THE CHANGES IN THE HEART RATE AND BLOOD "PRESSURES" RESULTING FROM SEVERE HÆMORRHAGE AND SUBSEQUENT INFUSION OF SODIUM BICARBONATE.

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INTRODUCTION.

One of several conclusions reached by Howell in his study of the phenomena of shock[1] is the following: "Injections of alkaline solutions of sodium carbonate, intravenously or into the rectum during shock, increase markedly the amplitude of the heart-beat and bring about a rise of arterial pressure. When the shock is moderate (aortic tension of 60–70 mm. Hg.), the injections may restore arterial pressure to an approximately normal level. When the shock is severe (aortic tension of 20–40 mm. Hg.), the injections may increase the arterial pressure by about 100 per cent for long intervals, and the effect when it wears off may be restored by repeating the injections. The effect of the injections is due chiefly or entirely to a direct action on the heart."

Having in mind the possible clinical value of injections of alkaline solutions as a means of combating the condition of shock, Professor Howell then suggested to the author to pursue this line of investigation still farther, a suggestion which resulted in the series of experiments which will now be described.

The present communication deals with the cardio-vascular effects of intravenous infusion of solutions containing sodium bicarbonate after severe hæmorrhage. The animals used were dogs, and the phenomena observed were the pulse rate and the blood "pressures," viz., systolic, mean, diastolic, and pulse

[1] *Contributions to Medical Research*, dedicated to V. C. Vaughan, Ann Arbor, 1903, p. 61.

pressure.[2] Naturally a careful study was made of the effects, not only of the infusion, but also of the hæmorrhage which preceded it. It has therefore been thought desirable to record the phenomena accompanying the hæmorrhage even at the risk of repeating some of the statements already proved by others.

METHOD.

Anæsthesia.—Each dog received from 0.6 to 1.2 grm. of morphia hypodermically, and an hour later was anæsthetized with ether, administered at first with a cone, but later through a tracheal cannula.

Hæmorrhage.—The blood was allowed to flow through a cannula inserted into the carotid artery, until an amount equal to from 2.3 to 4.4 per cent of the body weight had been removed. The bleeding occupied as a rule about five minutes.

Infusion.—The apparatus for infusing was simple. A Marriotte's bottle containing the liquid to be infused was kept at a fairly constant temperature in a bath of warm water. This bottle was connected by means of a short rubber tube to a large glass T. Into the upright limb of this T a thermometer was inserted, while of the two ends of the cross-piece one was connected with the bottle, as already stated, and the other entered directly into the jugular vein. The rate of infusion was regulated by means of a glass stop-cock inserted in the course of the rubber tube above mentioned. The time occupied by the infusion was usually from five to six minutes, and the amount of fluid infused varied from 1.8 to 4.4 per cent of the body weight. The solutions infused were of two kinds, first that containing only sodium chloride (0.8 per cent); and secondly, that which in addition to the sodium chloride (0.8 per cent) contained different amounts of sodium bicarbonate ($\frac{1}{10}$, $\frac{1}{4}$, $\frac{1}{2}$, or 1 per cent). [3]

[2] Each ventricular contraction causes a wave of positive pressure (the pulse) to pass along the arterial tree towards the periphery. Hence the rhythmic change in arterial pressure at any given point has been designated the "pulse pressure." It is, of course, calculated by subtracting the diastolic pressure at the point in question from the corresponding systolic pressure.

[3] The criticism might be made that the effects, which later in this communication will be ascribed to the specific action of the bicarbonate, might with equal

Recording Apparatus.—As a means of securing graphic records the following scheme was adopted. The left femoral artery was connected with the Hürthle manometer, so that the pulse rate could be accurately recorded. The right femoral artery also was connected with a tube which branched into three parts, each being in communication with a separate mercury manometer. In the course of the first branch there was inserted a maximum valve; in the course of the second, a minimum valve; while the third branch ran directly to its manometer. Consequently it was possible to obtain readings of the systolic, diastolic, and mean pressures, and from the first two to calculate the pulse pressure.[4]

reason be attributed to the fact that the alkaline solutions were more or less strongly hypertonic. That this is not the true explanation of the results obtained is shown by several experiments, in some of which strongly hypertonic solutions of sodium chloride were used, while in others the solution contained chloride and bicarbonate, each being present to the extent of 5 % ("5 to 5 solution"). The former group of experiments gave the results usually obtained with isotonic chloride solution, while the effect of the latter was similar to that obtained with such bicarbonate solutions as are mentioned in the text. It may also be observed in this connection that in the observations made by Howell (which suggested this line of enquiry) the "5 to 5 solution" was frequently employed. It is therefore certain that the results obtained in the present research were not due to variations in the osmotic pressure of the solutions employed.

[4] Why, it might be asked, was not the Hürthle manometer sufficient to furnish the desired data? It is because in the course of these and other experiments it has been found that the readings of the Hürthle and of the maximum and minimum manometers do not always agree, may, in fact, differ markedly. The reason for these discrepancies is not at all clear to the author, but it is hoped that, after sufficient data have been collected, the cause may become apparent. In the meanwhile, for the determination of the systolic and diastolic pressures, the clumsier but more reliable apparatus, namely, the valved manometers, has been employed.

It was subsequently found that the system of tubes connecting the femoral artery with the mercury manometers possessed more extensibility than had at first been supposed. Investigations were therefore undertaken to determine the seriousness of this instrumental error. A comparison of the apparatus used in these experiments with a much more perfect one subsequently devised showed that of the results obtained with the former the mean pressures were quite accurate, but that the systolic was too low and the diastolic was too high. Although the absolute error was not inconsiderable, the relation of the systolic to the diastolic pressures was the same with both instruments. It follows, therefore, that the data obtained in this series of experiments are relatively correct.

The form of valve used was that known as the "Williams valve." For recording the movements of all these manometers a Hürthle kymographion was employed.

Secondary Experiments.—Upon several of the animals "secondary experiments" were performed. By this is meant that, after the dogs had been bled and infused and then allowed to remain undisturbed for a couple of hours, a second bleeding and infusion were undertaken. The data obtained from these secondary experiments have not been interspersed among those obtained from the primary experiments. The reason for this is obvious, namely, that the animals in these two series of experiments, the primary and the secondary, were under conditions which were not at all comparable. These secondary experiments proved to be of sufficient importance to merit attention, and, though few in number, gave results which were suggestive.

"Principal Points."—Readings of the pulse rate and blood-pressures were made before, during, and usually for a considerable time after, the operations of bleeding and infusion. Just as temperatures are "charted" by the clinician, so in each of these experiments the rate and pressures were charted, so that the changes in these phenomena could easily be followed and studied. Obviously it would have been very inconvenient to reproduce many curves of this character, and, moreover, it would have been quite unnecessary to introduce as much detail as these curves contain into the present discussion. Hence certain "principal points" have been selected on each curve, and the data corresponding to them tabulated and compared. These principal points are: (1) immediately before bleeding, (2) soon after bleeding, but before infusion, (3) immediately after infusion, and (4) some time (about two hours) later. In the tables and discussion which follow, the data which correspond to these four points are, for the sake of brevity, designated as "before," "after," "immed.," and "late" pressures and rates respectively.

General Character of the Experiments.—The following table shows in a general way the character of each of the twelve primary and secondary experiments performed:

Date of experiment.	Weight of animal in kilogrammes.	Percentage of sodium bicarbonate in primary infusions.	Amount of blood withdrawn.[5]	Amount of infusion.[5]	Mean temperature of infusion.	Percentage of sodium bicarbonate in secondary infusion.	Amount of blood withdrawn.[5]	Amount of infusion.[5]	Mean temperature of infusion.
June 3	8.500	0	2.9 %	2.4 %	44°	—	—	—	—
" 7	4.500	0	3.3 %	4.4 %	38°	—	—	—	—
" 12	4.050	1	4.1 %	3.7 %	39°	0	2.4 %	2.4 %	40°
" 14	2.925	1	4.4 %	4.4 %	43°	—	—	—	—
" 18	7.650	1	4.2 %	1.9 %	42°	0	1.7 %	2.2 %	40°
" 24	8.685	0	2.8 %	1.7 %	48°	½	1.6 %	1.1 %	38°
" 27	8.000	0	4.0 %	2.4 %	43°	1	1.3 %	1.2 %	41°
" 30	4.950	½	3.3 %	3.0 %	42°	1	2.0 %	2.0 %	40°
July 1	6.750	0	3.9 %	2.9 %	40°	1	1.6 %	1.6 %	41°
" 3	5.400	½	4.2 %	1.8 %	43°	—	—	—	—
" 7	10.800	¼	4.0 %	2.3 %	48°	—	—	—	—
" 11	15.750	$\frac{1}{10}$	3.5 %	2.3 %	42°	—	—	—	—

THE EFFECT OF HÆMORRHAGE.

Pulse Rate in Primary Experiments.—As the result of hæmorrhage the pulse rate is usually much increased in the primary experiments. In these the amount of acceleration was very variable, the average increase being 29 per cent, the maximum being 96 per cent, while in only one case did the pulse rate remain unchanged.

The amount of acceleration did not bear any close relation to the severity of the hæmorrhage nor to the extent of the fall in the blood pressures. On the other hand, there is some evidence that *the amount of acceleration depends on the extent of the tonic activity of the vagus* at the time at which the bleeding was begun.

If, for instance, the normal rate be, say, 25 in 10 seconds, then the amount of the acceleration will be small; whereas in the case of a heart beating at the rate of, say, 13 in 10 seconds, there is a marked acceleration. This is shown in Table I, where it may be seen that in the first six experiments in which the acceleration is greater, the average normal heart rate is slow (18 in 10 seconds); while in the second six, in which the acceleration is less, the average normal heart rate is considerably greater (23 in 10 seconds). And, moreover, it may be observed that of the two hearts which showed the greatest acceleration,

[5] The amounts of blood withdrawn and of fluid infused are expressed in percentages of the body weight.

namely, Nos. 18 and 7u, one had much the slowest rate of all, and the other belonged to the group which comes next in order of slowness, namely, that composed of Nos. 7u, 30, and 12.[6]

Pulse Rate in Secondary Experiments.—The effect upon the pulse rate caused by the secondary bleedings is very different from that which occurs in the perfectly fresh animal. It has been shown that the acceleration due to hæmorrhage is probably due to the tonic action of the vagi. Now, at the time when the animal is about to undergo a second bleeding the heart is beating at about its maximum rate, so that no further increase in this rate would be expected. As a matter of fact, not only is the rate not increased, but it may even be diminished.[7]

A possible cause of this diminution is suggested by the investigations of Bergendal and Bergman. These authors have studied the effects upon the heart rate of rapid hæmorrhage from the carotid artery. They observed that as the bleeding proceeded, the preliminary acceleration gave place to a marked slowing. This slowing depended for its occurrence on the integrity of the vagi, and Bergendal and Bergman compared it to the similar phenomenon (likewise due to the action of the vagi) present in asphyxia, attributing both to the same cause, namely, the lack of oxygen. In the experiments of the author the effect of the primary hæmorrhage was to quicken the heart-beats. The infusion replaces the lost blood, but the oxygen carrying power of the circulating fluid remains low, so that when the secondary hæmorrhage took place the same result was obtained as if the primary hæmorrhage had been continued, i. e., the acceleration gave place to a slowing. Although the same result does not necessarily imply the same cause, yet the similarity is suggestive.

Blood Pressures in Primary and Secondary Experiments.—The abstraction of a considerable amount of blood results, of course, in a fall in the blood pressures which is more or less marked. Just before the end of the hæmorrhage, while the blood is still flowing from the artery, the lowest pressures are observed. On placing the clamp upon the artery, the pressures begin to rise

[6] These results accord with those obtained by Bergendal and Bergman (*Skand. Arch. f. Physiol.*, 1897, vii, 186).

[7] See Table II.

	No. of experiment.	Normal pulse rate.	Pulse rate "before."	Pulse rate "after."	Acceleration.	Hæmorrhage.	Fall in pressures, i. e., "after" ÷ "before" × 100.			
							S	M	D	PP
TABLE I.	18		13	26	+ 96 %	4.2 %	43	58	52	34
Primary experiments arranged in order of greatest acceleration.	7u		18	28	+ 59 %	3.3 %	26	29	25	26
	1		25	35	+ 37 %	3.9 %	25	21	19	33
	12		17	24	+ 37 %	4.1 %	32	29	26	50
	30		17	22	+ 29 %	3.3 %	23	24	27	17
	3u		21	27	+ 27 %	2.9 %	47	52	47	47
	27		21	25	+ 20 %	4.0 %	21	21	21	20
	24		28	21	+ 15 %	2.8 %	23	31	38	8
	11		25	28	+ 12 %	3.5 %	23	22	25	21
	3y		20	22	+ 12 %	4.2 %	36	34	35	31
	14		20	21	+ 8 %	4.4 %	34	35	29	44
	7y		25	25	± 0 %	4.0 %	25	31	31	16
TABLE II.	1	25	32	34	+ 6 %	1.6 %	22	24	23	20
Secondary experiments arranged in order of greatest acceleration.	27	21	28	28	− 1 %	1.3 %	23	23	26	17
	30	17	22	21	− 5 %	2.0 %	22	31	35	12
	24	28	31	30	− 5 %	1.6 %	21	24	26	14
	18	13	33	28	− 16 %	1.7 %	26	25	29	20
	12	17	34	22	− 40 %	2.4 %	22	20	20	25

Pulse rates are the number of beats in 10 seconds.
Hæmorrhage is the blood withdrawn in percentage of the body weight.
Here as elsewhere S is systolic, M is mean, D is diastolic, and PP is pulse pressure.
"Before" and "after" are the "principal points" defined on page 4.
In the secondary experiments "normal rate" is rate "before" in the primary experiments.

slowly, owing doubtless to the increased peripheral resistance caused by the occlusion of the artery. This rise is slight (amounting to not more than 10 mm. Hg.), and the pressure then remains constant until the beginning of the infusion.[8]

That no relation exists between the amount of the fall in the pressure and the degree of the acceleration[9] is not especially surprising, but it seems rather remarkable that *the extent of the fall does not depend closely upon the amount of the blood withdrawn*

[8] It should be noted that the "principal point" designated "after" occurs after this rise has taken place and the pressure has become fairly constant.
[9] See page 4, and also Tables I and II.

(i. e., in proportion to the body weight), a fact which is made evident by the following tables (Tables III and IV):

	No. of experiment.	Fall in pressures, i. e., "after" ÷ "before" × 100.				Hæmorrhage.	Acceleration.
		S	M	D	PP		
TABLE III.	24	23	31	38	8	2.8 %	+ 15 %
Primary experiments arranged in order of the amount of hæmorrhage.	3u	47	52	47	47	2.9 %	+ 27 %
	7u	26	29	25	26	3.3 %	+ 59 %
	30	23	24	27	17	3.3 %	+ 29 %
	11	23	22	25	21	3.5 %	+ 12 %
	1	25	21	19	33	3.9 %	+ 37 %
	27	21	21	21	20	4.0 %	+ 20 %
	7y	26	29	25	16	4.0 %	± 0 %
	12	32	29	26	50	4.1 %	+ 37 %
	18	43	51	52	34	4.2 %	+ 96 %
	3y	36	34	35	31	4.2 %	+ 12 %
	14	34	35	29	44	4.4 %	+ 08 %
TABLE IV.	27	23	23	26	17	1.3 %	— 1 %
	24	21	24	26	14	1.6 %	— 5 %
Secondary experiments arranged in order of the amount of hæmorrhage.	1	22	24	23	20	1.6 %	+ 6 %
	18	26	25	29	20	1.7 %	— 16 %
	30	22	31	35	12	2.0 %	— 5 %
	12	22	20	20	25	2.4 %	— 40 %

There are several possible causes for this want of agreement between the fall in pressure and the extent of the hæmorrhage. In the first place the amount of blood withdrawn is not an absolute indication of the severity of the hæmorrhage, for the amount of blood normally present in the dog varies somewhat in its relation to the body weight in different individuals. Consequently a hæmorrhage of, say, 4.5 per cent might be much more serious in one animal than in another. Secondly, the amount of the cardiac weakening due to the reduction in the blood supply of the coronary arteries varies in different hearts. Lastly, the amount of the peripheral constriction due to the anæmia might readily be supposed to vary in different individuals.

In order to analyse the relations of the systolic, mean, diastolic, and pulse pressures, both to the extent of the hæmorrhage and to one another, the author compiled a set of tables from the data obtained in these experiments. From these tables, which for the sake of brevity have been omitted, certain negative conclusions were drawn which apply not only to the primary but also to the secondary experiments. These are the following:

(1) There is apparently no constant difference between the effects of hæmorrhage upon the systolic and upon the diastolic pressure. Either may be diminished more than the other, or they may be equally decreased.

(2) The relation of the decrease in the mean pressure to the fall in the systolic and diastolic pressures is very variable.

(3) The pulse pressure always shows a marked diminution, but this does not correspond in extent with the amount of the fall in mean pressure nor to the severity of the hæmorrhage.

It is, however, only proper to state that these negative results may be entirely due to those instrumental errors which with this apparatus always occur at low pressures, and to which reference will again be made.

THE EFFECT OF INFUSIONS.

It has seemed to the author that the presentation of the results of infusion could best be accomplished by means of a series of tables and charts, and, consequently, this method has been employed. The relation of the tables to the charts is such that the latter contain the gist of the former. Hence the tables and all that pertain to them exclusively have been printed in small type. That the tables have not been entirely omitted is owing to the fact that they show the various steps in the construction of the charts, and also because they furnish more exact data to such persons as may desire to peruse them.

As the phenomena studied in these experiments, namely, the pulse rate and the blood pressures, appear to be quite independent of each other, they will be considered separately.

Pulse Rate in Primary Experiments.—As any preliminary remarks would be superfluous, one may pass directly to a discussion of the tables and chart.

Table V shows the effect of hæmorrhage and infusion on the pulse rate, the rate having been determined at the four "principal points" already defined.

This table shows, of course, only the absolute changes in the rate, and hence it is difficult to compare the effects found in one experiment with those occurring in another. It was therefore thought desirable to modify the table by converting the absolute values into percentages. Consequently in Table VII the rates are given in percentages of the original rate which obtained before the bleeding was begun ("before"), while in Table IX the standard taken is the rate occurring after the hæmorrhage but before the infusion ("after").

The object in view is, however, to compare, not the effect of infusions on various individuals, but the effect of varying the composition of the fluid infused, and hence it is advantageous to have tables by means of which the average results gotten with the pure chloride may be compared with those obtained after the addition of bicarbonate. The results obtained by averaging Tables V, VII, and IX are seen in Tables VI, VIII, and X respectively.

No. of experiment.	Table V. Actual number of beats in periods of ten seconds.				Table VII. Relative number of beats per ten seconds in per cent of the "before" and "after" rates.				Table IX.		
	Before.	After.	Immed.	Late.	Before.	After.	Immed.	Late.	After.	Immed.	Late.
3u	21	27	27	—	100	127	130	—	100	192	—
7u	18	28	29	—	100	159	164	—	100	103	—
24	28	31	33	31	100	113	119	112	100	102	112
27	21	25	25	28	100	120	142	135	100	85	91
1	25	35	30	32	100	137	118	125	100	85	91
11	25	28	26	27	100	112	104	108	100	92	96
7y	25	25	24	36	100	100	94	141	100	94	141
30	17	22	23	22	100	129	135	129	100	104	100
3y	20	22	26	29	100	112	132	147	100	117	131
14	20	22	26	—	100	108	131	—	100	121	—
12	17	24	22	34	100	138	128	194	100	93	142
18	13	26	15	33	100	196	111	244	100	51	124

	Table VI. (Averages.)				Table VIII. (Averages.)				Table X. (Averages.)		
0	22	29	30	31	100	132	130	125	100	99	102
$\frac{1}{10}$	25	28	26	27	100	112	112	108	100	92	96
$\frac{1}{4}$	25	25	24	36	100	100	94	141	100	94	141
$\frac{1}{2}$	18	22	25	26	100	120	133	128	100	110	115
1	17	24	21	33	100	147	123	220	100	90	132

A perusal of the foregoing tables and of chart I. shows that there is no very evident connection between the presence of sodium

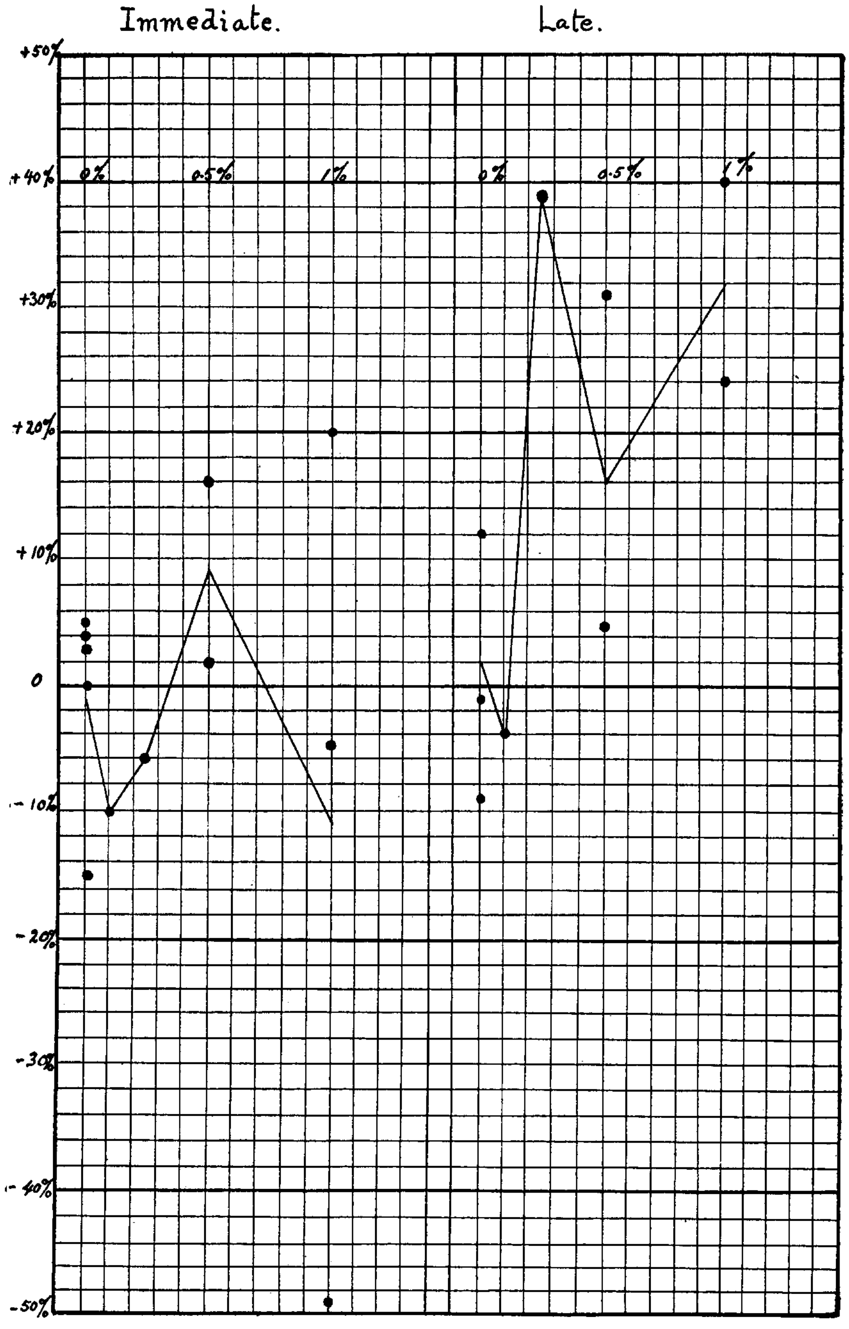

Chart I. Primary experiments

This chart, constructed from the data contained in Table X, shows the effect upon the pulse rate in the primary experiments of increasing the amount of bicarbonate infused. The percentage of sodium bicarbonate which was added to the solutions of 0.8 % chloride is indicated along the abscissa, while the percentage of acceleration, whether positive or negative, is given along the ordinate. The dots represent the results of single experiments, and the averages of these experiments are connected by means of a line. The terms "immediate" and "late" have already been defined.

bicarbonate and the rate at which the heart beats immediately after the infusion. On the other hand, there seems to be some difference with regard to the late effects. In this respect both tables and charts show that when bicarbonate is used, the heart rate continues to increase gradually and beats rapidly for some time.

Pulse Rate in Secondary Experiments.—The nature of what the author has chosen to call "secondary experiments" has already been explained. The results obtained in these experiments have been tabulated and charted in a manner precisely similar to that employed in the case of the primary experiments and will now be presented.

				TABLE XI.				TABLE XII.				TABLE XIII.		
No. of experiment.	Percentage of bicarbonate in primary infusion;	in secondary infusion.	Original rate.	Before.	After.	Immed.	Late.	Before	After.	Immed.	Late.	After.	Immed.	Late.
12	1	0	17	34	22	26	—	100	66	78	—	100	118	—
18	1	0	13	33	29	28	32	100	87	85	97	100	98	113
27	0	1	21	28	28	30	—	100	99	106	—	100	107	—
1y	0	1	25	32	34	32	34	100	106	100	106	100	94	100
24	0	½	28	31	30	31	31	100	96	99	100	100	103	104
30	½	1	17	22	18	19	19	100	82	86	86	100	105	105
				(Averages.)				(Averages.)				(Averages.)		
	1	0	15	33	25	27	32	100	72	81	97	100	107	114
	0	1	23	30	31	31	34	100	100	97	96	100	100	102
	0	½	28	31	30	31	31	100	96	99	100	100	103	104
	½	1	17	22	18	19	19	100	82	86	86	100	105	105

The effect of infusion upon the heart rate, which is observed in these secondary experiments, does not at all resemble that obtained at the time of the primary experiments. In the case of the primary experiments it will be remembered, the addition of sodium bicarbonate to the infused liquid had for its fairly constant result an increase in the amount of the cardiac acceleration, the rate increasing gradually and remaining high for a considerable period of time. There is no such increase in the case of the secondary experiments.

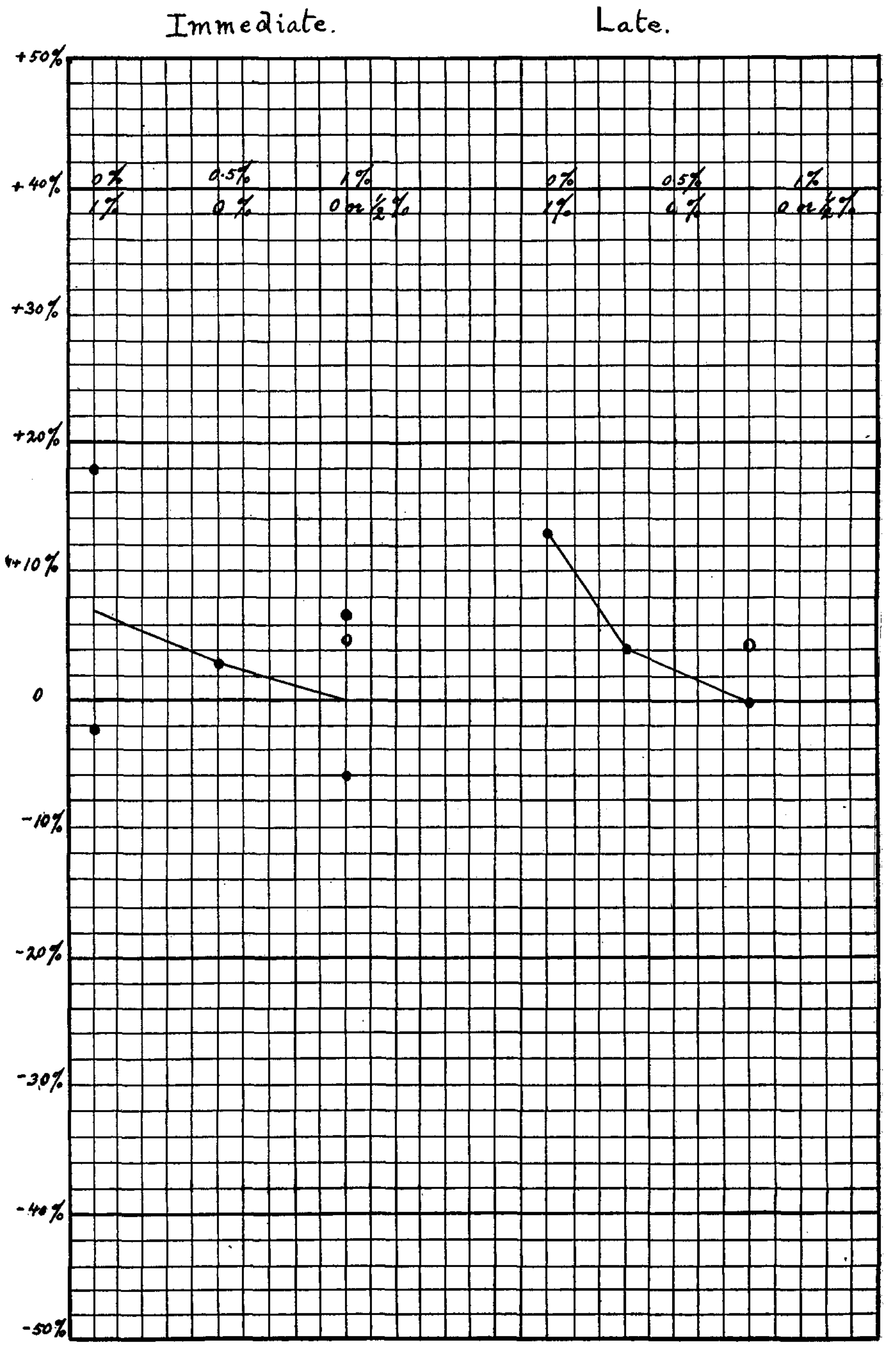

Chart. II. Secondary experiments.

This chart, compiled from the data contained in the latter part of Table XIII, shows for the secondary experiments what Chart I has already shown for the primary experiments. The explanation accompanying Chart I will serve to elucidate this one also. It may be added, however, that of the two numbers corresponding to each group of experiments, the upper gives the percentage of bicarbonate present in the secondary experiment, while the lower indicates the strength of bicarbonate infused in the preceding primary experiments performed upon the same animals. Since 1 % bicarbonate in some cases followed an infusion containing no bicarbonate, and in another case an infusion of ½ % of the same substance, separate designations have been employed, ● having been used for the former and o for the latter.

At the beginning of the secondary experiments the heart was beating at about its maximum rate. The effect of hæmorrhage is then (as has already been pointed out) to slow the rate. The immediate effect of the infusion (as shown by the tables and chart) is variable and inconsiderable. Thus the rate may be increased or decreased, or may suffer almost no modification whatsoever. Subsequently there is a slow increase until the heart rate approximates that which had originally obtained at the beginning of the secondary experiment.

Blood Pressures.—The effect of the infusions upon the blood pressures (systolic, mean, diastolic, and pulse pressure) can be presented most clearly by means of the method already employed, namely, by means of a series of tables and charts.

Primary Experiments.—In Table XIV are given the blood pressures as actually measured (mm. Hg.) in each of the primary experiments. This is immediately followed by Table XV, which shows the average pressures [10] compiled from those experiments in which animals were infused with liquids of the same

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[10] In making up these averages the following source of error had to be borne in mind, namely, that in experiments 3u, 7u, and 14 no late readings were obtained. From this it follows that in some cases the averages of the "before" pressures are hardly comparable with those of the "late" pressures, and hence a direct comparison should be avoided. For example, in the case of those experiments in which pure chloride was employed, five factors enter into the average of the pressures "before," while the average of the "late" pressures is derived from only three factors. To avoid this source of error, the author resorted to a simple manœuvre in proportion, of which the following may serve as an example:

Average systolic pressure "before" in 3u, 7u, 24, 27, and 1 = 164
" " " " " 24, 27, and 1 = 173
" " " "late" " 24, 27, and 1 = 136

Hence $\frac{x}{136} = \frac{164}{173}$, or x = 129.

This is as much as saying that if the sum of the "late" results of the three experiments in which the "late" readings were recorded bore the same ratio to the sum of the corresponding pressures "before," as the "late" results of all five experiments (had they been obtained) to the sum of the corresponding "before" pressures, then 129 is a more correct estimate of the late pressures than is 136. Although this assumption is somewhat gratuitous, it is thought that by making such a correction the figures obtained might be less likely to produce a false impression and to lie nearer the truth than would values obtained by simply averaging. Consequently, this corrective procedure has been adopted wherever it has been deemed expedient.

			Before.					After.					Immed.					Late.				
TABLE XIV. Actual pressures as measured in mm. Hg.	Bc %	No.	S	M	D	PP	PP %	S	M	D	PP	PP %	S	M	D	PP	PP %	S	M	D	PP	PP %
	0	3u	140	85	63	77	55	66	44	30	36	54	125	76	41	84	67	—	—	—	—	—
	0	7u	160	101	87	73	46	41	29	22	19	46	132	73	48	84	64	—	—	—	—	—
	0	24	155	103	79	76	49	36	32	30	6	16	130	75	64	66	51	135	96	78	57	42
	0	27	174	111	95	79	45	36	23	20	16	44	133	77	60	73	55	140	100	83	57	41
	0	1	190	120	106	84	44	48	25	20	28	58	125	73	58	67	54	135	103	85	50	37
	1/10	11	185	116	88	95	52	42	26	22	20	47	170	95	75	95	56	152	98	72	80	52
	1/4	7y	146	107	90	56	38	37	33	28	9	24	138	109	90	48	35	125	91	70	55	44
	1/2	30	150	102	84	66	44	34	25	23	11	32	155	101	85	70	45	120	67	52	68	57
	1/2	3y	170	113	100	70	41	61	39	35	26	43	178	101	83	95	53	115	75	62	53	46
	1	14	140	104	95	45	32	48	36	28	20	42	150	129	119	31	21	—	—	—	—	—
	1	12	140	115	100	40	28	46	33	26	20	43	154	128	116	38	25	105	82	65	40	38
	1	18	215	127	116	99	46	94	65	60	34	36	190	141	138	52	27	160	122	100	60	37
	Averages:		164	109	92																	
TABLE XV. (Averages.)	0		164	104	86	78	48	45	31	24	21	44	129	75	54	75	58	129	93	75	54	57
	1/10 and 1/4		165	111	89	75	45	39	29	25	14	35	154	102	82	71	45	138	94	71	67	48
	1/5		160	107	92	68	42	47	32	29	18	37	166	101	84	82	49	117	71	57	60	61
	1		165	115	104	61	35	63	45	38	25	40	164	133	124	40	24	123	96	79	44	37

Bc % is the percentage of sodium bicarbonate present in the solution infused. No. is number of the experiment. S, M, and D = systolic, mean, and diastolic pressures respectively. PP is pulse pressure, i. e., S minus D. PP % is percentage pulse pressure, i. e., D divided by S multiplied by 100. "Before," etc. = the "principal points."

composition.[11] Since, however, the normal pressures in individual animals varied considerably, Tables XIV and XV, for example, give little conception of the relative changes which took place. Consequently, from the data furnished by these tables, two others, Tables XVI and XVII, have been constructed, which present the pressure changes in percentages of the pressures "before" hæmorrhage.

			After.				Immed.				Late.			
	Bc %	No.	S	M	D	P	S	M	D	P	S	M	D	P
TABLE XVI.	0	3u	47	52	47	47	89	89	65	109	—	—	—	—
	0	7u	26	29	25	26	82	72	55	115	—	—	—	—
	0	24	23	31	38	8	84	73	81	87	87	93	99	75
	0	27	21	21	21	20	76	69	63	92	80	91	87	72
	0	1	25	21	19	33	65	61	55	79	71	86	80	59
	$\frac{1}{10}$	11	23	22	25	21	92	82	85	100	82	84	82	84
	$\frac{1}{4}$	7y	25	31	31	16	94	102	100	86	85	85	77	98
	$\frac{1}{2}$	30	23	24	27	17	103	99	101	106	80	66	62	103
	$\frac{1}{2}$	3y	36	34	35	31	105	89	83	136	68	66	62	75
	1	14	34	35	29	44	107	124	125	61	—	—	—	—
	1	12	32	29	26	50	110	111	116	95	75	71	65	100
	1	18	43	51	52	34	88	111	119	52	74	96	86	61
TABLE XVII. (Averages.)	0		28	31	30	27	79	73	64	96	79	89	87	69
	$\frac{1}{10}$ and $\frac{1}{4}$		24	26	28	18	93	92	92	93	83	84	79	91
	$\frac{1}{2}$		29	29	31	24	104	94	92	121	74	66	62	89
	1		36	38	36	42	102	115	120	69	84	76	83	54

Since the "before" pressures which correspond to the values given above are in every case equal to 100, they have been omitted from the table.

At first sight it might seem that it would have been more logical to give a table in which the pressures "after" hæmorrhage, but before infusion, had been taken as a standard, while the remaining pressures were presented as percentages of that standard. When, however it is remembered [12] that the smaller the pulse pressure and the lower the remaining pressures, the more inaccurate are the readings of the maximum-minimum manometer, it can readily be inferred that such a table would be worse than valueless.

Naturally the facts embodied in these tables can be grasped more easily when presented graphically, as in Chart III. In constructing this chart, showing as it does, all the blood pressures simultaneously, a difficulty was encountered, namely, the fact that one is here dealing with three independent quantities

[11] It should be noted that the two experiments in which the amounts of bicarbonate infused were $\frac{1}{4}$ and $\frac{1}{10}$ % respectively have also been grouped together.

[12] See above, p. 9.

(systolic, mean, and diastolic pressures), each of which should be represented under standard conditions by the figure 100. To avoid the confusion which would occur in the construction of a table requiring the use of three separate scales, the author resorted to the manœuvre of reducing all the values given in Tables XIV and XV to a common standard. This was accomplished in the following manner:

Consider Table XIV; the average normal systolic, mean, and diastolic pressures of the twelve experiments "before" hæmorrhage are respectively 164, 109, and 92. All the other values given in this table may be reduced to this common standard, thus:

In Experiment 3u systolic pressure "after" is 66 mm. Hg.
In Experiment 3u systolic pressure "before" is 140 mm. Hg.
Find the value of 3u syst. "after" when the syst. "before" is 164.

$$\frac{x}{164} = \frac{66}{140} \therefore x = \frac{66 \times 164}{140} = 77$$

This is the value of 3u syst. "after" given in Table XVIII, and this method was employed in obtaining all of the values presented in Tables XVIII and XIX. In Table XIX the averages for Table XVIII are given. These two tables are, however, to be regarded only as a step in the construction of Chart III, and are inserted here mainly for the sake of completeness.

			After.			Immed.			Late.		
	Bc %	No.	S	M	D	S	M	D	S	M	D
TABLE XVIII.	0	3u	77	56	44	146	97	60	—	—	—
	0	7u	41	31	23	135	79	51	—	—	—
	0	24	38	34	35	138	79	74	143	101	90
	0	27	33	22	19	125	75	58	132	98	80
	0	1	41	23	17	107	60	50	116	94	74
	$\frac{1}{10}$	11	37	24	23	150	89	78	134	92	75
	$\frac{1}{4}$	7y	41	37	28	154	111	92	140	93	71
	$\frac{1}{2}$	30	37	27	25	169	108	93	131	72	57
	$\frac{1}{2}$	3y	58	37	32	178	97	76	110	72	57
	1	14	56	38	27	175	135	115	—	—	—
	1	12	54	31	24	180	122	107	123	78	60
	1	18	71	55	47	144	120	109	122	104	79
TABLE XIX. (Averages.)	0		46	33	28	130	78	59	130	98	81
	$\frac{1}{10}$ and $\frac{1}{4}$		39	30	25	152	100	85	137	92	73
	$\frac{1}{2}$		47	32	28	170	102	84	120	72	57
	1		60	41	33	166	126	110	122	91	69

Since the "before" pressures which correspond to the values given above are in every case S 164, M 109, and D 92, they have been omitted from the table.

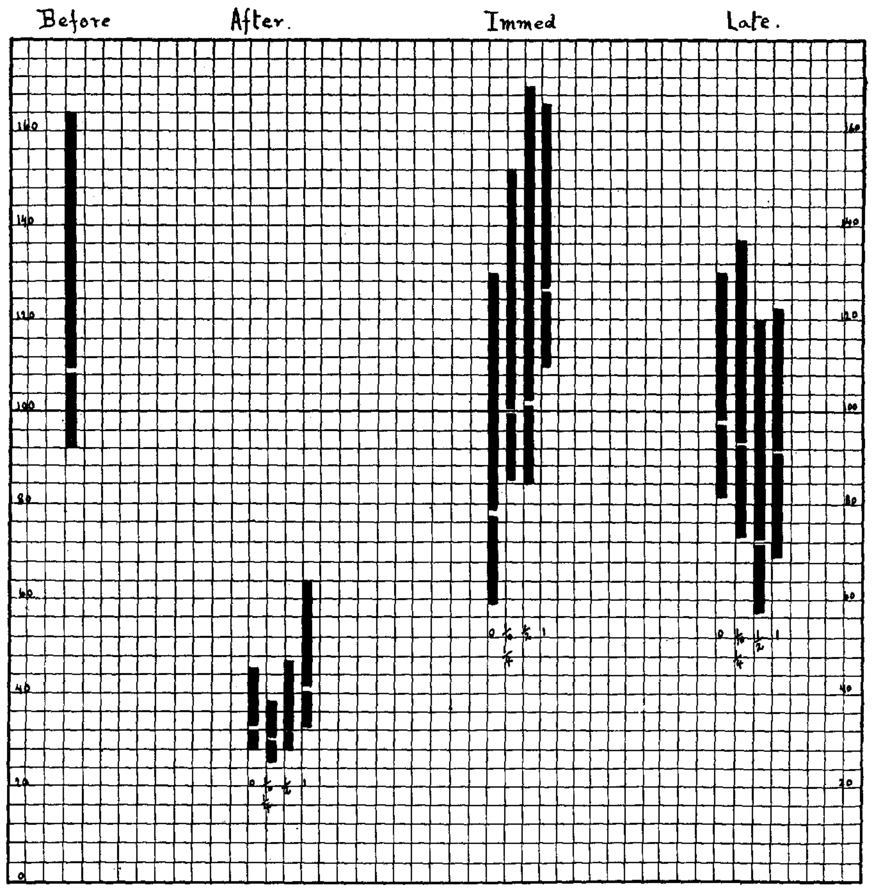


Chart III. Primary experiments.

This chart shows the effects of infusion upon the "blood pressures" in the twelve "primary" experiments. The dark vertical lines represent the "blood pressures," the top of the lines being the systolic, the bottom the diastolic, pressure; the point at which the line is broken indicates the mean pressure, while each line as a whole represents a pulse pressure. The terms "before," "after," etc., are the "principal points" which have already been defined.

The first vertical line represents the average of the pressures in all twelve experiments immediately "before hæmorrhage." The second vertical line represents the condition of the pressures "after" bleeding in those dogs which were afterwards infused with pure sodium chloride, or, in other words, with a solution containing 0 % of sodium bicarbonate, as indicated by the zero placed below the line. The sixth and tenth lines represent the pressure conditions obtaining in the same series of animals "immediately" after the infusion and some hours "later" respectively. The absence of bicarbonate from the liquid infused in these cases is indicated by the 0 placed beneath the vertical lines in question.

The third, seventh, eleventh, and fifteenth lines show the corresponding values for the experiments in which $\frac{1}{10}$ % and $\frac{1}{4}$ % bicarbonate were added to the 0.8 % chloride. The signification of the remaining lines can easily be inferred.

TABLE XX.

Bc. % Prim.	Bc. % Sec.	No.	Before. S	Before. M	Before. D	Before. PP	Before. PP%	After. S	After. M	After. D	After. PP	After. PP%	Immed. S	Immed. M	Immed. D	Immed. PP	Immed. PP%	Late. S	Late. M	Late. D	Late. PP	Late. PP%
1	0	12	105	82	65	40	38	23	16	13	10	43	122	71	45	77	63	—	—	—	—	—
1	0	18	160	122	100	60	37	41	31	29	12	29	160	109	85	75	46	—	—	—	—	—
0	1	27	140	100	83	57	41	32	23	22	10	31	190	102	70	120	60	—	—	—	—	—
0	1	1y	135	103	85	50	37	30	25	20	10	33	153	136	113	40	26	86	63	54	32	37
0	½	24	135	96	78	57	42	28	23	20	8	28	170	99	67	103	60	110	70	48	62	56
½	1	30	120	67	52	68	57	26	21	18	8	30	100	52	45	55	55	89	46	38	51	57
Averages:			132	95	77																	

TABLE XXI. (Averages.)

Bc. % Prim.	Bc. % Sec.	No.	Before. S	Before. M	Before. D	Before. PP	Before. PP%	After. S	After. M	After. D	After. PP	After. PP%	Immed. S	Immed. M	Immed. D	Immed. PP	Immed. PP%	Late. S	Late. M	Late. D	Late. PP	Late. PP%
1	0		132	102	82	50	38	32	23	21	11	34	141	90	65	76	54	—	—	—	—	—
0	1		137	101	84	53	39	31	24	21	10	32	171	119	91	80	46	87	64	54	32	37
0	½		135	96	78	57	42	28	23	20	8	28	170	99	67	103	60	110	70	48	62	56
½	1		120	67	52	68	57	26	21	18	8	30	100	52	45	55	55	89	46	38	51	57

Secondary Experiments.—The next series of tables deals with the secondary experiments. These tables resemble in form those already given, and their contents may be summarized as follows:

Table XX contains actual pressures in mm. Hg., followed by Table XXI, containing the averages of the preceding. These two correspond to Tables XIV and XV of the primary experiments.

Table XXII contains percentage pressures, the pressures "before" hæmorrhage being represented by 100. Table XXIII presents the corresponding averages. These two are similar to Tables XVI and XVII of the primary experiments.

Table XXIV contains relative pressures reduced to the standard S being 132, M, 95, and D, 77, these being the values of the average pressures "before" hæmorrhage in all the secondary experiments, while Table XXV gives the

				After.				Immed.				Late.			
	Bc. % Prim.	Bc. % Sec.	No.	S	M	D	PP	S	M	D	PP	S	M	D	PP
TABLE XXII.	1	0	12	22	20	20	25	116	86	69	192	—	—	—	—
	1	0	18	26	25	29	20	100	89	85	125	—	—	—	—
	0	1	27	23	23	26	17	136	120	84	210	—	—	—	—
	0	1	1y	22	24	23	20	113	133	132	80	64	61	63	64
	0	½	24	21	24	26	14	126	103	86	181	81	72	61	109
	½	1	30	22	31	25	12	85	78	86	81	74	69	73	75
	(Averages.)														
TABLE XXIII.	1	0		24	22	24	22	108	87	77	158	—	—	—	—
	0	1		22	23	24	18	124	126	108	145	45	60	67	59
	0	½		21	24	26	14	126	103	86	181	81	72	61	109
	½	1		22	31	35	12	83	78	86	81	74	69	73	75

Since the "before" pressures which correspond to the values given above are in every case equal to 100, they have been omitted from the tables.

				After.				Immed.				Late.			
	Bc. % Prim.	Bc. % Sec.	No.	S	M	D	PP	S	M	D	PP	S	M	D	PP
TABLE XXIV.	1	0	12	29	18	15	14	153	82	53	100	—	—	—	—
	1	0	18	34	24	22	12	132	85	65	67	—	—	—	—
	0	1	27	30	22	20	10	179	97	65	114	—	—	—	—
	0	1	1y	29	23	18	11	149	125	102	47	84	58	49	35
	0	½	24	27	23	20	7	166	98	66	100	107	69	47	60
	½	1	30	29	30	27	2	110	74	67	43	91	65	56	35
	(Averages.)														
TABLE XXV.	1	0		31	21	18	13	142	83	59	83	—	—	—	—
	0	1		29	22	19	10	164	111	83	81	84	58	49	35
	0	½		27	23	20	7	166	98	66	100	107	69	47	60
	½	1		29	30	27	2	110	74	67	43	91	65	56	35

The "before" pressures which have been omitted from these tables are in every case S 132, M 95, D 77, and PP 55.

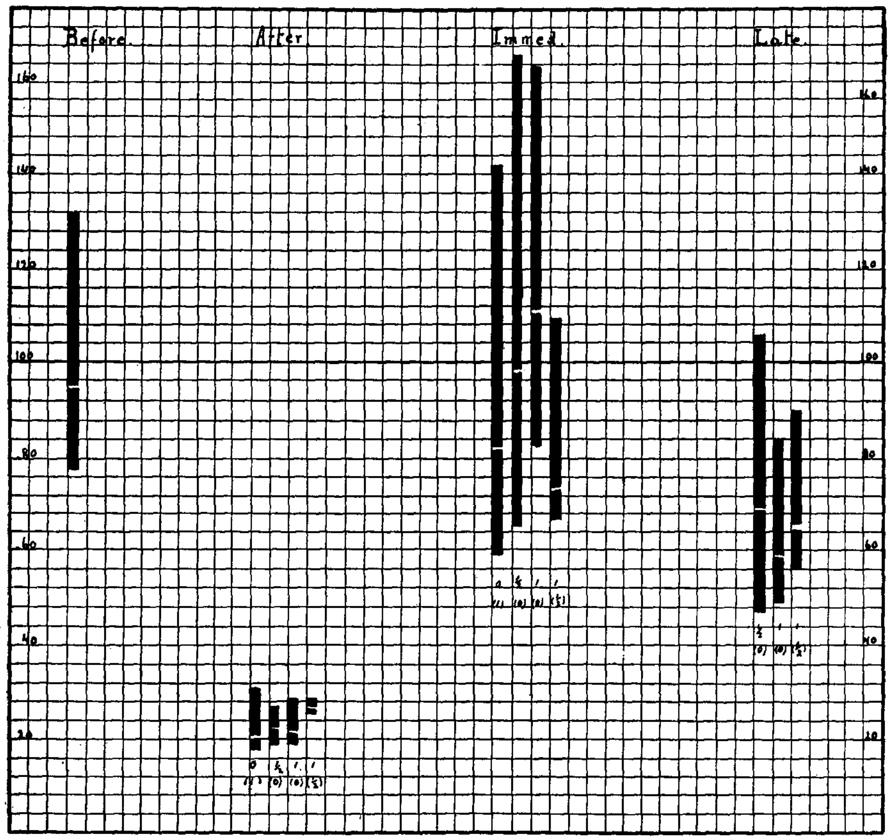


Chart IV. Secondary experiments.

This chart shows the effects of infusion upon the blood "pressures" in the six "secondary" experiments. The explanation accompanying the preceding chart (Chart III) will serve to elucidate this one also. It may be added, however, that, of the two numbers which are placed at the foot of each vertical line, the upper one corresponds to the secondary infusion, while the lower one (placed in parentheses) indicates the nature of the primary infusion. Thus $\frac{\frac{1}{2}}{(0)}$ means that the group of animals of which the pressures are indicated by the line above the symbols received first an infusion of 0.8 % sodium chloride, and later an infusion of 0.8 % sodium chloride + 0.5 % sodium bicarbonate.

averages. These correspond to Tables XVIII and XIX of the primary experiments. It is from the data given in Table XXV that Chart IV has been constructed.

Relative Efficiency of Different Infusions.—On inspection of Table I it may be seen that the chloride and bicarbonate were not infused in equal quantities, the amount of the latter being less (sometimes very much less) than that of the former. If, then, it be desired to compare the chloride and the bicarbonate with respect to their powers of raising the blood pressure, the fact that it requires less of the latter than of the former to bring about the same result should not be forgotten.

In estimating the power of a substance to raise the blood pressure, it should be borne in mind that within limits the extent of the rise in the pressure will depend upon the amount of the fluid infused. Moreover, other things being equal the efficiency of a given amount of an infused liquid will depend upon the amount of blood previously removed. With the former (the amount of the fluid infused) the efficiency will vary directly, with the latter (the amount of the hæmorrhage) inversely.

Thus if E = the efficiency, I = the amount of infusion,
H = the amount of hæmorrhage and K be a constant,
then $\frac{E}{K} = \frac{I}{H} \therefore \frac{EH}{I} = K.$

Strictly speaking, E should be the ratio of the pressures $\frac{\text{"Immed." or "Late"}}{\text{"After"}}$ i. e., the rise in pressure due to infusion. The author is, however, loath to employ the "after" pressures as divisors, since the determination of these pressures almost certainly involves a comparatively large amount of experimental error,[13] so that he has preferred to take the ratios $\frac{\text{"Immed." or "Late"}}{\text{"Before"}}$ as indicating the efficiency of the liquid in restoring the blood pressures to their normal levels. Consequently the equation, $\frac{\text{"Immed." or "Late"}}{\text{"Before"}} \times \frac{H}{I} = K$ may be considered as equivalent to the equation $\frac{EH}{I} = K.$

[13] See pages 9 and 16.

In Table XXVI are seen the values of the ratio $\frac{H}{I}$ i. e., $\frac{\text{Hæmorrhage}}{\text{Infusion}}$ and here also are to be found the values of the expression $\frac{\text{Immed. and Late}}{\text{Before}} \times \frac{H}{I}$. Table XXVII contains the corresponding averages.

	Character of the infusion.	No. of experiment.	$\frac{H}{I}$	Relative efficiency. Immed. S	Immed. M	Immed. D	Late. S	Late. M	Late. D
TABLE XXVI. Primary experiments.	o	3u	120	107	107	78	—	—	—
	o	7u	75	61	53	41	—	—	—
	o	24	164	138	120	133	143	152	162
	o	27	166	126	114	104	133	151	144
	o	1	134	87	82	74	95	115	107
	1/10	11	152	138	123	127	123	126	123
	1/4	7y	173	163	176	173	147	147	133
	1/2	30	110	113	109	111	88	73	68
	1/2	3y	233	245	207	193	158	154	144
	1	14	100	107	124	125	—	—	—
	1	12	110	122	123	129	83	78	72
	1	18	221	194	245	263	163	212	190
TABLE XXVII (Averages.)	o		132	104	96	84	129	142	137
	1/10 and 1/4		162	151	149	149	134	136	128
	1/2		171	178	161	157	126	113	106
	1		143	146	164	172	123	145	131

These data have also been determined for the secondary experiments and are presented in Tables XXVIII and XXIX.[14]

[14] The chart corresponding to Table XXIX has been omitted for the sake of brevity.

	Primary infusion.	Secondary infusion.	No. of experiment.	$\frac{H}{I}$.	Relative efficiency. Immed.			Late.		
Table XXVIII.					S	M	D	S	M	S
	1	0	12	100	116	86	69	—	—	—
	1	0	18	130	129	115	109	—	—	—
	0	1	27	90	125	110	77	—	—	—
	0	1	1y	100	113	133	132	64	61	63
	0	½	24	70	87	71	59	56	50	42
	½	1	30	100	83	78	86		7469	73
Table XXIX. (Averages.)	1	0		115	122	100	89	—	—	—
	0	1		95	119	121	104	64	61	63
	0	½		70	87	71	59	56	50	42
	½	1		100	83	78	86	74	69	73

It can readily be seen from the foregoing tables that K ($\frac{EH}{I} = K$) is by no means a constant quantity, but that it varies greatly, due probably to individual differences in the animals. This fact renders the danger of relying on average figures even greater than usual, and consequently it has been deemed advisable to present a chart (Chart V) containing not only the averages, but likewise the data from all the experiments.

Experiments 12 and 1y.—Up to the present the fact has not been emphasized that the secondary experiments were performed upon the same animals as the primary experiments. If all the experiments had been performed upon separate animals, then the phenomena which have been attributed to the effect of the bicarbonate might have been due to the idiosyncracies of the individual animals. The probability of this explanation decreases, of course, as the number of the experiments increases, but the crucial test would be obtained by performing a double experiment on two dogs, injecting into A chloride and then bicarbonate, while injecting into B the same solutions in the reverse order.

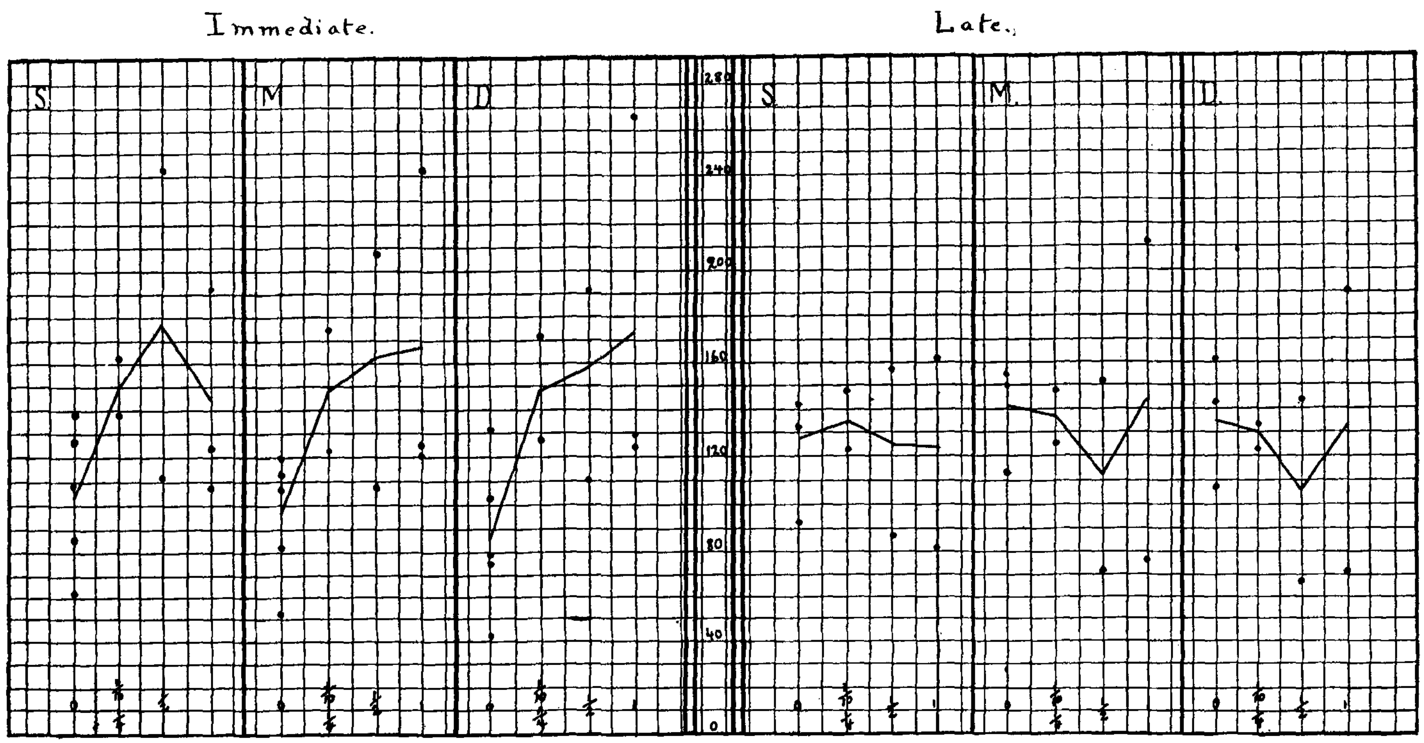


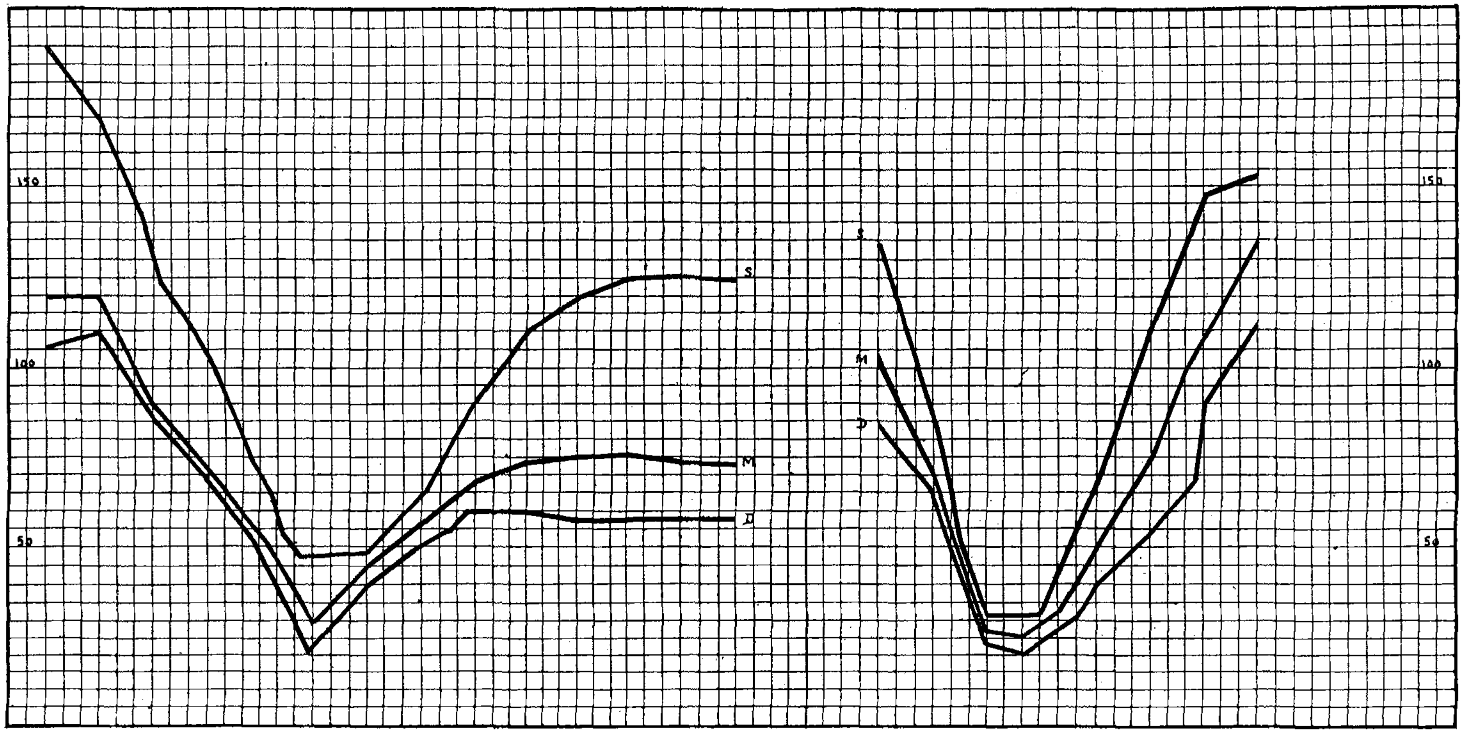
Chart V.

This chart shows that the efficiency of the solution in raising the blood-pressure is increased by increasing the amount of bicarbonate of sodium. S, M, and D signify the systolic, mean, and diastolic pressures respectively. The dots represent the results of single experiments while the averages of these experiments are connected by a line. The percentages of bicarbonate present in the various solutions are indicated along the abscissa, and the units of efficiency are marked off along the ordinate.

No. 12. Primary, 1%. Chart VI. Secondary, 0%.

This chart shows the results of two experiments performed on dog No. 12. In the primary experiment the amount of blood withdrawn was 4.1 % of the body weight. After this the animal was infused with a solution of 0.8 % sodium chloride + 1.0 % sodium bicarbonate, amounting to 3.7 % of the body weight. In the secondary experiment the amount of blood withdrawn was 2.4 % of the body weight, while the infusion contained only 0.8 % sodium chloride and amounted to 2.4 % of the body weight.

The line designated by the letter "S" represents the systolic, "M" the mean, "D" the diastolic pressure, while the distance between S and D shows the pulse pressure.



No. 1y. Primary, 0 % Chart VII. Secondary, 1 %

This chart should be compared with the preceding (Chart VI). It shows the results of two experiments performed on dog No. 1y. In the primary experiment the amount of blood withdrawn was 3.9 % of the body weight, and the infusion was one of 0.8 % sodium chloride, amounting to 2.9 % of the body weight. In the secondary experiment the amount of blood withdrawn was 1.6 % and the amount of the infusion also 1.6 %, the latter containing 0.8 % sodium chloride + 1.0 % sodium bicarbonate.

Such an experiment has actually been performed as is seen when both the primary and secondary experiments performed upon dogs 12 and 1y are taken into consideration. The charts obtained in these experiments, after having been somewhat simplified, are presented as Charts VI and VII. on pages 26 and 27.

Conclusions.—After a careful study of the data presented above, the author has reached the conclusions which are given below and which, if legitimate, should be capable of verification by any one who will compare them with the foregoing tables and charts.

(1) If sodium chloride be infused after severe hæmorrhage, the immediate effect is an increase of the blood pressures. Of these the systolic pressure is the most nearly restored to normal, next in order of completeness of the restoration comes the mean, and lastly the diastolic, these pressures being 79, 73, and 64 per cent, respectively, of the original pressures. Since the increase of the systolic pressure is greater than that of the diastolic, the pulse pressure remains large and is, in fact, nearly normal (96 per cent).

(2) If, now, to solutions of the chloride an increasing percentage of sodium bicarbonate be added, the rise in the pressures is markedly increased.

(3) The rise in the systolic pressure may reach a maximum of 115 per cent of its original value. This maximum occurs with the addition of ½ per cent bicarbonate to the chloride, and a further addition of carbonate (up to 1 per cent) is not accompanied by a further increase in the systolic pressure.

(4) The rise of the mean and of the diastolic pressure differs from that of the systolic pressure in that the maximum is not reached with a solution of ½ per cent of bicarbonate. The maxima were, for the mean, 115, and, for the diastolic pressure, 120 per cent of the original ("before") pressures, and were obtained with a solution containing 1 per cent of the bicarbonate, i. e., the strongest solution used.

(5) With a concentration of bicarbonate which is not greater than ½ per cent, the pulse pressure is increased considerably (121 per cent) above the normal. Owing to the fact that the

maximum systolic pressure is reached with a lower concentration than is the maximum diastolic, an increase in the amount of bicarbonate present in the infusion fluid to 1 per cent is accompanied by a marked diminution of the pulse pressure (69 per cent of the original value).

If, two hours after the infusion, the pressures be again observed, it is found that:

(6) In those experiments in which the chloride alone was used, the mean and diastolic pressures have, since the time of the infusion, gradually risen, although the systolic pressure has remained unchanged.

(7) On the other hand, when the carbonate is used all the pressures decrease considerably, so that the systolic is now no greater than it is with infusions of pure chloride, while the mean and diastolic pressures have become less, sometimes considerably less.

(8) In all cases the pulse pressure is considerably diminished. With pure chloride and with 1 per cent bicarbonate the diminution is greater (69 and 54 per cent of the original value respectively), while with a concentration of bicarbonate not greater than $\frac{1}{2}$ per cent the diminution is less (averaging 90 per cent).

Allowing for the fact that in the experiments with pure chloride the amount of fluid infused was almost always greater than in those experiments in which the bicarbonate was added, and when, in this connection, Chart V is carefully examined it is seen that:

(9) The bicarbonate appears still more efficient than the pure chloride, since the rise which is immediately brought about by the former is considerably the greater, while in the late effects the two solutions differ but little.

Although the secondary expermets arine somewhat wanting both in completeness and in numbers, nevertheless the conclusions to which they point are not without interest. These conclusions are the following:

(10) In the secondary experiments the results obtained by

infusions of pure chloride and of solutions containing bicarbonate are strikingly similar to those already described in the primary experiments.

(11) In the late effects, however, some difference is seen. Here while the diastolic pressures are nearly equal, whether the ½ or 1 per cent of bicarbonate be added, still both the mean and systolic and consequently the pulse pressure are considerably greater in the former (½ per cent) than in the latter (1 per cent).

(13) The infusion of 1 per cent bicarbonate after a previous infusion of ½ per cent is not productive of beneficial results, the rise in all the pressures being comparatively small. Here, also, the rise in the mean and diastolic pressures is greater than the rise in the systolic pressure would lead one to expect. The subsequent ("late") fall is proportionately much less than is the case in the other secondary experiments.

THE CLINICAL VALUE OF INFUSIONS OF SODIUM BICARBONATE.

Until we know more about the inter-relations of the blood pressures (systolic, mean, diastolic, and pulse pressures) in health and in disease, and until we know more exactly how sodium bicarbonate acts upon the cardio-vascular mechanism, one must be cautious in drawing inferences with regard to the clinical value of infusions of sodium bicarbonate. Nevertheless, the results of the experiments described above indicate that under certain conditions the addition of the bicarbonate to the infused fluid may be expected to have a beneficial action. In extreme cases of that variety of shock which is due to loss of blood, the addition of from ½ to 1 per cent of the bicarbonate to the solution of 0.8 per cent sodium chloride may be of advantage in two respects. In the first place, the rise in all the pressures, but especially in the diastolic pressure, is more pronounced than when the pure chloride is used, and consequently the circulation (so far as the pressures are concerned) can be restored more nearly to the normal condition; secondly, the quantity of fluid required is smaller than is the case with the pure chloride, and hence the greater is the rapidity with which the solution can be hurried into the circulation, a matter of some importance in desperate cases.

There is, however, one possibility which ought not to be overlooked in the employment of bicarbonate, namely, that of overworking the heart. Some experiments of a series not yet completed show that very strong solutions of sodium carbonate and bicarbonate act as cardiac stimulants to a degree which is simply astounding, and it is probable that such solutions as were used in the above experiments act in part, perhaps chiefly, upon the heart, as suggested by Howell.[15] It would therefore be the duty of the physician to decide in each case whether a cardiac stimulant is or is not contraindicated.

It would seem to the author to be a rational procedure to begin an intravenous infusion with a solution containing bicarbonate, and in this way to hurry the pressures upward, so to speak, and then when the pressures had reached a considerable height the bicarbonate might, if thought advisable, readily be omitted from any subsequent infusion which might be required to maintain the pressure at the desired level.

In conclusion, the author wishes to acknowledge his great indebtedness to his wife, by whom he was assisted in the performance of these experiments.

[15] Loc. cit.