the subject, through faradic stimulation of the skin and other measures.

Partial asphyxia was brought about by having the subject breathe gas with a reduced concentration of oxygen (between 7.1 and 15 volumes per cent) delivered from a Tissot spirometer. Rebreathing was avoided. After the experiment had been concluded, the oxygen content of the gas mixture was analyzed by the Haldane apparatus. In the experiments in which asphyxia was employed the temperature of the bath in which the hand was immersed was maintained between 32° and 34° C. The subject, after resting for half an hour, was connected to the spirometer tubing, but breathed room air for a period of 10 to 15 minutes while determinations of blood flow were being made. After a stable flow had been recorded during this control period, the valve was turned to the spirometer. Precautions were taken to prevent the subject from being aware of the change in gas mixture. The period of partial asphyxia lasted for 10 to 40 minutes. During this time, observations on blood flow were made at frequent intervals. The valve was then turned to room air, and a second series of control observations was made. Between 4 and 9 measurements of the volume flow of blood were taken at each determination during the experiment. On the average, 8 groups of determinations were made during the period of asphyxia, while 9 groups of determinations were made during the control periods. The volume of blood flows listed in Table I are each, therefore, the average of approximately 60 measurements.

A. TRAUMATIC STIMULI

Results

Cold uniformly reduced the volume flow of blood even though the hand was maintained at constant temperature. Figure 1 illustrates the reduction in circulation when the room temperature was lowered from 22° to 16° C. Similar results

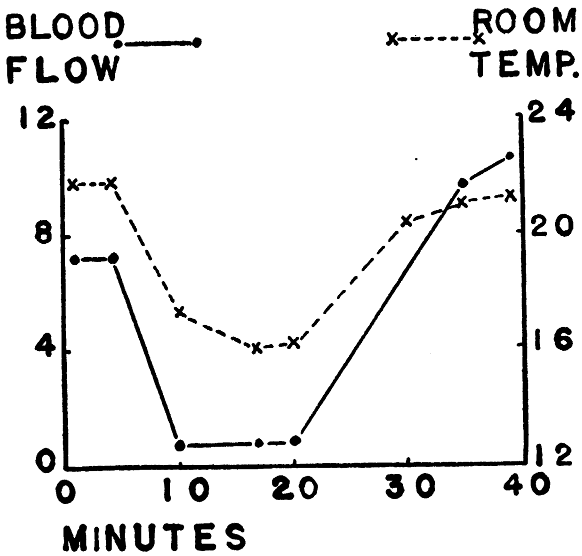

FIG. 1. EFFECT OF LOWERING ROOM TEMPERATURE ON VOLUME FLOW OF BLOOD THROUGH THE HAND MAINTAINED AT CONSTANT TEMPERATURE (32.4 ± .3° C.).

Ordinates: cubic centimeters of blood flow per 100 cc. hand volume per minute and room temperature, degrees Centigrade. Abscissae: time, minutes. Solid line: blood flow; interrupted line: room temperature.

were obtained in each experiment on 3 different individuals.

The effect of pain produced by the inflation of a balloon which had been inserted, with the patient's consent, into an ileostomy opening [1] is illustrated in Figure 2. The balloon was inserted at *A*. Manipulation at *B* and *C* did not alter the blood flow. Inflation of the balloon inside the ileostomy (*D*) now caused the patient to complain of cramp-like pain, and within a few minutes he became nauseated. The rate of blood flow diminished sharply and continued to be depressed as long as the cramps persisted. It returned promptly to the original level when the balloon was deflated. Eight experiments with various types of pain gave essentially similar results.

Figure 3 demonstrates the effect of apprehen-

[1] The patient had had an ileostomy performed 18 months previously for ulcerative colitis. The colon had been removed 6 months later. Present observations were made, with the consent of the patient, 2 weeks after a minor operation.

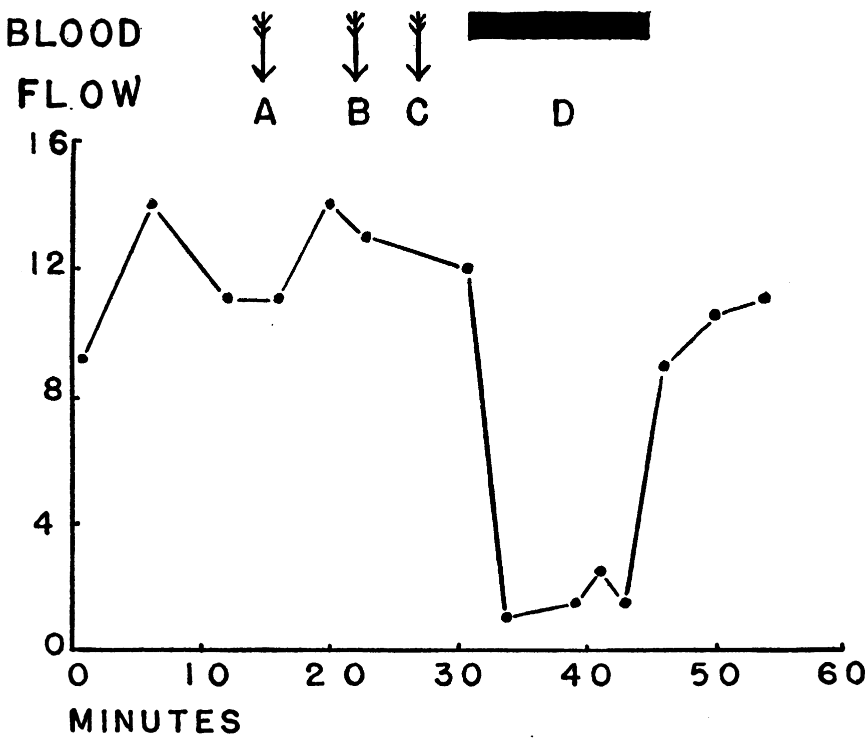

FIG. 2. EFFECT OF PAIN, PRODUCED BY INFLATION OF A BALLOON IN THE ILEUM, ON THE VOLUME FLOW OF BLOOD THROUGH THE HAND MAINTAINED AT CONSTANT TEMPERATURE (31.6 ± .4° C.).

Ordinates: cubic centimeters of blood flow per 100 cc. hand volume per minute. Abscissae: time, minutes. Arrow *A* indicates the insertion of the balloon into the ileum. The balloon was manipulated at arrows *B* and *C*. The broad black line, *D*, indicates the inflation of the balloon.

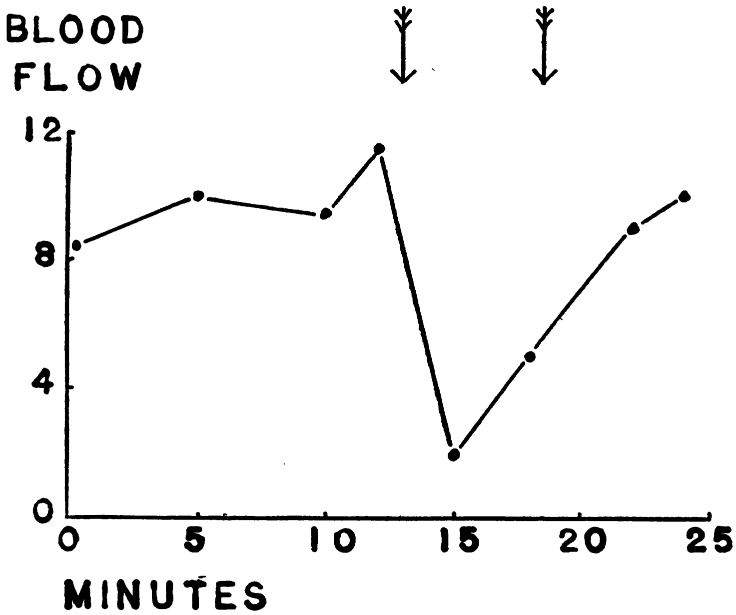

FIG. 3. EFFECT OF APPREHENSION ON VOLUME FLOW OF BLOOD THROUGH THE HAND, MAINTAINED AT CONSTANT TEMPERATURE.

Ordinates: cubic centimeters of blood flow per 100 cc. hand volume per minute. Abscissae: time, minutes. At the first arrow, the subject was informed that a balloon was to be inserted into her colostomy. The balloon was actually inserted at the second arrow.

sion on the rate of blood flow. The subject[2] was accustomed to the apparatus by previous experiments. As soon as the rate of flow became relatively stable, the subject was informed that a balloon was to be inserted into her colostomy. She made no comment, but her facial expression revealed apprehension and repugnance as the balloon was being prepared and the dressing removed from the colostomy. The volume flow of blood declined from 10 to 2 cc. per minute within 2 minutes (Figure 3, first arrow). The return of the circulation was not affected by the presence of the balloon in the colon (second arrow). A decrease in blood flow from emotional trauma so frequently accompanied experiments designed for other purposes that it was eliminated only with great difficulty. Not only fear and apprehension but embarrassment, disgust, anxiety and annoyance reduced the rate of blood flow. Loud noises and interruptions were carefully avoided, and the patient was even cautioned against spontaneous thoughts of a high emotional content.

Partial asphyxia[3] generally produced an increase in the volume flow of blood, although frequent reductions in circulation were noted. The experimental data are listed in Table I. No correlation of the direction of the change with the concentration of oxygen was observed. In Experiment 6, the blood flow increased 37 per cent when the oxygen was reduced to 7.1 volumes per cent. It *decreased* 38 per cent in Experiment 15 with a similar concentration (7.3 volumes per cent). In the same individual (J. C. S.) a concentration of 13.2 volumes per cent was associated with an increase of 45 per cent on one occasion (Experiment 2), while on another occasion (Experiment 14), with practically the same amount of oxygen, the blood flow decreased by 12 per cent.

Since it is recognized that asphyxia stimulates the sympathetic nervous system (4), experiments were conducted on patients in whom the vasoconstrictors to the upper extremity had been previously interrupted because of Raynaud's disease.

[2] The subject had had a colostomy performed 3 weeks previously for relief of a rectal stricture.

[3] The authors wish to express their appreciation to Dr. D. B. Dill of the Harvard Fatigue Laboratory for his assistance in the experiments on asphyxia.

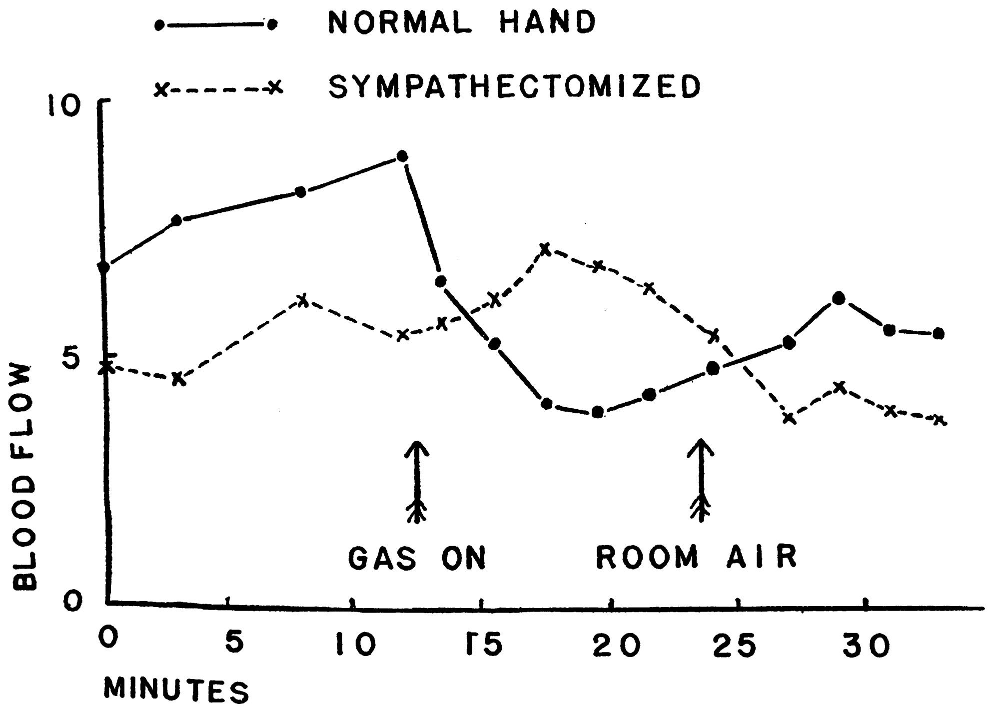

FIG. 4. EFFECT OF ASPHYXIA ON THE VOLUME FLOW OF BLOOD THROUGH THE HANDS MAINTAINED AT CONSTANT TEMPERATURE.

Solid line: left hand, normal (33.0 ± .4° C.). Interrupted line: right hand sympathectomized (33.4 ± .6° C.). Ordinates: cubic centimeters of blood flow per 100 cc. hand volume per minute. Abscissae: time, minutes.

In each experiment (see Table I), asphyxia brought about an increase in the blood flow through the sympathectomized hand. In two patients, in whom only one extremity had been sympathectomized, the effect of asphyxia on the circulation was determined in both hands simultaneously. Figure 4 illustrates the reaction which one of the patients presented. With asphyxia, induced by breathing a gas mixture containing 11.88 per cent oxygen, the blood flow through the normal hand declined abruptly, while at the same time it increased on the sympathectomized side. The gradual decline of blood flow through the hand in which the vasomotor nerves had been interrupted may have been the result of adrenal secretion (5). In the other patient (Table I, Experiment 19) the blood flow increased by 66 per cent on the sympathectomized side, while only a slight change was noted on the side with intact vasomotor innervation.

B. SURGICAL SHOCK

Before attempting to determine whether or not the peripheral circulation in shock is reduced, it is necessary to define a normal blood flow.

There are many factors which influence the volume flow of blood through the hand in the normal individual. The effect of cold, pain, fear and asphyxia have been shown above. In a previous communication, the part played by temperature in controlling the circulation has been discussed (2). The basal metabolic rate also has an important effect (6). In addition to the various factors which are recognized, there may be many others, physiological or pathological, which have not been elucidated. Without recognizing *all* the factors, it is impossible adequately to control the variables so that basal conditions can be maintained. We were, therefore, forced to a numerical comparison of the average rates of blood flow in normal individuals and patients in shock under a given set of

TABLE I

Effect of asphyxia on volume flow of blood

Experiment number	Name	Age	Sex	O_2 concentration	Control periods				Asphyxia periods				Per cent change in blood flow	Remarks
					Blood flow	Respiration	Pulse	Blood pressure	Blood flow	Respiration	Pulse	Blood pressure		
		years		*volumes per cent*	*cc. per minute per 100 cc. hand volume*	*per minute*	*per minute*	*mm. Hg*	*cc. per minute per 100 cc. hand volume*	*per minute*	*per minute*	*mm. Hg*		
								NORMAL						
1	J. C. S.	25	M.	15.0	*12.1*	13	56		*13.2*	8	60		+ 9	Respiration deep.
2	J. C. S.	25	M.	13.2	*6.1*	12	50	110/68	*8.9*	8	55	100/64	+45	Lips dusky. Respiration deep with inspiratory pause.
3	J. C. S.	25	M.	10.0	*9.2*				*10.9*				+18	
4	D. B. D.	44	M.	11.5	*6.9*	18	72	120/70	*8.7*	11	84	122/76	+26	Arterial oxygen saturation 59 per cent.
5	D. B. D.	44	M.	10.7	*3.2*	16	56	104/70	*3.9*	7	70	108/68	+22	Moderate cyanosis of lips
6	D. B. D.	44	M.	7.1	*2.4*	14	76	120/80	*3.3*	20	100	130/70	+37	Lips and nail beds cyanotic. Unconscious. Convulsive movements.
7	F. C.	22	M.	10.7	*12.5*	20	60	118/76	*14.0*	18	80	124/72	+11	Lips and fingers cyanotic.
8	F. C.	22	M.	10.7	*14.0*	18	60	122/76	*19.6*	18	84	128/68	+40	Lips and fingers cyanotic
9	J. L.	21	M.	11.6	*1.2*	20	90	130/80	*4.4*	20	108	134/78	+260	Arterial oxygen saturation 51 per cent. Lips and fingers slightly cyanotic.
10	J. L. S.	33	M.	13.0	*6.2*	14	66	128/84	*6.2*	12	80	134/80		
11	J. L. S.	33	M.	13.5	*2.8*	16	72	130/88	*1.5*	14	78	130/85	−46	
12	J. L. S.	33	M.	10.2	*3.7*				*2.9*				−21	
13	J. L. S.	33	M.	10.0	*7.6*				*4.6*				−39	
14	J. C. S.	25	M.	13.1	*5.7*	12	48	100/62	*5.0*	10	60	110/64	−12	Lips dusky. Slightly dizzy.
15	H. D.	21	M.	7.3	*8.3*	16		130/50	*5.1*	20			−38	Arterial oxygen saturation 46 per cent. Lips cyanotic. Convulsive movements.
								SYMPATHECTOMIZED						
16	P. R.	24	F.	15.0	*6.1*	18	60	110/54	*9.3*	10	72	108/52	+52	Slight dizziness.
17	P. R.	24	F.	12.5	*5.7*	16	60	110/62	*9.1*	22	60	110/60	+60	Nail beds dusky. Dizzy. Nauseated.
18	P. R.	24	F.	11.7	*6.1*				*8.3*				+36	Slight cyanosis.
19	M. E. B.	23	F.	8.1?	*1.7* *7.7*	(Normal hand) (Sympathectomized)			*1.9* *12.8*				+12 +66	Exact gas mixture not known because of faulty nose clip.
20	E. L.	22	F.	11.9	*6.3* *4.5*	(Normal hand) (Sympathectomized)			*4.9* *6.0*				−22 +33	Cyanosis of lips.

conditions, with the realization that many variables might be operative.

An additional method of ascertaining whether or not the peripheral circulation is reduced in shock is to evaluate one of the functions of the blood flow, e.g., the nutrition of the tissues. The volume of blood flow through the hand at any specific temperature is determined, within certain limits, first, by the metabolic needs of the hand, and secondly, by the needs of the body for thermal regulation (2). It is impossible to separate the total flow into a part which is utilized in heat loss and another portion used for tissue nutrition. In the sympathectomized hand, however, the heat-regulating mechanism is absent. The entire blood flow is probably related to the tissue needs (2). By noting the rate of blood flow through the sympathectomized hand at a specific temperature, it is possible to state what the " normal " circulation from the standpoint of tissue nutrition at that temperature should be. Additional information in relation to the nutrition of the body tissues can also be gained by noting the differences between the oxygen content of the arterial and the venous blood.

Another index of the state of tissue nutrition is afforded by the phenomenon of reactive hyperemia. It has previously been shown (2) that the blood flow debt, created through obstruction of the arterial inflow, is exactly repaid during the period of reactive hyperemia. The studies were made on the sympathectomized hand in which the normal blood flow presumably just satisfied the tissue demands. When the tissue needs were increased through deprivation of arterial blood, the increase in blood flow after release of the tourniquet not only indicated the greater tissue demand, but also demonstrated the ability on the part of the circulation to reimburse the tissues for this blood flow debt. Reactive hyperemia was therefore studied in patients in order to learn whether or not it was possible for the circulation in surgical shock to meet increased demands of the tissues.

Results

The peripheral circulation in the normal individual is represented in Figure 5. The patient, N. G. (Case 1, Table II) was a 47 year old Armenian clerk, who was studied in the laboratory 2 days after an operation, under local anesthesia, for ligation and injection of varicose veins. He was ambulatory and suffering only mild inconvenience. His mouth temperature was 99.1° F., and his pulse, respiration and blood pressure were normal. As the temperature of the hand was raised, the rate of blood flow increased. When the temperature of the hand was at 37.4° C., the volume flow of blood reached 18 cc. per 100 cc.

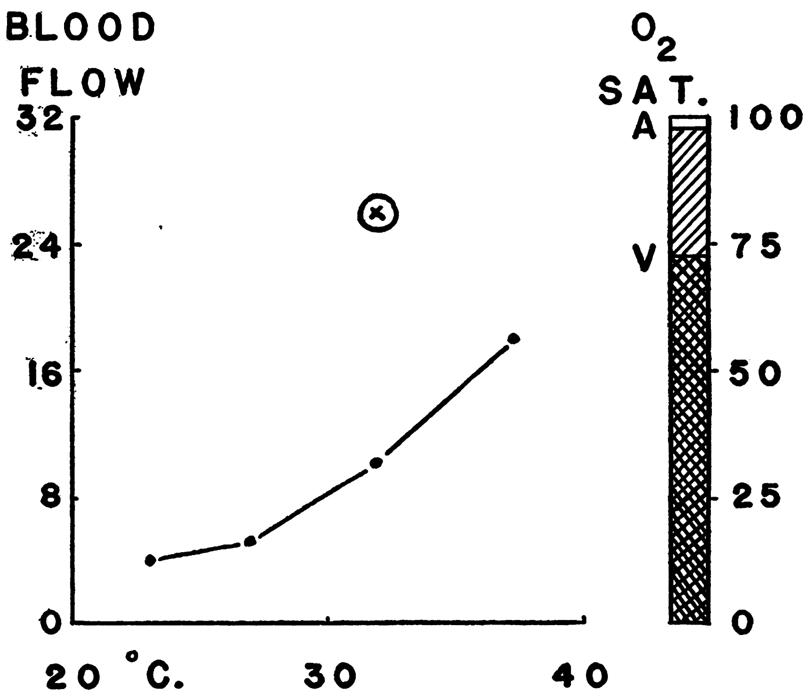

Fig. 5. Normal Control.

Solid line: effect of increasing the temperature of the hand on the volume flow of blood. Ordinates: cubic centimeters of blood flow per 100 cc. hand volume per minute. Abscissae: temperature of bath in which hand was immersed. The cross surrounded by the circle indicates the flow 10 seconds after release of a tourniquet which had occluded the circulation at 31.8° C. for 5 minutes. Column at right: oxygen saturation of *A*, the arterial, and *V*, the venous blood. The samples of arterial and venous blood were taken at the conclusion of the observations.

hand volume per minute. The results in 2 other normal patients (Cases 2 and 3) are summarized in Table II. The average blood flow at 37° C. in 26 normal patients (data previously obtained) was 9.8 cc. per 100 cc. hand volume per minute. The values ranged from 6 to 26 cc. per minute. In 9 sympathectomized hands, in which the blood flow just equalled the nutritional needs (vide supra), the average flow at 37° C. was 7.8 cc. per 100 cc. hand volume per minute. The individual readings varied only between 5 and 10 cc. per minute. From these data, the normal blood flow at 37° C. was considered, for purposes of comparison, to be above 7 cc. per minute, per 100 cc. hand volume.

The cross surrounded by the circle in Figure 5, indicates the volume flow of blood, 26 cc. per 100 cc. hand volume per minute, determined 10 seconds after release of a tourniquet which had occluded the circulation for 5 minutes at 31.8° C. When the tissue needs were increased by temporary deprivation of blood flow, prompt and effective compensation followed release of the obstruction. Similar results were obtained in the normal controls (Cases 2 and 3 and confirm the data previously obtained in sympathectomized hands (2)).

The oxygen saturation of the arterial blood (Figure 5, A) was 99 per cent. The saturation of the venous blood, 73 per cent (Figure 5, V), indicated that the circulation was quite adequate. The normal range of the venous oxygen saturation is between 60 and 85 per cent (7).

In comparison to this normal control, Figure 6 represents the circulation in a typical case of surgical shock. The patient, M. T. D., was an Irish housewife of 54, who was suffering from intestinal obstruction due to carcinoma of the sig-

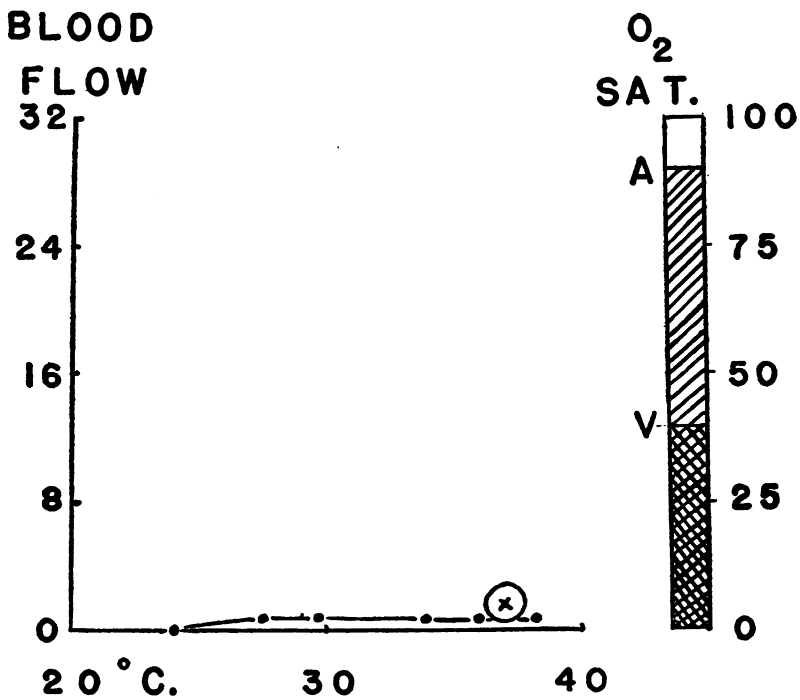

FIG. 6. SURGICAL SHOCK.

Solid line: effect of increasing the temperature of the hand on the volume flow of blood. Ordinates: cubic centimeters of blood flow per 100 cc. hand volume per minute. Abscissae: temperature of bath in which hand was immersed. The cross surrounded by the circle indicates the flow 10 seconds after release of a tourniquet which had occluded the circulation at 36.8° C. for 5 minutes. Column at right: oxygen saturation of *A*, the arterial, and *V*, the venous blood. The samples of arterial and venous blood were taken at the conclusion of the observations.

TABLE II

Effect of general condition on volume flow of blood

Case number	Name	General condition	Sex	Age	Clinical diagnosis	Room temperature	Temperature	Pulse	Respiration	Blood pressure	Blood flow at 37° C.	Blood flow during reactive hyperemia	O_2 saturation Arterial	O_2 saturation Venous	CO_2 content	Comment
				years		° *C.*	° *F.*			*mm. Hg*	*cc. per minute*	*cc. per minute*	*per cent*	*per cent*	*volumes per cent*	
1	N. G.	Good	M.	47	Varicose veins 2 days after ligation and injection	22.1	99.1	80	22	110/80	18.0	26	99.0	73.0	43.0	Normal control.
2	W. McD.	Good	M.	48	Cervical abscess 5 days after incision and drainage	22.1	99.1	86	20		7.0	13.2	87.0	67.0		Normal control.
3	M. C.	Good	M.	23	Inguinal hernia preoperative	23.8	98.6	66	20	130/80	14.0	20.0	94.0	79.0	44.0	Normal control.
4	M. O.	Poor	F.	46	Volvulus of small intestine	21.5	101.6	138	20	78/60	1.6	3.6		41.2	53.0	Severe shock.
								116	16	140/70	7.6	20.0				Immediately after 500 cc. 6 per cent acacia.
5	A. M.	Poor	F.	45	Pelvic sarcoma 7 days after exploratory laparotomy	21.7	103.2	135	24	95/70	3.5			32.5	35.1	Died next day.
6	M. T. D.	Poor	F.	54	Carcinoma of sigmoid, intestinal obstruction, pelvic peritonitis	24.3	101.0	126	30	80/?	.8	1.0	90.0	41.5	53.0	4 hours after cecostomy. Died 5 hours later.
7	K. S.	Poor	F.	66	Diverticulitis of sigmoid 3 days after cecostomy	22.0	100.0	80	30	135/44	5.7	6.5	96.7	77.0	57.2	Barely recovered after 12 weeks. Gangrene of wound. Pressure necrosis of buttocks.
8	J. M.	Poor	M.	53	Carcinoma of stomach, exploratory laparotomy	24.5	101.0	120	22	100/62	8.0	21.0	96.0	32.6	45.5	1 day preoperative.
						25.4		120	28	120/90	1.3	2.2				During operation.
						24.4	100.6	140	22	86/56	4.0	9.0	85.2	58.7	32.5	4 hours postoperative.
						25.2	101.0	110	22	112/64	8.0	17.0				3 days postoperative. Final recovery.
9	A. L. S.	Fair	M.	62	Carcinoma of sigmoid, cecostomy followed by combined abdominoperineal resection of rectum	22.3	98.6	80	20	124/76	3.8	9.0	98.6	31.1	63.5	10 days after cecostomy.
						24.9	100.0	80	20	120/80	8.3	37.0		35.7	64.0	16 days after cecostomy.
						25.2	98.6	84	20	120/70	9.5	30.0	90.8	80.0	48.5	24 days after cecostomy. Combined abdominoperineal resection of rectum 7 days later. Recovery.
10	J. B.	Poor	M.	47	Carcinoma of bile ducts. Before exploratory laparotomy	22.7	98.1	60	16	140/80	6.5	7.1	98.0	72.0	49.0	Poor general condition. Exploratory laparotomy sent blood pressure to 80/50. Recovery.
11	A. B.	Fair	M.	55	Tabes, luetic aortitis, arsenic poisoning	22.5	98.0	100	20	80/40	13.0		96.0	80.0	37.9	Recovery from low blood pressure. Sudden collapse 24 hours later.

moid. Perforation with pelvic peritonitis had occurred. She was studied on the ward, 4 hours after a cecostomy had been performed under local anesthesia. At this time her temperature was 101° F., her pulse 126, respiration 30, and blood pressure 80/?. Her skin was cold and clammy. Her tongue was dry. She was restless and kept crying for water. Her face was grey and drenched in sweat. Her blood flow failed to increase when the temperature of the hand was raised. Even at 37° C. the maximum flow was only 0.8 cc. per 100 cc. hand volume per minute. After release of a tourniquet, applied for 5 minutes at that temperature, the reactive hyperemia amounted to only 1.0 cc. Although the oxygen saturation of her arterial blood was close to normal (90 per cent), the venous blood, taken at the conclusion of the observations, was only 41.5 per cent saturated with oxygen. In spite of a second transfusion, she failed to rally and died 5 hours later.

In Table II are listed the significant findings in 5 additional patients in poor condition (Cases 4, 5, 7, 8, and 9). In no case was the blood flow higher than 6.5 cc. per minute at 37° C., and the reactive hyperemia was markedly reduced. The oxygen saturation of the venous blood was low in every patient but one (Case 7). In 2 of the patients the process of recovery was followed (Cases 8 and 9). As the clinical condition of the patient improved, the volume flow of blood increased. The reactive hyperemia and the oxygen content of the venous blood indicated that the circulation had become more adequate to care for the tissue needs.

Precisely which of the traumatic stimuli was responsible for the reduction in circulation in any particular patient, it was difficult to say. A certain degree of apprehension was probably associated merely with the patient's presence in the hospital. Cold was generally avoided by adequate protection. The effect of pain, however, was frequently observed. Even though the patient's consciousness might have been dulled by a general anesthetic, the physiological effects of pain could be discerned. The reaction of the circulation through the hand to manual dilatation of the pyloric sphincter is illustrated in Figure 7. The patient, J. P. F., male, age 41, was being operated upon for a gastro-jejuno-colic fistula under avertin (100 mgm. per kilo) and ether anesthesia. At the time indicated by the arrow the pylorus was dilated by the finger of the surgeon, inserted through an opening in the wall of the stomach. The rate of blood flow, which was originally rapid from the ether anesthesia, dropped to 2.4 cc. per minute. Traction on the mesentery and manipulation of the abdominal contents produced comparable effects.

The effect of asphyxia is shown in Figure 8. This patient was markedly emaciated from pulmonary tuberculosis. His right lung had been collapsed by a thoracoplasty done in 3 stages. After the third operation the tuberculous process had extended to the opposite side with extensive involvement of the left lung. Although he was unaware of any change in the mixture of gas which he was receiving, reduction of his oxygen intake caused a marked decrease in his peripheral circulation.

A reduced effective blood volume, either from hemorrhage, transudation, exudation or dehy-

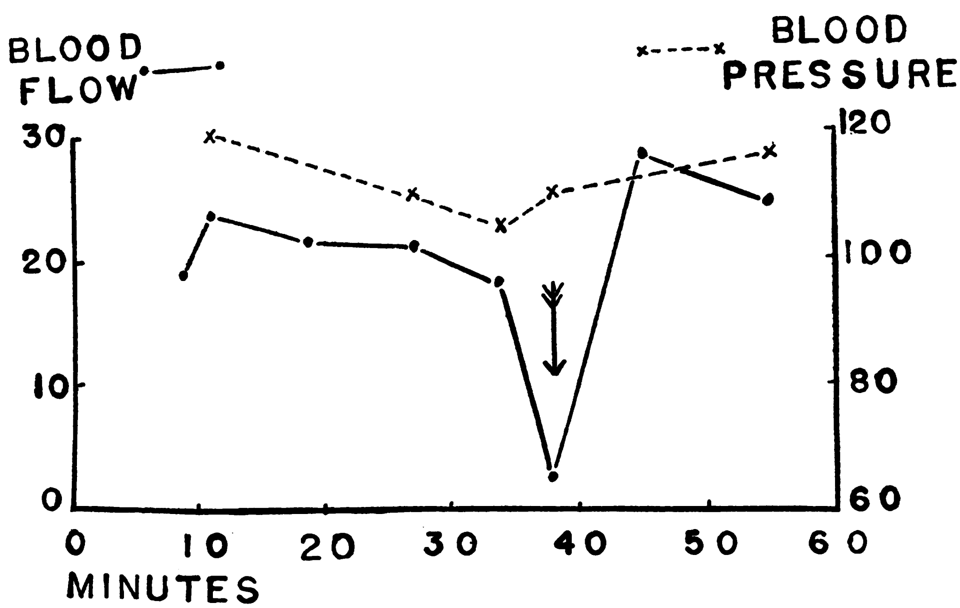

Fig. 7. Effect of Dilating Pyloric Sphincter under Avertin and Ether Anesthesia on the Volume Flow of Blood through the Hand Maintained at Constant Temperature (34.7° C.).

Solid line: blood flow; interrupted line: blood pressure. Ordinates: cubic centimeters of blood flow per 100 cc. hand volume per minute and blood pressure, mm. mercury. Abscissae: time, minutes. The arrow indicates the time of dilatation of the pyloric sphincter.

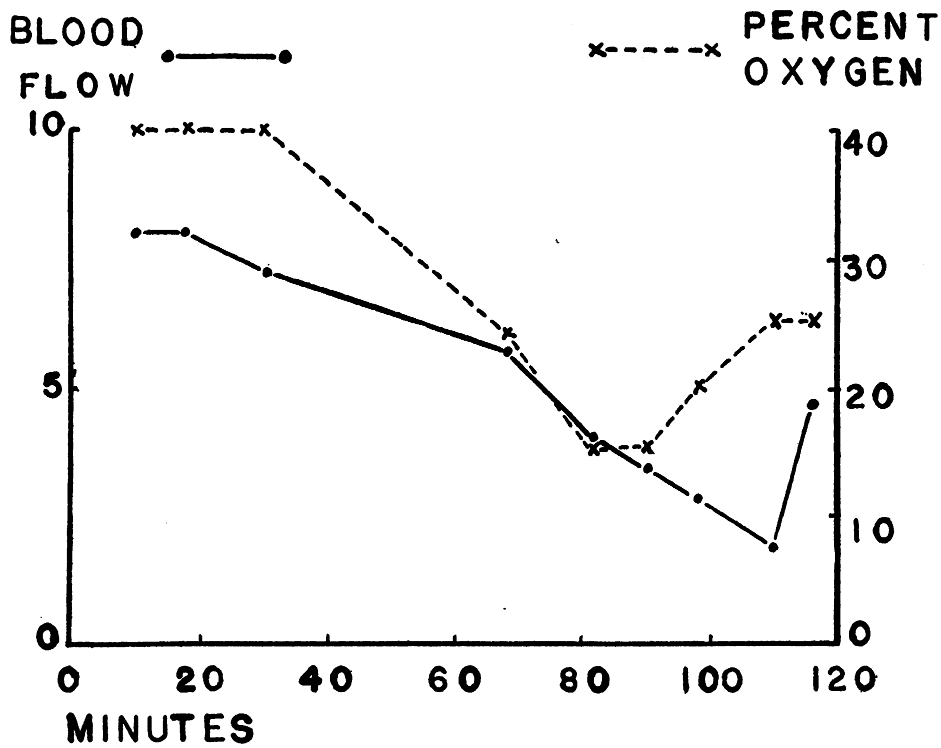

FIG. 8. EFFECT OF DECREASING THE CONCENTRATION OF OXYGEN IN AN OXYGEN TENT ON THE VOLUME FLOW OF BLOOD THROUGH THE HAND MAINTAINED AT CONSTANT TEMPERATURE (32.4 ± .2° C.).

Solid line: blood flow; interrupted line: per cent oxygen in tent. Ordinates: cubic centimeters of blood flow per 100 cc. hand volume per minute, and per cent oxygen mixture in tent. Abscissae: time, minutes.

dration, was almost invariably present in the patients who were in poor condition. The effect of restitution of a diminished blood volume on the peripheral blood flow is pictured in Figure 9. This patient, M. O., was apparently suffering from intestinal obstruction. At the time she was first observed, she presented the classical picture of shock. Her temperature was 101.6° F., her pulse 138, respiration 20 and blood pressure 78/60. Her extremities were cold. She was very restless and complained of severe thirst. At 37° C. the volume flow of blood through her hand was only 1.6 cc. per minute per 100 cc. hand volume. Reactive hyperemia raised the flow to 3.6 cc. per minute. Her venous blood was 41.2 per cent oxygenated. She was given 500 cc. of 6 per cent acacia in normal saline intravenously. As shown in Figure 9, her blood flow increased gradually to 7.6 cc. per minute. At the end of the injection her extremities were warm and dry. Her blood pressure had risen to 140/70 and her pulse had fallen to 116. Now, after release of a tourniquet applied for 5 minutes, the circulation increased to 20 cc. per minute, in comparison with 3.6 cc. per minute 2 hours earlier. She relapsed into shock again a few hours later. Postmortem examination revealed a volvulus of the entire small intestine. There were 2 liters of fluid present in the peritoneal cavity. The protein concentration of this fluid was 3.8 per cent. Her blood volume had probably been reduced by this loss of blood plasma into the peritoneal cavity.

DISCUSSION

It has previously been shown (2) that the circulation to the hand is under a dual control. Through the vasomotor nerves, the flow of blood is modified in accordance with the needs of the body as a whole. After removal of this control

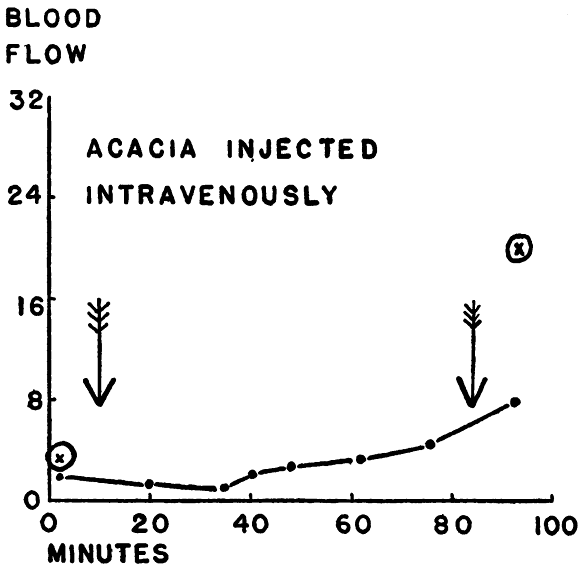

FIG. 9. EFFECT OF AN INTRAVENOUS INJECTION OF 500 CC. OF 6 PER CENT ACACIA IN NORMAL SALINE ON THE VOLUME FLOW OF BLOOD THROUGH THE HAND MAINTAINED AT CONSTANT TEMPERATURE (30.6 ± .2° C.).

Ordinates: cubic centimeters of blood flow per 100 cc. hand volume per minute. Abscissae: time, minutes. The crosses surrounded by the circles indicate the extent of the reactive hyperemia before and after the injection. Between the arrows the patient received intravenously 500 cc. of 6 per cent gum acacia in normal saline solution.

by sympathectomy, the second factor is disclosed. The blood flow is then determined by the metabolic demand of the tissues. When the metabolism of the tissues is increased, by raising the temperature of the hand, the blood flows more rapidly. After release of a tourniquet, the blood flow is increased until the circulatory debt has been repaid.

Through vasoconstriction, the body is enabled to mobilize its circulation for the conservation of heat (8) or to divert the blood to the more vital centers in an emergency (9). At the same time, the circulation to the peripheral regions may be seriously reduced.

In the present experiments, the metabolic demands of the tissues of the hand were stabilized by maintaining it at constant temperature. It was then shown that traumatic stimuli, such as cold (see Figure 1), pain (see Figure 2) and fear (see Figure 3), produced a decrease in the volume flow of blood. These quantitative findings confirm the qualitative observations of many investigators. The blood flow was studied with the metabolic needs stabilized in order to illustrate to what extent the demands of the peripheral tissues might be sacrificed to the needs of the body as a whole.

With asphyxia, a variable effect was observed (see Figure 4, and Table I). In the hand, with vasomotor control intact, a decrease in blood flow was observed in 6 cases, while an increase in circulation was found in 11 cases. Adequate confirmation for either result is furnished by the literature on the subject. Some investigators (10) have found an increase, while others (11) have noted a decrease in the peripheral circulation. The explanation for these conflicting observations, we believe, is afforded by the experiment illustrated in Figure 4. The blood flow decreased in regions subject to vasomotor control. It was simultaneously increased in the sympathectomized hand. It will be observed in Table I that the systolic blood pressure was raised but slightly, while the diastolic blood pressure more frequently was lowered during the period of asphyxia. In the 12 experiments in which the blood pressure was determined, the maximum rise in systolic pressure was only 10 mm. of mercury. In Experiment 16, while the blood flow increased by 50 per cent as a result of the asphyxia, the blood pressure actually declined. It is unlikely that the head of arterial pressure affected the results. It is recognized that asphyxia stimulates the sympatho-adrenal system (4). The resultant vasoconstriction reduces the circulation. Asphyxia of the degree employed in these experiments, however, also decreased the oxygen tension in the arterial blood (12, and cf. Experiments 4, 9 and 15, Table I). According to the concept previously established, (2), the flow of blood is modified by the metabolic demand of the tissues. With less oxygen available per unit volume of blood during asphyxia, an additional supply of blood would be required in order to maintain an equilibrium in the tissues. Two forces are therefore simultaneously called into play—reflex vasoconstriction and local vasodilatation. The final result, so far as the circulation through the hand is concerned, depends upon which of the two forces is dominant. In these experiments no clear indication was found as to which reaction would prevail, although when the subject was apprehensive, a decreased blood flow was generally observed (cf. Figure 3). As far as the harmful effects of asphyxia on the oxygen supply to the tissues is concerned, the results are clear. Not only does the reduced oxygen saturation of the arterial blood necessitate a more rapid circulation, but through reflex vasoconstriction the supply of blood at the same time may even be reduced.

A reduction in the circulating blood volume has been recognized as a dominant feature in surgical shock since the work of Keith (13) and Robertson and Bock (14). Because the factors recognized to be of significance in the production of shock, such as cold, pain, fear, asphyxia, hemorrhage and dehydration are also stimulants of the sympathetic nervous system, the hypothesis was advanced (15) that the reduction in blood volume found in shock, where it could not be accounted for by hemorrhage or transudation (16) might be the result of sympathetic hyperactivity. In a series of experiments on cats, a decrease in blood volume was found to result from prolonged hyperactivity of the sympathetic nervous system. Since a reduction of the circulation leads to tissue anoxemia and an increase in the permeability of the capillaries (17), it was suggested that vasoconstriction with the attendant reduction of blood flow to large areas of the body might be the mechanism for this decrease in blood volume. The experiments here reported on the effect of cold, pain, fear, and asphyxia on the volume flow of blood through the hand indicate to what extent vasoconstriction may deprive the tissues of an adequate circulation.

The decreased volume of blood flow to the hand found in cases of surgical shock (Figure 6) is an objective record of a well recognized clinical observation. In experimental shock, produced by a variety of methods, Erlanger and his collaborators (1) invariably found an increased peripheral resistance. A diminished rate of blood flow through the salivary gland from hemorrhage and tissue abuse was consistently observed by Gesell (18). These investigators concluded that a reduced circulation is of fundamental importance in the development of shock.

If the volume flow of blood is decreased while the oxygen consumption of the tissues remains the same, it is to be expected that more oxygen should be removed from the blood during its passage through the tissues. Consequently, the oxygen content of the venous blood should be decreased. The observations reported above in Figure 6 and Table II accord with this expectation. In the more severe cases of shock, the oxygen saturation of the venous blood was below 50 per cent. These findings are in accord with the experimental observations of Aub and Cunningham (19) and Blalock and Bradburn (20).

The inability of the tissues to obtain an adequate supply of blood was indicated by the observations on reactive hyperemia. In the normal subject (Figure 5), the circulation increased rapidly after release of the tourniquet. In patients who were in shock, a comparable increase was not observed (Figure 6 and Cases 4, 5, 7, 8, and 9, Table II). In spite of the fact that the needs of the tissues of the hand were increased during the time that the tourniquet was applied, reflex vasoconstriction was sufficiently powerful to prevent an effective increase in blood flow after the arterial circulation had been released. Patient J. M. (Case 8, Table II) furnishes an illustration of this phenomenon. Before operation, although he was in poor condition, his blood flow increased to 21 cc. per minute during the reactive hyperemia which resulted from application of the tourniquet for 5 minutes. The following day, at the end of the exploratory laparotomy, the maximum increase in blood flow was only to 2.2 cc. Four hours later, the reactive hyperemia had increased to 9.0 cc. and in 3 days to 17 cc.

This patient also illustrates the fact that the arterial blood pressure does not necessarily indicate the adequacy of blood flow to the tissues. Before operation his blood pressure was 100/62 and his blood flow 8 cc. per minute. At the end of operation even though his blood pressure had *risen* to 120/90 his blood flow had *decreased* to 1.3 cc. per minute. Clinically he presented the picture of surgical shock. His pulse was feeble, his color grey, and his skin cold and moist. Through vasoconstriction during the operation his blood pressure had been maintained but at the expense of his peripheral tissues. The blood pressure reading presented a false indication of his general condition. Four hours later, although his blood pressure had fallen to 86/56, his blood flow had increased to 4 cc. per minute. In 3 days it had risen to the preoperative level, 8 cc. per minute, and he progressed to final recovery. The blood pressure in Patient A. B. (Case 11, Table II) was only 80/40, yet the circulation at 13 cc. per minute was quite adequate. In comparison, Patient M. J. D. (Case 6, Table II), at the conclusion of operation had a blood pressure of 125/80, but her blood flow was only 1.6 cc. per minute. She went on to death in 10 hours. The blood pressure is an expression of the quantity of blood in the circulation and of the peripheral resistance. If the blood volume is reduced, the blood pressure may still be sustained by increasing the peripheral resistance through vasoconstriction. With vasoconstriction, however, the nutrient flow to the tissues becomes reduced. If attention is focused chiefly on the level of the arterial pressure, the blood supply to the tissues, the ultimate goal of the circulation, may be overlooked.

The use of adrenalin or ephedrin in the treatment of surgical shock furnishes an example of this fact. The blood pressure may be increased, but only at the expense of the blood flow. The observations that adrenalin can produce shock (21) and cause a reduction in blood volume (15) accord with the clinical opinion as to its therapeutic ineffectiveness. Where the lowered blood pressure is the result of a reduced volume of blood in the vascular bed, physiological treatment necessitates the administration of blood or some blood substitute. The results of an intravenous injection of acacia in the treatment of a reduced plasma volume is illustrated in Figure 9. A comparable reaction from the administration of blood or acacia was noted by Gesell (18) in experimental shock.

The objection may be raised that these studies on the blood flow through the hand need not necessarily apply to the circulation through other areas of the body, such as the splanchnic area and the muscles. It would be difficult, if not impossible, in man, to study the flow of blood in these areas. We have, however, the clinical evidence of constricted vessels in the splanchnic area and the periphery (22). Finally, we have the low oxygen content of the mixed venous blood (20) and the decreased cardiac output (23) in experimental shock. These observations indicate that the reduced blood flow in the hand, observed in clinical cases of surgical shock, represents a deficiency of circulation which is probably general throughout the body.

The "emergency function" of the sympathoadrenal system was first emphasized by Cannon in 1914 (24). According to this concept, the sympathetic nervous system is thrown into activity when the organism is exposed to danger or to the expectation of harm. Under such circumstances, it enables the organism to survive. Experiments on cats which have survived total removal of the sympathetic nervous system have demonstrated that they can no longer adjust to various stresses in a normal manner. They readily succumb to cold and to excessive heat (25). Struggle causes them to faint (26). They are extremely sensitive to hemorrhage (27) and to asphyxia (28). The sympathetic nervous system appears to be necessary to enable the organism to adjust itself to an emergency. In a crisis, the non-essentials are sacrificed. The experiments and observations which have been presented in this paper indicate in what manner the needs of the tissues, not essential for the immediate survival of the body as a whole, may be sacrificed in an emergency. But if the reactions to the crisis are too severe and protracted, then vasoconstriction, the very mechanism by which the organism strives to survive, may lead to its destruction.

SUMMARY

1. Traumatic stimuli, such as cold, fear, and pain reduced the volume flow of blood through the hand maintained at constant temperature. The decrease in blood flow which resulted from intestinal manipulation was not prevented by general anesthesia.

2. Asphyxia brought about an increase in blood flow in the sympathectomized hand in 5 cases. In the normal hand, the blood flow was increased in 11 cases and decreased in 6 cases. The mechanism for these reactions is discussed.

3. The blood flow through the hand in clinical cases of surgical shock was markedly reduced.

4. The low oxygen saturation of the venous blood indicated the severity of the tissue asphyxia.

5. The reactive hyperemia which followed occlusion of the circulation for 5 minutes in cases of shock was slight and of short duration.

CONCLUSIONS

Surgical shock is the clinical manifestation of a process which has its origin in the physiological reactions of the body to various traumatic stimuli. These reactions preserve the organism through diversion of the blood supply to the vital centers. As a consequence, the outlying tissues become deprived of adequate nutrition. Recovery from the process of shock is associated with progressive improvement in the circulation of blood to the periphery. The therapy of surgical shock should be directed toward the reestablishment of an adequate supply of oxygenated blood to the body tissues.

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