A practical method for determining the amount of blood passing over during direct transfusion / E. Libman and R. Ottenberg.

A Practical Method for Determining the Amount of Blood Passing Over During Direct Transfusion

E. LIBMAN, M.D.
AND
R. OTTENBERG, M.D.
NEW YORK

Reprinted from The Journal of the American Medical Association
March 7, 1914, Vol. LXII, pp. 764-767

A PRACTICAL METHOD FOR DETERMINING THE AMOUNT OF BLOOD PASSING OVER DURING DIRECT TRANSFUSION *

E. LIBMAN, M.D., AND R. OTTENBERG, M.D.
NEW YORK

It is obvious that it would be a great improvement in the therapeutic application of direct blood transfusion if there were some accurate method of determining, during the actual course of the transfusion, how much blood is being transfused. As with all forms of medication, so with transfusion, the correct dosage may be the determining factor in obtaining a proper therapeutic result.

Up to the present there has been no such method, and surgeons have generally followed some rough and ready rule, such as to transfuse for from fifteen to forty-five minutes, or until the donor showed distinct signs of acute anemia, or until the percentage of the patient's hemoglobin showed a rise.

An accurate method of estimating the amount being transfused would be of especial importance from two points of view: (1) in order to avoid any danger to the donor from the taking of an excessive amount of blood; (2) to determine when the patient has received enough to obtain the desired therapeutic effect.

Earlier studies on the blood-pressure of both patient and donor during transfusion have convinced us that variations in the blood-pressure are too irregular to be of the slightest assistance in determining the amount of blood which is being transfused. In fact, the compensatory powers of the body, in regard to the blood-pressure, are rather remarkable, the pressure of donor and patient often remaining practically unchanged in

* From the Mount Sinai Hospital, New York; work done with the aid of the Eugene Meyer, Jr., Fellowship of the Mount Sinai Hospital.

spite of the transfer of a considerable amount of blood. The variations in the pulse-rate of either donor or patient are likewise too irregular and too subject to disturbance from psychic causes to be of help.

The rise in the percentage of hemoglobin, on the other hand, when the patient's hemoglobin is low at the start of the transfusion, is a phenomenon which occurs with great regularity and is susceptible of very accurate measurement. In fact, for three years before the method of calculation to be described was followed, we and others used the hemoglobin rise as a rough guide in the course of transfusion. The question, however, of how high the hemoglobin can be raised in a given case, cannot be answered, except by precise calculation.

The principle on which our method of calculation is based is a simple arithmetical calculation. If two fluids, having different percentages of any substance in solution are mixed in unequal volumes, the percentage strength of the resulting mixture is the sum of the products of volume multiplied by the percentage of each solution, divided by the volume of the total mixture. Thus, if one volume of a 50 per cent. solution is mixed with two volumes of a 100 per cent. solution, the percentage strength of the resulting solution will be:

$$\frac{(1\times 50)+(2\times 100)}{1+2}=83.3 \text{ per cent.}$$

In order to calculate the exact amount of blood, and not merely the relative volume transfused, it is necessary to know the blood volume of donor and patient. As blood volume, even in health, undergoes slight variation, and there is at present no practical method for accurate determination of blood volume, it is impossible at present to know the blood volume in each instance with great accuracy. Nevertheless, a large number of experimental observations by various authors have shown that blood volume bears a rather constant relation to body-weight. The conclusions of different authors on this subject do not all agree; but from a large number of accurate determinations by various methods it has recently become clear that the original estimate of Welcker in 1858, accepted for many years—that human blood-weight is approximately one-thirteenth of the body-weight — is wrong, and that the actual proportion of

blood is much smaller and corresponds more nearly to one-nineteenth of the body-weight.[1]

On this basis, disregarding for the time being possible variations in the blood volume, the approximate weight of blood of the donor and of the patient is easily calculated. If, then, it is determined that it is safe to take from the donor any known proportion of his total blood-weight, we have all the data necessary to figure out to what percentage the hemoglobin of the patient will be raised by transfusing this predetermined weight of blood.

An example will make this clear: The donor weighs 190 pounds; the approximate weight of his total blood is therefore 10 pounds, and if it is determined that it is safe to take one-fourth of his blood, then 2½ pounds can be taken. His hemoglobin is 100 per cent. The patient weighs 114 pounds; his approximate blood-weight is therefore 6 pounds. His hemoglobin is 30 per cent. The result then of mixing 6 pounds of 30 per cent. blood with 2½ pounds of 100 per cent. blood is expressed by the following formula:

$$\frac{(6\times 30)+(2.5\times 100)}{6+2.5} = 50.5 \text{ per cent.}$$

It may be seen that the result of transfusing 2½ pounds of blood, or a quarter of the donor's blood volume, will be to raise the patient's hemoglobin from 30 to 50 per cent.

Observations made during the course of the earliest transfusions at which we were present indicated that if more than one-quarter of the donor's blood was taken, symptoms of collapse, ordinarily of short duration, were apt to supervene. We have, therefore, usually reckoned on transfusing that amount, although as much as one-third can often be safely transfused.

The donor should be sharply watched as soon as the hemoglobin rise of the patient nears a point that indicates that one-quarter of his blood has been transfused. Larger amounts of blood can be removed, if, when near this point, the flow be made intermittent by interruptions of the flow for a few minutes at a time.

---

1. Behring: Beitr. z. exper. Therap., 1899, i, 1054. Haldane and Smith: Jour. Physiol., 1900, xxv, 331. Plesch: Ztschr. f. exper. Pathol. u. Therap., 1909, vi, 380. Smith: Trans. Path. Soc., London, 1900, ii, 311. Oerum: Deutsch. Arch. f. klin. Med., 1908, xciii, 356.

Scattered warnings in the literature as to the danger of acute dilatation of the patient's heart from excessive transfusion led us, at first, to make a similar calculation as to the amount of blood which a given patient could receive. Experience, however, in over one hundred transfusions has shown that this is necessary only when there is a disparity between the size of patient and donor, as in the transfusion of children or small adults. Usually the circulation adjusts itself rapidly and easily to the increase of blood volume, and it is practically impossible (except in the preceding instances) for a donor, without collapsing to give up enough blood to embarrass seriously the circulation of an adult recipient. In fact, in both donor and patient, circulatory embarrassment resulting from transfusion appears to depend on the speed with which the blood is transfused rather than the amount transfused; and by transfusing slowly it is generally possible to avoid any unfavorable symptoms on the part of either.

In over 130 transfusions,[2] during which we were able to control the amount to be transfused, we saw no instance of any circulatory embarrassment. But we know of a number of other instances in which this did occur. We have records of two of these. The one was a case of subacute bacterial endocarditis resulting in death a few hours after the transfusion and showing, post mortem, numerous infarctions in the heart-muscle. The other was a case in which an unjustifiably large transfusion was followed by edema of the lungs and hematuria lasting two days. This was the type of case in which trouble could have been easily avoided if a calculation had been made, as there was great discrepancy in the sizes of donor and patient. The donor weighed 190 pounds and had 95 per cent. of hemoglobin. The patient weighed 97 pounds and her hemoglobin was 15 per cent. Calculation shows that if 2½ pounds of blood (equivalent to one-quarter of the donor's or one-half of the patient's blood volume) had been transfused the hemoglobin would have been raised to 31 per cent. Instead it was raised in twenty minutes to 52 per cent. (indicating that over 4 pounds of blood had been transfused[1]).

---

2. Performed by the various surgeons on the staff of the Mount Sinai Hospital.

In cases in which cardiac insufficiency with edema is present (particularly as seen in severe grades of pernicious anemia) we are in the habit of putting the patient on the Karell diet for two days (no other food than 900 c.c. of milk a day and no water). The diuresis obtained gives room in the circulation for the blood to be later added by transfusion.

There are several possible sources of error in this calculation, due to variations in the blood volume. The first of these, of course, is due to loss of blood in acute hemorrhage. When the hemorrhage has occurred within a few hours of the transfusion, if it is possible to form some idea of the amount of blood lost, an allowance can easily be made for this. When the hemorrhage has occurred more than from twelve to twenty-four hours before the transfusion, it is probably unnecessary to make any allowance, because, after hemorrhage, the circulating blood very rapidly takes up plasma from the tissues, and this probably brings the blood volume to somewhere near normal. Variations in the blood volume undoubtedly occur in chronic anemias and other diseases, but our knowledge of them at present is too scanty to allow us to take them into calculation. Probably they are not great enough to affect the result seriously.

Another source of error which enters into practically every case, and for which it is impossible to make allowance, is the absorption of plasma from the circulation by the tissues. This is seen, for instance, in the almost continued rise of hemoglobin for some hours after transfusion. In practically every one of the forty cases in which the hemoglobin was estimated again within from a few hours to twenty-four hours after the transfusion, the hemoglobin percentage was found to have risen from 3 to 10 per cent. above the height reached at the end of the transfusion (exclusive, of course, of those cases in which hemorrhage continued). In all of the cases in which hemoglobin estimations were made within one or two hours of the end of the transfusion, it was found that most of the subsequent rise had already taken place. It appears, therefore, that concentration of the blood by removal of plasma goes on very rapidly, and it is obvious that some of it must go on even during the transfusion.

If we make any allowance for this, it will be to raise slightly the level to which it is safe to carry the hemo-

globin, as, on account of the process of blood concentration, the apparent amount calculated from the hemoglobin rise will be slightly larger than the real amount already transfused at any given moment. Our experiences, however, in which accurate weighings of donor or patient were used to control the calculation, showed that, while these sources of error may exist, in most cases they are not large enough to affect materially the result of the calculation.

We have observations on the hemoglobin rise in ninety-nine transfusions. In thirty-two of these, calculations were made on the assumption that it was safe to transfuse one-quarter of the donor's blood volume; and these calculations were used as a guide in the transfusion. In the great majority of cases, the hemoglobin was raised to approximate the calculated amount. In only one of these cases in which the calculated amount was not exceeded was there any collapse of the donor. In nine cases the calculated hemoglobin limit was exceeded by less than 5 per cent., and in two cases it was exceeded by respectively 9 and 10 per cent. without any serious symptoms on the part of donor or patient.

It is possible, of course, not merely to calculate the hemoglobin rise to be anticipated from transfusing a given volume of blood, but also to estimate, from an observed hemoglobin rise, the volume of blood which must have been transfused. This is done by simple algebraic calculation, substituting the unknown factor, X, for the volume of blood transfused, in the preceding formula. Thus, the illustration previously given may be taken. Suppose the donor weighs 190 pounds and has a hemoglobin of 100 per cent. The patient weighs 114 pounds and has a hemoglobin of 30 per cent. The observed rise in hemoglobin is to 50.5 per cent. Then, substituting X for the unknown amount of blood transfused, we have the equation:

$$\frac{6\times 30+(X\times 100)}{6+X}=50.5$$

Simplifying which, we get: $X = 2.5$ pounds of blood transfused.

In order to test the accuracy of the method of calculation, we have by means of this formula calculated back from the observed rise in hemoglobin to the amount of blood transfused in eleven cases in which the amount

of blood transfused was determined by accurate weighings of either donor or patient immediately before and after transfusion. The correspondence between the calculated and actually transfused amount has been surprisingly close, as the accompanying table shows.

In the weighings, of course, allowance was made for the fluids taken by donor and patient, as the case may have been, the fluids being carefully measured in each instance. It is noticed that, except in three instances, the agreement between the calculated amount and the observed amount of blood transfused was so close as to

BLOOD TRANSFUSION IN ELEVEN CASES

Case No. (New Series)	Patient		Donor		Per Ct. of Hb. Rise Observed	By Calcul. of Bl. Transf., Lbs.	By Wgt. of Bl. Transf., Lbs.	Determinations and Remarks*
	Wgt.	Hb.	Wgt.	Hb.				
	Lbs.	%	Lbs.	%				
5	160	30	190	90	44	2.5	2.7	Donor's loss.
7	160	45	144.50	90	58	3.4	5	Donor's loss; severe collapse; profuse sweating.
10	120	23	161.25	76	42	3.5	3.3	Donor's loss.
16	22.56	33	120	76	50	0.71	0.6	Patient's gain.
18	130	53	211.87	80	60	2.7	3	Donor's loss.
31	44.81	21	178.37	85	39	0.9	1.06	Patient's gain.
37	119	13	162.81	87	23	0.84	1.62	Donor's loss; slow transfusion; flow lasting 1 hr. 27 min.; donor on table 2½ hrs.
39	120	55	151.50	82	60	1.4	1.3	Donor's loss.
43	120	36	169	84	53	3.4	3.4	Donor's loss.
49	95	31	158.25	86	52	3	3	Donor's loss and patient's gain.†

* The calculations are based on the donor's loss or the patient's gain, as indicated respectively.

† The patient gained 2 pounds, 12 ounces. The donor lost 3 pounds, 4 ounces. The discrepancy is explained on the assumption that each of them lost 4 ounces by sweating.

leave no doubt of the value of the calculation. In these three instances special disturbing factors entered. Thus, in Case 7, in which the donor lost a great deal more weight than he was calculated to have lost by transfusion of blood, the additional loss probably is partly accounted for by a severe collapse, during which exceedingly profuse sweating occurred. In Case 37, there was only a very small amount of blood transfused in proportion to the size of the patient; and here again the difference is probably accounted for by the loss of weight by sweating during the unusually long time (two and one-half hours) that the donor was on the operating-

table. The discrepancy of almost a pound, in Case 45, is hard to account for, but was probably due to sweating.

It is noticed that in all of the cases in which there was a discrepancy between the calculated and the observed blood transfer, it was the donor who was weighed and the discrepancy was always in the same direction, namely, the donor apparently lost more weight than he should have, by calculation. In the three instances (Cases 16, 31 and 49) in which it was possible to weigh the patients, the agreement between the calculated and the weighed amounts of blood was strikingly close. In most of the cases, however, the patient was far too ill to be put on the scales before transfusion, and the patients' weights which are used as a basis of calculation are generally approximations arrived at from the weight which the patients were known to have had before illness. This, of course, constitutes also a slight source of inaccuracy in calculation.

A recent indirect transfusion by the syringe method in which, of course, the exact amount of blood transfused was precisely known, has also given us the opportunity to confirm the correctness of the calculation. In this case 900 c.c. (approximately 1.8 pounds) of blood were transfused. The patient's weight was between 150 and 160 pounds. His hemoglobin was 38 per cent. The hemoglobin of the transfused blood was 90 per cent. According to calculation, the patient's hemoglobin should have been raised to 47.3 per cent. by the transfusion of the 900 c.c. It was actually raised to 48 per cent. The calculation used was the following:

$$\frac{(8\times 38)+(1.8\times 90)}{9.8}=47.3 \text{ per cent.}$$

Close examination of the figures in the table reveals the fact that in a number of cases the amount of blood transfused was very large in proportion, either to the blood volume of the donor or of the patient. Thus, in Case 10, the donor, weighing 161 pounds, had approximately 8.4 pounds of blood; the 3.3 pounds which he lost was 40 per cent. of his blood-weight. He fainted on attempting to stand ten minutes after the transfusion, but was restored without stimulation, and had no further trouble.

In Case 43, the donor weighed 169 pounds, and had 8.8 pounds of blood, so that the 3.4 pounds of blood

which he lost represented 39 per cent. of his total blood volume. He rose and walked away from the operating-table and had no symptoms of blood-loss whatever.

With regard to the amount that can be received by the patient, Case 31 is interesting. The child weighed 44 pounds. Its presumptive blood-weight was 2.3 pounds, and the amount transfused, therefore, was almost one-half as much as the child's own blood volume. The vessels were not depleted before transfusion, as this was not a patient who had been suffering from acute hemorrhage.

We have a number of other observations in which no weighings were made, but in which calculation from the hemoglobin rise showed that the amount of blood transfused must have been very large in proportion to the patient's own blood volume. Thus, in Case 4, Old Series, the hemoglobin was raised from 30 to 90 per cent., and two days later was 110 per cent. This was in a new-born infant suffering from melena neonatorum.

In Case 12, Old Series, a child of 4, suffering from hemophilia, the hemoglobin was raised from 11 to 70 per cent., and two hours after the transfusion it was 90 per cent. In this case the child was stuporous and had dilated pupils for two days after the transfusion, but recovered completely.

In Case 13, Old Series, also that of a child, which had a chronic anemia from osteomyelitis, the hemoglobin was raised from 24 to 75 per cent. in twelve minutes, with subsequent complete recovery. In adults there were never any such striking rises, simply because it would have taken the blood of several donors to produce such marked increase in the hemoglobin. It would seem, however, on general principles that certainly in persons past middle life, or with any tendency to arteriosclerosis, one should be cautious about transfusing more than perhaps one-quarter as much as the patient's own blood volume.

The method of calculation which we offer is applicable in nearly all cases which need transfusion. There is only one class of cases in which it cannot be applied, namely, cases which are not anemic, that is to say, cases in which the patient's hemoglobin percentage is approximately the same as that of the donor. Practically the only cases of this kind that come to transfusion are cases of acute hemorrhage in previously healthy persons. In

these cases, of course, there is no hemoglobin rise at the time of transfusion. In over one hundred cases in which we have observed the hemoglobin closely, there were only four cases of this kind.

SUMMARY

1. It is as necessary to control the amount of blood transferred during a direct transfusion as it is to control the dosage in any other therapeutic procedure.

2. A simple arithmetical formula is given by which it is possible to calculate how much rise in the percentage of hemoglobin will be obtained by transfusion of a given volume of blood. The formula is:

$$\frac{\text{(Patient's blood weight} \times \text{patient's hemoglobin per cent.)} + \text{(weight of blood transfused} \times \text{donor's hemoglobin per cent.)}}{\text{Patient's blood weight} + \text{weight transfused (in pounds)}} = \text{Hemoglobin per cent. reached.}$$

The patient's blood-weight is estimated as one-nineteenth of the body-weight.

3. The amount to be transfused may be decided arbitrarily, with regard to the patient's need, or with regard to the donor's ability to give up blood.

4. It is always safe to take one-fourth of the donor's blood; it is often safe to take as much as one-third of the donor's blood volume, provided the transfusion is not done too rapidly.

5. Though the danger of overloading the circulatory system of the patient is not as great as has been thought, yet probably it is not wise to add more than one-fourth, or at most one-third, as much blood as a person of the patient's weight normally has. This needs to be taken into account only in children or very small adults, transfused from large donors, because in most cases a single donor will collapse before he can give enough blood to embarrass the circulation of a full-grown adult patient. If more than one donor is used this part of the calculation becomes of great importance.

6. By means of exact weighings of either donor or patient or both, before and after transfusion, in a series of eleven cases, we have shown that the formula which we give corresponds quite closely to the actual amount of blood transfused.

7. By using this calculation as a guide and determining before each transfusion the point to which the hemoglobin ought to be raised, it is possible to avoid untoward symptoms in either donor or patient. We have demonstrated this in a large number of transfusions.

8. The method is of value, not only for determining the amount of blood being transferred during direct (vessel to vessel) transfusions, but also for determining beforehand how much blood ought to be transferred during indirect transfusions (whether by syringe or some other method).

We wish to express our obligations to the surgeons on the staff of Mt. Sinai Hospital for the privilege of making these studies.