SERIAL MICROHEMATOCRIT DETERMINATIONS IN EVALUATING BLOOD REPLACEMENT

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THE problem of determining the amount of blood to be administered during and after operation has not been solved satisfactorily. The more commonly used criteria of changes in the blood pressure and pulse may result in over or under-transfusion. Therefore, other methods [1, 2] have been evolved to determine blood loss. Among these are measurements of blood loss [3-6] and of the calculation of the circulating blood volume.[7, 8] Both methods have deficiencies:

(1) Methods of measuring blood loss in the operating room are cumbersome and time consuming. They often do not include blood on the drapes, gowns and floor, and at best, offer only a rough estimate. During massive blood replacement when five or more liters are exchanged, the usual gravimetric, volumetric and colorimetric methods of determining blood loss can be in error by as much as a liter.

(2) The determination of circulating blood volume has numerous technical and theoretic shortcomings when applied to the specific situation of hemorrhage. All current methods require the injection of a dye or radioisotope, and the measurement of a sample after a period of mixing. This may take 30 or more minutes. These methods require trained personnel and costly equipment and often lose their accuracy during multiple determinations.

There is need for a simple, inexpensive, accurate and rapid means of determining the amount of blood, plasma and plasma substitutes to be administered. One such method is that of serial microhematocrit determinations. The key to this method is an understanding of the dynamics of hemodilution.

The hematocrit reading falls in response to blood loss, and this fall is due to hemodilution.[9, 10] The source of fluid producing this hemodilution is the extravascular fluid. It was believed that this hemodilution took place in hours or even days.[9] But in both animals [11] and man [12, 13] it has been found that this hemodilution can occur within minutes after hemorrhage. Hemodilution occurs by relative expansion of the plasma volume acting as a buffer to maintain a relatively constant total blood volume. Allen and Semple [11] have shown with serial samplings in dogs during blood loss, that these adjustments in plasma volume occur from moment to moment. We have demonstrated that these changes are as rapid in human beings. Therefore, there should be relatively little change in total blood volume, despite considerable blood loss, until the body loses its ability to compensate. Serial hematocrit determinations consequently reflect blood loss and replacement more accurately than blood volume determinations.

Let us examine the factors which contribute to the degree and speed of variation in hematocrit values. Since the human body has no normal mechanism for rapidly destroying or producing red cells, an acute change in hematocrit represents a change in plasma volume.

What controls plasma volume? [9, 13]

First is red cell volume. When, as in polycythemia vera, the red cell mass is expanded, plasma volume will shrink, resulting in a compensatory hemoconcentration. In response to whole blood loss there is hemodilution by transcapillary refilling of the plasma volume to restore the total blood volume.

Second is the serum protein concentration. A reduction in the total amount of circulating protein reduces the effective intravascular osmotic pressure and thus reduces plasma volume. Conversely, an increase in circulating protein tends to increase plasma volume. This correlation is, at best, only approximate, but can be important in states of protein depletion, such as dietary deficiency and hepatic insufficiency.

Accepted for publication December 29, 1960.
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Third is the salt concentration in the body. In salt loss the extracellular fluid compartment shrinks. The water and salt in the plasma is in equilibrium with extracellular fluid and thus, plasma volume diminishes. Conversely, when salt is retained in the body, the extracellular fluid, including plasma volume, increases.

The rate at which hemodilution takes place varies with other factors.[9, 12] First is the amount of extracellular fluid which is available for the hemodilution. In cases of severe dehydration and malnutrition, there may be no hemodilution, even with severe blood loss. Second is the rate of blood loss. The faster the hemorrhage, the faster the hemodilution. Third, vasodilatation contributes to the ease with which there can be transcapillary refilling of the plasma volume. During anesthesia there is vasodilatation and this may partly contribute to our observations of more rapid and dramatic changes in hematocrit readings during surgery and anesthesia than those reported in the literature during acute trauma and other hemorrhage. Fourth, the lower the systolic blood pressure, the more readily the fluid can permeate the vessel wall to establish equilibrium between intravascular and extravascular compartments.

We have studied over 200 patients with serial microhematocrit determinations during various degrees of surgical hemorrhage. Samples of blood were drawn before anesthesia, on arrival in recovery room and at intervals thereafter. In instances where blood was transfused at rapid rates and where the estimation of under or over-transfusion was difficult, samples were drawn during operation. Our samples were usually from the arm, jugular or femoral veins. Microhematocrit determinations were made from capillary tubes spun for three minutes in an ultra-centrifuge at 15,000 r.p.m. The technique is simple, accurate, reproducible and requires five minutes from the time of veni-puncture. The information obtained proved to be a valuable index during and after operation for fluid therapy requirements in cases of massive transfusion, dehydration and plasma loss.

The application and reliability of serial microhematocrit determinations are shown by the following cases.

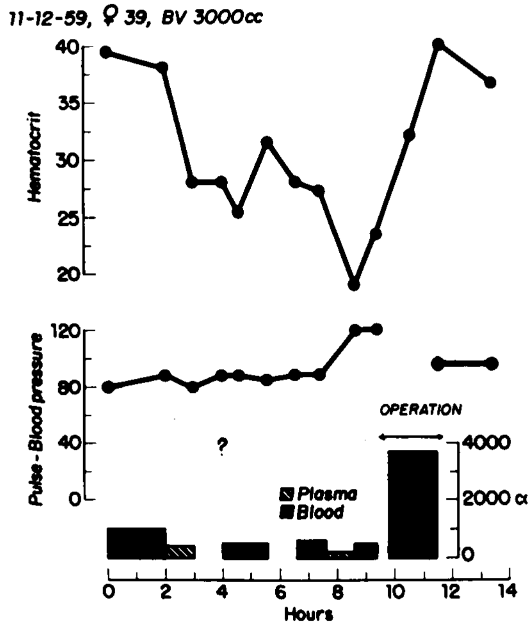

FIG. 1. Case 1. After two hours of surgery, falling hematocrit reading despite transfusions in the recovery room (see text).

CASE REPORTS

Case 1 (*Fig. 1*). A 39 year old woman, weighing 50 kg., with an ideal blood volume of 3,000 ml. underwent a radical Shauta hysterectomy for cancer of the cervix. During the two hours of operation she lost an estimated 1,350 ml. of blood and was transfused 1,000 ml. of whole blood. The preoperative hematocrit was 39.5 and the preanesthetic blood pressure was 90/60 with a pulse of 96. On arrival in recovery room her blood pressure was 70/50 and pulse 88, and the postoperative hematocrit reading was 38.0. In the next hour she was given 700 ml. of 5 per cent dextrose in water, 300 ml. of isotonic saline and 300 ml. of plasma. Her blood pressure and pulse remained unchanged during this period, but the hematocrit reading fell to 28. During the second postoperative hour her blood pressure fell to 50/? without an appreciable change in pulse. The hematocrit reading remained at 28. At this point an infusion of blood was started. Her blood pressure rose to 70/50, but the hematocrit reading remained low. During the course of the following four hours, despite the infusion of 1,750 ml. of whole blood, 250 ml. of anti-hemophilic plasma, 300 ml. of saline and 350 ml. of dextrose in water, her hematocrit value reached a low of 19. This indicated that severe hemorrhage was occurring and upon re-exploration, several large open vessels were found and ligated. During the second operation she was given 4,000 ml. whole blood and 500 ml.

anti-hemophilic plasma. The hematocrit determination halfway through operation was 40 and remained between 36 and 40 throughout the next 24 hours.

The most significant indication of continued blood loss in the recovery room was the inability to maintain a normal hematocrit despite transfusion. Bleeding through to the dressings was not apparent because of two large packs that had been placed in the pelvis for hemostasis. The patient's pulse did not change appreciably and her blood pressure which had always been moderately hypotensive, did not reflect the degree of hypovolemia that was apparent from the changes in the hematocrit. If the hematocrit value had not been observed to drop to 19, she might well have remained in the recovery room without re-exploration until late at night when the staff available might have been inadequate to cope with the situation.

Case 2. An obese, hypertensive 57 year old woman, weighing 91 kg., with an ideal blood volume of 5,000 ml. underwent two hours of extensive pelvic surgery for ovarian carcinoma. The hypertension had been controlled preoperatively with Rauwolfia compounds and diuretics. Her blood pressure on admission was 140/78 and her hemoglobin three days preoperatively was 15.0 Gm. The preanesthetic hematocrit reading was 40.5 and the blood pressure, 155/85. Just before the surgical incision, her blood pressure was 120/70 and pulse, 60. Shortly after the incision was made it was apparent that the blood loss would be great and the operation extensive. Therefore, seven minutes after the incision, the infusion of the first unit of blood was started. The blood pressure had already fallen to 95/60. The pulse remained essentially the same. Within the first 15 minutes of surgery her blood pressure fell to 60/40, blood was administered by pressure as rapidly as possible. After 40 minutes of operation, 2,000 ml. of blood had been given. Blood pressure was 70/50, the pulse was difficult to palpate and the hematocrit value was 33. During the next 20 minutes the pulse and blood pressure became imperceptible. Then, after an additional 1,800 ml. of blood, the blood pressure rose to 110/80. The hematocrit reading at this time was 28, just 12 minutes after no perceptible circulation. The operation was completed an hour and 10 minutes later; and after 1,200 ml. more blood she arrived in recovery room with a blood pressure of 125/85, a pulse of 100 and an hematocrit value of 41.5. During the operation the patient received a total of 5,000 ml. of blood, 150 ml. of 5 per cent dextrose in water, 300 ml. of normal saline and 250 ml. of anti-hemophilic plasma. The estimated blood loss was between 5,000 and 6,000 ml. The patient's blood pressure remained between 135/80 and 160/80 with pulse of 100 and an hematocrit value between 39 and 40 for the rest of the evening. The patient was not given further blood in the next 24 hours.

In this case hemorrhage was so profuse that the nurses could not weigh sponges and packs as fast as they were discarded from the surgical field. During the two hours of operation, her hematocrit reading went from 40.5 to 33 to 28 to 41.5. Had we drawn samples during the 20 minute interval between the hematocrit determinations of 33 and 28 at the time when there was no perceptible circulation and when the replacement was obviously inadequate, the reading would probably have been even less than 28. The changes in hematocrit values were probably not instantaneous, but surely offered a shorter lag interval than the best gravimetric and volumetric estimates our busy nurses could offer. When one is replacing a patient's entire blood volume in two hours and managing the anesthesia for a difficult operation at the same time, there must be a guide more reliable than pulse and blood pressure to the adequacy of blood replacement. Frequently vital signs are unchanged until 15 per cent or more of total blood volume is lost. It is also common to have blood pressure changes unrelated to blood loss and there is no clear indication from blood pressure that more blood is replaced than has been lost. The stable clinical picture and the minimally fluctuating hematocrit readings during the recovery room course without further transfusion indicated our blood replacement was correct.

Case 3. An 81 year old woman, weighing 61 kg., with an ideal blood volume of 3,660 ml., underwent a pelvic operation lasting one hour and 15 minutes. During this time her blood pressure and pulse were within normal limits. The estimated blood loss was about 500 ml., and as her vital signs and clinical appearance did not suggest hypovolemia, she was not given blood in the operating room. She did, however, receive 500 ml. of 5 per cent dextrose in water and 400 ml. of isotonic saline. The hematocrit reading before anesthesia was 46.5. On her arrival in the recovery room her hematocrit value was 35.0, her blood pressure 130/70 and pulse, 92. Fifteen minutes later her blood pressure had fallen to 100/70 and forty-five minutes later was not perceptible. Her respirations were shallow and her skin pale and warm. She was given methoxamine (Vasoxyl) 10 mg. intramuscularly and 10 mg. intravenously and her blood pressure returned to 130/70 and then to 160/70. Thirty minutes after the vasopressor had been given her blood pressure was down to 80/60 and her pulse was 72. The hematocrit reading at this time was still 35.0, which indicated that there was no further blood loss since the end of operation. The initial hematocrit value of 46.5 led us to believe that she had a depleted blood volume with profound hemoconcentration due to dehydration. The 900 ml. of fluid given during surgery was a source for hemodilution. Hence, the drop in hematocrit value of 11.5 points after a relatively small blood loss. The short duration of blood pressure response to the vasoconstrictor further bore out this impression. She was given 500 ml. of whole blood and her blood pressure gradually rose to 120/60, and the pulse remained between 70 and 80. The hematocrit value rose to 41. Her vital signs remained stable throughout the afternoon. Her hematocrit reading did not fall below 38 and she was discharged to her room in good condition.

This case demonstrates another facet of fluid balance. Blood loss was not measured accurately here since it probably was no more than 500 ml., and this amount is not generally replaced. In this patient, however, the 500 ml. probably represented between 15 and 20 per cent of her total circulating volume. Therefore, small changes in this already diminished blood volume produced large changes in hematocrit value, especially since the parenteral fluids administered during operation were available for the hemodilution. The changes in blood pressure and pulse, however, were not apparent until after she was in the recovery room. Obviously, the correction in blood pressure by vasoconstrictors cannot have a prolonged effect in such a person and indeed, transfusion was found to be necessary to remedy the situation. Had not the change in her hematocrit reading been properly interpreted, she might have been maintained with prolonged vasoconstrictor therapy rather than the indicated fluid therapy.

Case 4 (*Fig. 2*). A 51 year old man, weighing 102 kg., with an ideal blood volume of 6,600 ml., underwent a six-hour esophagogastrectomy for adenocarcinoma of the esophagus. During the operation both pleural cavities, as well as the peritoneal cavity were opened. The dissection was extensive and difficult. The anesthetic course was not remarkable. Respiration was maintained by a mechanical respirator for much of the operation. A total of 2,000 ml. of blood was given during the procedure which appeared to be adequate replacement for that lost. His blood pressure at the beginning and end of operation was 140/90; his pulse increased from 80 at the beginning to 100 at the end of operation. In the recovery room his blood pressure for the first hour and a half was about 110/60 and the pulse about 140. The patient was given meperidine 75 mg. for pain and discomfort. Following this he became more comfortable, his blood pressure rose toward its normal level but the tachycardia of 120 to 140 persisted. Two hours after admission to recovery room, his hemoglobin and hematocrit were determined. They were respectively 18 Gm. and 51. Throughout that evening and early next morning his vital signs remained unchanged. A small volume of intravenous fluids was continued. Other than a temperature between 101.8 and 102.6, his condition was not remarkable. At 8 o'clock of the first postoperative morning, while still in the recovery room, his skin was observed to be cool and damp. His blood pressure was 105/90; his pulse, 138; his temperature, 101.8. An hematocrit determination

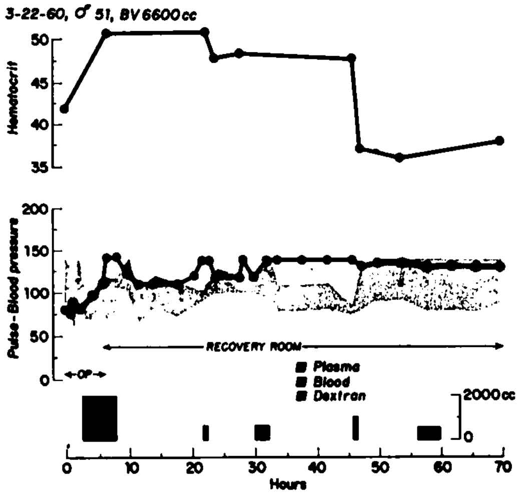

FIG. 2. Case 4. Hemoconcentration due to plasma loss in denuded areas in thoracic and peritoneal cavities (see text).

was found to be 51. He was given two units of (600 ml.) plasma. When the plasma had been absorbed, the hematocrit at 10:30 a.m. was 48; his blood pressure 125/100 and pulse, 120. During the remainder of the morning and afternoon his condition remained about the same with a blood pressure between 120 and 140 systolic and a pulse of between 100 and 140. The patient was unable to cough and frequent tracheal suction was necessary to maintain a reasonably clear airway. At 2:10 p.m. of the first postoperative day his hematocrit reading was 48.5. At 4:30 p.m. another two units of plasma were infused. The vital signs remained unchanged. His elevated temperature and pulse rate continued throughout that night and the second postoperative morning. His lower respiratory tract continued to collect secretions. At 7:30 of the second postoperative morning his pulse became faint with a blood pressure of 95/70. The hematocrit was determined and found to be 48.0. One thousand milliliters of Dextran was administered rapidly, and 30 minutes later his hematocrit value was 37 and the blood pressure was 125/80. He was placed on a cooling mattress to reduce his temperature and given another 2 units of plasma. After the second unit of plasma had infused at about noon of the second postoperative day, his hematocrit value was 36. His blood pressure was relatively stable at 140/90, and his pulse ranged between 120 and 140. The patient's condition became more stable. The tachycardia persisted but the blood pressure remained in the 140/80 range throughout the entire afternoon and evening and on into the third postoperative day. One unit of whole blood was given the evening of the second postoperative day and on discharge from the recovery room on the third postoperative morning his hematocrit determination was 38. During his total recovery-room stay he received 1,800 ml. of plasma, 1,000 ml. of Dextran and 600 ml. of isotonic saline. At each occasion of his shock-like picture his hematocrit value was found to be high and his shock was treated with rapid administration of plasma or plasma substitute. This man was losing plasma into his pleural cavity and the plasma was being drained off by underwater chest drainage. We have found that high hematocrit values postoperatively, especially associated with oliguria, represents plasma or fluid loss, and must be treated with plasma or plasma substitutes. This man had two thoracenteses during his recovery room stay; fluid was also being lost by way of chest drainage and more was accumulating in the third space [14] compartments in both his chest and abdominal cavities. He undoubtedly would have been spared his hypotensive episodes had he been given plasma and Dextran as soon as the hematocrit determination showed hemoconcentration. Treating this man's shock with either vasoconstrictor or whole blood would have been unsatisfactory and probably harmful.

Discussion

In all four of the cases cited, information was obtained from serial hematocrit determinations which helped to clarify the state of fluid balance of the patient, and therefore, led to faster and more rational treatment. These cases demonstrate four different categories in which serial microhematocrit readings were of value. In the first case the hematocrit determination helped detect otherwise hidden blood loss. In the second case, blood loss was so profuse that conventional methods of determining the rate of transfusion were inadequate, and the hematocrit reading indicated the degree to which we were behind, if at all, in blood replacement. In the third case, the hematocrit determination helped make the diagnosis of a preoperative hypovolemia. This information could have been afforded by a preoperative blood volume determination, but this laboratory work had not been performed because the patient appeared to be in good condition. Here, similar information was afforded by a more simple and less expensive test. In the fourth case the high hematocrit reading was recognized as an indication of fluid and plasma loss, not over-transfusion (a common misinterpretation of postoperative hemoconcentration). The correct interpretation of the high hematocrit reading led to rational plasma and plasma substitute therapy and this line of treatment was continued after he left the recovery room.

Not all of the patients followed had such dramatic changes in hematocrit reading, and admittedly, the conventional methods of determining transfusion therapy were adequate for many patients. The number of patients who benefitted by having had serial hematocrit determinations performed was large enough, however, for us to make this procedure routine whenever extensive operation is anticipated.

In static situations such as chronic anemia or debility of a chronic nature, the determination of total blood volume is helpful in the evaluation of the patient. When such a patient is prepared for operation information about his blood volume is essential. Under the dynamic conditions of hemorrhage due to trauma or operation or plasma loss due to ileus, burns and open wounds and of rapidly changing intravascular volumes such as seen with extracorporeal pumps during open-heart and other perfusion procedures, the rapid shift in fluid compartments makes blood volume determinations less meaningful.

Our experience with serial hematocrit determinations in over 200 cases shows that hemodilution occurs within a few minutes. Hematocrit and hemoglobin values reflect only relative concentrations, and therefore, a single hematocrit or hemoglobin value is insignificant, but the change in these values during serial determinations gives insight into the changing fluid compartments in dynamic situations.

The hematocrit value is not our only guide to fluid therapy. The entire clinical picture is necessary for intelligent interpretation of serial hematocrit determinations. Blood pressure, pulse, urine output, the observation of possible sources of fluid or blood loss must all be scrutinized carefully before hematocrit changes can be understood.

Summary

An accurate, rapid, inexpensive, sensitive and simple method for determining proper blood replacement is essential because: (1)

Current methods of determining blood loss are only grossly accurate, especially during massive transfusion. (2) Blood volume determinations are time consuming, costly and complicated. (3) The plasma volume acts as a buffer to maintain a relatively constant blood volume, and adjustments in plasma volume tend to minimize changes in total blood volume despite blood loss.

The hemodilution which results in a falling hematocrit reading occurs within minutes of blood loss.

Serial hematocrit determinations reflect changes in degree of hemodilution. They, therefore, reflect the adequacy of blood replacement during the dynamic situations of hemorrhage during surgery and trauma. They give information regarding the degree of plasma loss from burns, ileus, open wounds and denuded serous surfaces such as peritoneal and pleural cavities. They follow the shifts in blood compartments seen in the rapidly changing intravascular volumes that occur with extracorporeal pumps during open-heart and other perfusion procedures.

Over 200 cases with varying degree of blood loss were followed with serial microhematocrit determinations. The results of the determinations were invaluable guides to correct and timely blood and plasma administration in cases of surgical hemorrhage, dehydration and plasma loss.

The microhematocrit determination takes five minutes from time of venipuncture. It is reproducible, inexpensive, simple and accurate.

REFERENCES

1. Pierce, V. K., Boyan, C. P., and Masterson, J. G.: Studies on venous blood pressure in patients undergoing major surgical procedures, Surg. Gynec. Obstet. **96**: 310, 1953.
2. Padhi, R. K., Nanson, E. M., and Lynn, R. B.: Hemodynamic changes in graded hemorrhage with special reference to peripheral circulation, Ann. Surg. **148**: 827, 1958.
3. Borden, F. W.: Loss of blood at operation, method for continuous measurement, California Med. **87**: 91, 1957.
4. LeVeen, H. H., and Rubricus, J. L.: Continuous automatic, electronic determinations of operative blood loss, Surg. Gynec. Obstet. **106**: 368, 1958.
5. Baronofsky, I. D., Treloar, A. E., and Wangensteen, O. H.: Blood loss in operations: statistical comparison of losses as determined by gravimetric and colorimetric methods, Surgery **20**: 761, 1946.
6. Gatch, W. D., and Little, W. D.: Amount of blood loss during some more common operations, J. A. M. A. **83**: 1075, 1924.
7. Albert, C. A., Thergaonkar, R. D., Henley, E. E., Bain, M., Rafii, A., and Albert, S. N.: Value of blood volume determinations in surgical procedures, Surg. Gynec. Obstet. **107**: 685, 1958.
8. Balagot, R. C., Grove, W. J., Sadove, M. S., and Jobgen, E.: Why blood volume in surgery, Exhibit, American Medical Association Convention, June 1960.
9. Moore, F. D.: Metabolic Care of the Surgical Patient. Philadelphia, W. B. Saunders Co. 1959, pp. 135–260.
10. Mollison, P. L.: Blood transfusion in clinical medicine, ed. 2. Springfield, Illinois, Charles C Thomas, Publisher, 1956.
11. Allen, T. H., and Semple, R. E.: Effects of repeated sampling on plasma and cell volumes in dogs as estimated with small and large amounts of T-1824, Amer. J. Physiol. **165**: 205, 1951.
12. Albert, S. N., Spencer, W. A., Albert, C. A., Shibuya, J., and Henley, E. E.: Blood volume determinations with radioactive isotopes and observations on blood volume fluctuations, U. S. Atomic Energy Comm. TISE 1958.
13. Gregersen, M. I., and Rawson, R. A.: Blood volume, Physiol. Rev. **39**: 307, 1959.
14. Randall, H. T.: Water and electrolyte balance in surgery, Surg. Clin. of N. Amer. **32**: 1, 1952.