BLOOD VOLUME IN WOUNDED SOLDIERS.

I. BLOOD VOLUME AND RELATED BLOOD CHANGES AFTER HEMORRHAGE.

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INTRODUCTION.

Our knowledge on the subject of hemorrhage and the subsequent restoration of the circulation is in a state of rapid change. New facts are constantly coming to light which necessitate revision of previous conceptions. Furthermore, the data at hand, although much increased of late, are by no means complete. This work is therefore presented with the realization that the interpretation of some of our findings may be open to question, and that as regards their significance further observations may lead to somewhat different conclusions. However, certain phenomena have occurred so consistently that it has seemed safe to make fairly definite deductions in these instances.

There is a lack of general agreement among investigators on problems of blood loss as to the data which are of most value in determining the actual condition of the patient after hemorrhage, and the ensuing changes which occur in his blood. The principal reason for this diversity of opinion appears to lie in the fact that all the methods heretofore employed in the estimation of blood changes have failed to take into account variations occurring in the volume of the blood. It is well recognized that following hemorrhage the body promptly begins to add fluid to the circulation in an attempt to make up the total blood bulk to its previous amount, but little actual knowledge
exists concerning the rapidity with which this diluting process occurs and the factors controlling it. Thus it is not surprising that the data given by red cell counts, hemoglobin per cent, hematocrit determinations, etc., when taken alone, are often difficult to interpret, since they indicate only the variations occurring in one unit of blood. These same data, however, when viewed side by side with blood volume determinations, take on an entirely different significance. Changes in hemoglobin and red cells, whose cause has heretofore seemed most obscure, become, in the light of this more complete knowledge, readily explainable and are seen to occupy their proper place in relation to a changing blood volume. For example, a marked drop in hemoglobin per cent following the rise produced by transfusion, has been generally regarded as an unfortunate occurrence due to hemolysis or perhaps to some less rapid destruction of the introduced cells. Repeated blood volume estimations have revealed the true nature of this phenomenon, showing that in such cases the volume was under normal, even after the transfusion, and that the drop in hemoglobin was due to progressive dilution of the blood as the volume was made up.

The present study includes a series of twenty-one cases of hemorrhage, which were observed as completely as circumstances would permit. Blood volume tests were made in fourteen cases, and with one or two exceptions the tests were performed repeatedly. The patients were of two types,—those suffering (a) from the late effects of primary hemorrhage and (b) from secondary blood loss. Infection was present in the majority of instances. The charts of those cases are shown which serve to illustrate best the various findings. Reference only is made to the other cases.

A. Initial Changes in Circulation after Hemorrhage.


Blood volume determinations, following hemorrhage, made by the vital red method,\(^1\) on a number of cases showed a surprising reduction

\(^1\) This test was devised by Keith, Rowntree, and Geraghty. It has given very satisfactory results in our hands (Keith, N. M., Rowntree, L. G., and Geraghty, J. T., Arch. Int. Med., 1915, xvi, 547).
in the total blood bulk. Patients giving a history of loss of blood when first wounded, with a second hemorrhage several days to a week or more afterwards, as a rule had a volume of 60 per cent or less of the normal. Cases that reached the Base without a positive history of a severe bleeding had not infrequently a diminution in blood volume of 20 to 30 per cent. Text-figs. 1 and 2 (from Cases 1 and 2) are those of patients with secondary hemorrhage. In Case 1 the initial determination, made within an hour after hemorrhage, showed a volume of 3,060 cc.—59 per cent of normal. Case 2 (Text-fig. 2) had a blood volume of 2,663 cc. (estimated by a method described later), or 54 per cent of total volume, shortly after hemorrhage. Case 7 (Text-fig. 7) showed a volume of 3,350 cc., or a reduction to 62 per cent some days after primary hemorrhage. It is not definitely known how low the volume can drop and the patient still live. The lowest figure in this series was 54 per cent. It is possible that lower figures might be obtained in determinations made soon after primary hemorrhage.

With the single exception of blood pressure readings, none of the other data obtained in these cases, such as hemoglobin per cent, findings with the hematocrit, etc., gave any indication of a diminished volume, and it was only after a number of observations on blood volume had been made that we were enabled to associate a lowered pressure with a small blood bulk. The blood pressure, however, is of assistance in judging the volume only when below a certain point. For there may be a considerable reduction of the total blood without any appreciable drop in the pressure. This is due undoubtedly to the fact, now well recognized, that the vasomotor mechanism responds within certain limits to the lessened blood bulk by producing a vasoconstriction which maintains the pressure. Just how great a diminution can occur before the blood pressure falls cannot be stated, and there would seem to be some variation with the individual case. In the present series we have had patients whose volume was reduced to 70 per cent of normal, yet a normal blood pressure was still maintained. Such patients probably had some fall in pressure immediately after hemorrhage, since a blood loss of the amount indicated, unless

2 The text-figures with their legends will be found at the end of Paper II.
very gradual, practically always causes a drop. But the compensatory mechanism was able to restore the pressure to normal. The patients who had a reduction in volume below 70 per cent showed, with one exception, a blood pressure below normal, the decrease in blood pressure corresponding roughly with the amount of reduction in blood volume. The cases with a volume of 54 to 60 per cent of the normal showed systolic blood pressures of 70 to 80 mm. of mercury. One alone had a pressure of 90 mm. It is somewhat difficult to compare these figures, as the readings were not taken at the same intervals after hemorrhage, some being taken immediately and others after many hours or days. However, low blood pressure has been found to be associated so constantly with reduced volume that it seems fair to draw certain general inferences from these observations. We have come to feel that in hemorrhage cases when a blood pressure is below 95 mm. the blood volume is probably under 70 per cent. With a blood pressure of 80 mm. or less the volume is probably only 60 per cent or less. It is possible that a larger series of cases will show that these estimates need modification and that even more accurate inferences can be made from the blood pressure changes.

Patients suffering from acute blood loss and considerably diminished volume showed a much reduced pulse pressure, to 20 mm. or less. Other cases in which the hemorrhage had taken place more slowly or some time previously had a pulse pressure not under 30 (Text-figs. 3 and 5), although the blood volume was considerably lessened and the blood pressure lowered.

2. **Amount of Blood Loss or Actual Degree of Anemia.**

The actual amount of 100 per cent hemoglobin blood remaining in the circulation was calculated by multiplying the hemoglobin per cent\(^3\) by the blood volume, and dividing this figure by the normal blood volume (obtained later).\(^4\) This gave the total per cent of hemoglobin—assuming that the patient's hemoglobin normally is

\(^3\) Hemoglobin tests were made by the Palmer method (Palmer, W. W., *J. Biol. Chem.*, 1918, xxxiii, 119), which has been of great value in this study. We agree with Palmer that it is accurate to within at least 1 per cent, and we have often made repeated readings to \(\frac{3}{4}\) of 1 per cent.

\(^4\) The normal blood volume could also be calculated from the weight.
100 per cent. Estimations made in this way showed that many of these patients have lost more blood than is commonly supposed. Two markedly anemic patients had a reduction of total hemoglobin to 16 per cent of normal (Text-figs. 4 and 5). These cases, however, both gave a history of the first hemorrhage occurring several weeks before. Case 2 (Text-fig. 2) had his initial hemorrhage only the day before and showed a reduction to 35 per cent. Case 7, with a history of only one hemorrhage, showed the same reduction. Other patients showed a reduction of 60 to 75 per cent of their total hemoglobin. How much they lose with a single hemorrhage it is not possible to estimate, since one cannot be sure that they have bled only once. The cases showing a marked reduction in total hemoglobin must have bled repeatedly. These results show that with a remarkably small amount of hemoglobin the circulation can supply enough oxygen to the tissues to keep the patient alive. It seems probable that a reduction much below 16 per cent would be incompatible with life. Both the patients showing this low figure were critically ill.


Numerous hemoglobin estimations made on blood from the ear and vein taken simultaneously have shown a definitely higher hemoglobin per cent on the capillary side when the blood pressure is low (Text-figs. 5, 6, and 9). The greatest difference in the two readings has been 8 points. The degree of discrepancy does not seem to parallel the extent of blood pressure drop in the different cases, since in the case showing 8 points difference between ear and vein the blood pressure was only 95 mm., while in Case 9 (Text-fig. 9) the difference was 6 points with a blood pressure of 65 mm. However, repeated readings in the same case show that the degree of discrepancy between ear and vein hemoglobins does have a relation to the blood pressure, since this discrepancy diminishes as the pressure rises. We have come

6 This is supported by the findings of Rous and Wilson (Rous, P., and Wilson, G. W., J. Am. Med. Assn., 1918, lxx, 219) in animals. They found that an abrupt reduction of the total hemoglobin to one-quarter of the original normal was well tolerated when blood volume was maintained.
to regard these readings as giving valuable evidence on the state of circulatory efficiency. A difference of 6 to 8 points between the capillary and venous blood must mean a considerable stagnation of red cells with a consequent diminished oxidation. It is apparently not necessary that a marked drop in blood pressure should occur before the capillary and vein hemoglobins begin to differ.

B. Progressive Changes in the Circulation after Hemorrhage.


Methods Employed for Estimating Volume Changes. (a) Vital Red.—Repeated vital red tests were made on a number of cases (Text-figs. 1, 2, 4, and 7).

(b) Gum Acacia.—Blood volumes were also estimated from the drop in hemoglobin per cent produced by the intravenous injection of a known amount of 6 per cent gum acacia solution. Text-fig. 3 illustrates the use of this method. Case 3 had a hemoglobin of 61.5 per cent. After the injection of 580 cc. of gum acacia solution the hemoglobin fell to 52.5 per cent. This was a drop of 9 points, or 14.6 per cent of 61.5. With the addition of a colorless diluent to a colored fluid the drop in color should be in inverse proportion to the increased volume of the solution; therefore taking 61.5 per cent as 100, the formula for estimating the new volume would be

$$\frac{100}{14.6} : : x : 580$$

$$14.6 \times x = 58,000$$

$$x = 3,973$$

Subtracting 580 from 3,973 gives the volume before the gum injection. Estimations made with vital red at the same time showed a volume of 3,844 cc., which would give an error of 3 per cent to the gum acacia estimations.

Blood volume estimations might be made in this way with other kinds of colorless fluids injected intravenously. However, gum acacia solution is particularly well adapted to this purpose, since it is retained in the blood stream, while the majority of other solutions are rapidly eliminated from the circulation.

(c) Hemoglobin Changes.—Blood volume changes were estimated in a third way by changes in hemoglobin per cent occurring as a re-
sult of fluid absorption into the circulation. The approximate increase in the blood bulk can be calculated in this manner only if the blood volume has been already determined by one of the two methods just mentioned. Such a starting-point is necessary. Case 7 (Text-fig. 7) shows the method by which the estimation is carried out. This patient had a drop in hemoglobin from 48.5 to 38.5 per cent occurring in the course of 24 hours, which equals a fall of 20.6 per cent of his original hemoglobin. His blood volume before the drop occurred was 3,665 cc. One uses the same formula as for the gum acacia volume estimation, except that in this instance we know the previous volume; therefore 100 - 20.6, or 79.4 is taken as the new hemoglobin per cent. Then

\[
\frac{100}{79.4} : : x : 3,665
\]

\[
79.4 \times = 366,500
\]

\[
x = 4,617
\]

A second vital red estimation done at this time gave a volume of 4,715 cc. This difference of 100 cc. can be accounted for to a certain extent by the increased production of erythrocytes as shown by the presence of 8 per cent reticulated cells. Even though the error were several times as great as this—and it may be said that the calculation did not work out so closely as the above in all cases—the method is still of value.

**Effect of Transfusion and the Injection of Gum Acacia.**—In the present series of cases transfusions were given with both citrated blood and whole blood (paraffin tube). The blood volume was increased by both procedures, and the increase persisted equally well following either method. The effect of gum acacia injections was entirely similar in this respect. However, gum acacia solution was not used in very anemic patients. The most interesting fact revealed by the repeated blood volume tests was that transfusion or infusion only begins the work of restoration of the blood bulk. Case 2 (Text-fig. 2) is a good example. The estimated initial volume in this case was 2,660 cc., or 54 per cent of the normal. Transfusion of 800 cc. of blood increased the volume to 3,460 cc., which was still 1,440 cc. below the patient's normal volume. In other words, even after transfusion the volume was only 70 per cent of normal. It is obvious that in such
cases the volume must still be increased considerably before we can say that the circulation has been restored to a state of normal efficiency. The lacking fluid bulk is made up by the patient from his own body fluids. It has been found necessary in practically all cases to increase the fluid intake in order to bring this about promptly. By this means, in the patient referred to (Text-fig. 2) the volume was increased progressively to normal during the 2½ days following transfusion. (This was indicated by the drop in hemoglobin to the lowest level reached on April 30 and was shown to be the fact by a vital red test made the next day.) This case is typical of others studied in the same way. Text-fig. 3 shows the same increase in volume after gum acacia solution injection. With the progressive increase in volume after transfusion the hemoglobin falls, which is itself an index of increasing blood bulk. Thus we have come to expect in transfusion cases a drop in hemoglobin and the volume of formed elements (hematocrit) following a preliminary rise. If this does not occur it is taken to signify that the patient's blood is not diluting as it should, or, otherwise expressed, is not receiving the expected fluid increment from the tissues; and an increased fluid intake is indicated. When the hemoglobin per cent drops and then gradually becomes stationary, the volume has probably reached a level well up toward normal, provided the fluid intake has been good. An exception to this is to be found in the cases of well marked anemia discussed later.

2. Relation of Blood Volume to Hemoglobin Per Cent.

The extent to which the blood becomes diluted through a restoration of its volume after hemorrhage seems to depend within certain limits on the total amount of hemoglobin remaining. We have observed in patients with a very low hemoglobin per cent that the blood volume does not show a marked increase until the amount of hemoglobin rises, no matter how much fluid they are given. There would appear to be two forces at work in these cases—one which tends to restore the blood bulk so that the circulation has a sufficient volume to work with effectively, and the other a mechanism tending to inhibit dilution of the blood with the consequent lowering of the
hemoglobin per cent thus entailed. Until a very low per cent of hemoglobin is reached by bleeding, the former force is the stronger, and the blood dilutes to the volume needed for a good blood pressure. There seems to be a point at about 20 per cent hemoglobin where the latter force is the more effective and the blood does not dilute—which would reduce the hemoglobin below this point—even though the volume may be so small as to be barely compatible with life. Case 4 (Text-fig. 4) showed a condition of profound anemia—hemoglobin 20 per cent. A fairly large fluid intake was maintained, yet the blood showed no tendency to dilute, even though the volume was less than 68 per cent of the normal. Case 5 (Text-fig. 5) shows a first hemoglobin reading of 26.5 per cent and 30 per cent from vein and ear respectively. At this time the blood volume (estimated) was 2,605 cc., or 56 per cent of normal. This volume was evidently too small for the circulatory needs, and dilution was permitted to occur until the hemoglobin reached 23 per cent. At this point the hemoglobin remained practically stationary, the volume having increased meanwhile sufficiently to bring the blood pressure up to normal.

When this balance between the opposing forces of blood dilution and blood volume has been reached, any further increase in volume seems to be dependent on an increase in hemoglobin. In Case 4 (Text-fig. 4) it is seen that the blood volume stayed low until the 23rd; then, coincident with a well marked increase in hemoglobin—due to the tremendous bone marrow stimulation present, as shown by the great number of reticulated cells—the volume took a decided rise. The same phenomenon is seen in Case 1. Following the second transfusion on April 9, the volume remained as before at about 4,300 cc., then showed a tendency to drop off (the patient had marked sepsis at this time, and an amputation was performed). During this period the hemoglobin stayed at a level of 38 to 39 per cent. The production of new red blood cells, as indicated by the number of reticulated elements, had dropped almost to normal. On April 14 a marked stimulation of the bone marrow must have occurred, for the per cent of reticulated cells rose rapidly until it had reached a high figure. Coincident with this increase in blood production the blood volume began to increase, and by the 20th, if not sooner, the
volume had reached normal. Even though a volume estimation is lacking here, the fact that there was no rise in hemoglobin per cent in spite of the great increase in blood production would have led one to infer that the total blood bulk must be increasing.

It would seem from the observations in the present series of cases that in the absence of severe complications, as sepsis, shock, etc., this failure of the volume to return approximately to normal occurs only when the hemoglobin is below 40 to 50 per cent. In patients with more hemoglobin than this the volume increases to somewhere near normal very promptly. In one or two cases of marked sepsis the rule did not hold.

This finding indicates definitely the beneficial effect of transfusion in patients in whom there is a marked reduction in total hemoglobin. By the addition of new red cells to the circulation the organism is enabled to restore the blood volume to a much greater extent than would have been possible without transfusion. In other words, by means of transfusion we have taken the patient out of the class of limited blood dilution and put him into the class in which well marked blood dilution can occur.

3. Relation of Blood Pressure to Hemoglobin Per Cent.

The cases with the most marked anemia, uncomplicated by any noteworthy sepsis, have shown an increase in blood pressure to above normal when the blood volume has been increased. This high pressure has persisted until an increase in hemoglobin occurred. The abnormally high blood pressure has been accompanied by an increased pulse rate as well. Case 4 (Text-fig. 4) is the best instance, as this was the most anemic patient of the series. As long as the hemoglobin remained at 25 per cent or under the blood pressure varied from 135 to 145 mm. with a pulse rate of 140. With a rise in hemoglobin the pressure fell to normal where it remained. The pulse rate showed a parallel drop, though it did not reach normal. Text-fig. 1 shows the same phenomenon. After the second hemorrhage on April 6, which was followed by a drop in hemoglobin per cent to 26, the pressure rose to 145 mm. and remained high until after transfusion which increased the hemoglobin to 38 per cent. The pulse
followed the general curve of the blood pressure but did not show a parallel drop, owing, no doubt, to the presence of marked sepsis at this time.

There seems reason to believe that this increase in blood pressure and pulse during the period of marked anemia is a compensatory reaction, which takes place in order to produce a more rapid blood flow and thereby a more effective utilization of the small amount of circulating hemoglobin. As might be expected, this increased blood pressure did not occur when the volume was very much reduced. The relation between blood volume and blood pressure has already been discussed.


In cases showing a difference in hemoglobin per cent between the blood of capillary and vein, we have found that as the pressure rises with the increase in volume, this discrepancy diminishes progressively until the two readings finally become the same, indicating that an even redistribution of the red blood cells has been effected (Text-figs. 5, 6, and 7). Case 9 (Text-fig. 9) shows further the relation between the blood pressure and the amount of the difference between the hemoglobin of ear and vein. In this patient a secondary drop in blood pressure was accompanied by an increased separation of the two hemoglobin readings. It is interesting to note also in these cases that a considerable rise in blood pressure is necessary to bring the two readings together. On Text-fig. 6 it is seen that even after transfusion, when the blood pressure had reached 105 mm., the ear and vein hemoglobins were still 2 points apart. Later, following dilution of the blood and a rise in pressure to 110 mm., there was a separation of only 1 point between ear and vein hemoglobin, a difference which is practically negligible. In Case 7 with the blood pressure at 93 mm. there was a separation in ear and vein hemoglobins of 6 points. In this case also the two readings had not come together until the blood pressure reached 110 mm.

A diminishing difference between ear and vein hemoglobin may be taken as a decidedly favorable indication, even though there has not been much change in blood pressure, since it seems to show even
more accurately than the blood pressure the direction the case is taking. It is possible that this is a more delicate indication of a beginning increase in blood volume than is the blood pressure. A lack of such a diminishing difference, on the contrary, may be regarded as an unfavorable sign. This last was observed by Cannon and his coworkers\(^6\) in shock cases. The hematocrit readings made on ear and vein blood have been found to parallel the hemoglobin changes.

5. Blood Production.

We have made reticulated red cell counts in all these cases at frequent intervals, usually daily. The rapidity of increase and the height to which the per cent of these cells rises seem to depend largely on the degree of anemia present. In other words, the strength of the stimulus controls the degree of increase in blood production. In the markedly anemic cases the number of reticulated cells rises rapidly so that within 24 hours after hemorrhage the blood production may have increased to many times normal. Text-fig. 4, Case 4, shows, the day following a marked hemorrhage, reticulated cells at 5.2 per cent. By the next day they had increased to 15 per cent, and the rise continued until it had reached 25 per cent on the 7th day. The reason for the tremendous bone marrow stimulation may be interpreted here as the very low hemoglobin, beginning at 20 per cent. A contrast to this case is afforded by Text-fig. 3. The patient showed a moderate degree of anemia, with a hemoglobin of about 50 per cent. The reticulated cells increased much more slowly and finally reached only 8 per cent, or about one-third the highest per cent of Case 4. The stimulus in this instance was very much less.

As soon as the increase in hemoglobin occurs, the per cent of reticulated cells falls. This is shown well by Case 5. With a hemoglobin at 23 per cent the reticulated cells numbered 12 per cent. At this point the patient was transfused. The hemoglobin rose to 40 per cent, and the reticulated cells fell to approximately half their number. Text-fig. 4 also showed a rapid drop when the hemoglobin rose over 30 per cent.

There seems to be another factor which influences the production of new blood in these cases, and that is the dilution of the blood with the restoration of the volume after hemorrhage. Reticulated red cell counts were made on an earlier series of hemorrhage cases before particular attention was paid to the restitution of blood volume. In these cases no attempt was made to restore the fluid bulk of the circulation by increasing the fluid intake, and the lack of more than a slight drop at most in hemoglobin and red cell count in these patients after transfusion or after hemorrhage when not transfused, showed that the blood volume was being made up only slowly. The percentage of reticulated cells did not go much over 3 to 4 per cent in any of the patients and usually there was very little increase over normal. Further, when the increase did occur it was much slower than in the present series of cases in whom the volume was made up rapidly. Text-fig. 7, Case 7, shows the effect of volume restoration on blood production. The patient had the primary hemorrhage 1 week previous to the first observations, and at the time of these the reticulated cells were only 2 per cent. With the restoration of the blood volume the number of reticulated cells increased rapidly so that at the end of 24 hours they had reached 8 per cent. The reason for the relatively great percentage of reticulated cells in the present series of cases is not altogether clear. However, a possible explanation lies in the fact that in them the hemoglobins were lower on the average than in the first series, owing to blood dilution consequent on restoration of the blood volume. The diminished hemoglobin per cent per unit of blood may act as the needed stimulus to the bone marrow.

Text-fig. 4, Case 4, illustrates the value of reticulated red cell estimations as an aid to prognosis. On account of the presence of intestinal hemorrhage, transfusion in bulk was considered inadvisable, since it was thought possible that an increase in blood pressure might start bleeding. The patient was in a very critical condition, with a hemoglobin of 20 per cent, and repeated small transfusions were considered. The rapid rise in the number of reticulated cells, however, led us to believe that the patient might take care of the hemoglobin deficiency himself, provided no more bleeding occurred. Two small transfusions only were given. As can be seen on the chart, blood production occurred very rapidly—except for a pause
from the 21st to the 23rd due to possible fresh bleeding—and by the end of 6 days the patient had practically doubled his total hemoglobin.

**Blood Destruction.**—In order to determine whether or not increased blood destruction was occurring, spectroscopic tests for hemoglobin and urobilin were made on the urine in all the patients studied. No evidence of increased blood destruction was found in any of these cases.

**Blood Groups.**—Compatible donors were used for transfusion in every instance. With one or two exceptions the donors belonged to Blood Group IV. No reactions occurred after transfusion.


Successive hematocrit readings were made on most of the cases at frequent intervals. The initial results with the hematocrit were found to parallel the hemoglobin percentages, and the later findings showed practically corresponding variations. However, when blood production began to increase, the increase in cell volume, as shown by the hematocrit, rose above the hemoglobin; i.e., the color index became less than 1. This difference became well marked during the middle period of regeneration, then tended to diminish in most instances as the hemoglobin reached 70 to 80 per cent. The patients could not be kept long enough to observe when the color index rose to 1 again. The repeated hematocrit readings served as a check on the hemoglobin per cent, but aside from indicating a low color index yielded no additional information.

**SUMMARY.**

Blood volume tests made by the vital red method (Keith, Rowntree, and Geraghty) on patients after hemorrhage showed a marked reduction in the total blood bulk. Not uncommonly the blood volume was less than 60 per cent of the normal. The reduction after a certain point had been reached seemed to parallel the decrease in blood pressure. This relation of diminished blood volume to low pressure suggested a rough method of estimating blood volume from the change in blood pressure.
By means of the blood volume and the hemoglobin per cent the actual amount of blood loss was determined. Cases of severe anemia showed a loss of as much as five-sixths of their total hemoglobin.

Progressive changes in blood volume following hemorrhage were estimated in three ways: (1) repeated vital red tests; (2) calculation from changes in hemoglobin per cent produced by the injection of gum acacia; (3) calculation from changes in hemoglobin per cent following the dilution of the blood by the patient's own body fluids.

The effects of the different methods of transfusion and of injection of gum acacia on blood volume were observed. No differences were apparent. It was found that transfusion and gum injections only partially restored the blood volume. Forced fluids by mouth were found to bring about its complete restoration in a comparatively short time.

It was observed that the organism did not restore its blood volume beyond a certain point when a further increase in it would, by dilution, have brought the hemoglobin per cent to a very low figure. In such cases a further increase of the blood volume occurred only when the hemoglobin rose. In cases with a low hemoglobin per cent as the result of a restoration of the blood bulk an abnormally high blood pressure appeared, which continued until the hemoglobin per cent again increased.

Accompanying the low blood pressure seen shortly after hemorrhage was a well marked difference in hemoglobin per cent between capillary and venous blood, with a relative concentration on the capillary side. As compensation occurred and blood pressure rose this difference lessened until the two readings were identical, indicating an even redistribution of the red blood cells.

Reticulated red cell counts made in these cases showed that a marked bone marrow stimulation occurs after hemorrhage. However, except in the very anemic cases the degree of increased blood production seemed to depend largely on the restoration of the blood volume. The patients who were put on forced fluids, with consequent rapid restoration of blood volume, showed a much higher percent of reticulated cells than those in whom no attempt was made to increase the amount of fluid in circulation.