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Brief Report

Calculations in Apheresis

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It's important to work smoothly with your apheresis equipment when you are an apheresis nurse. Attention should be paid to your donor/patient and the product you're collecting. It gives additional value to your work when you are able to calculate the efficiency of your procedures. You must be capable to obtain an optimal product without putting your donor/patient at risk. Not only the total blood volume (TBV) of the donor/patient plays an important role, but also specific blood values influence the apheresis procedure. Therefore, not all donors/patients should be addressed in the same way. Calculation of TBV, extracorporeal volume, and total plasma volume is needed. Many issues determine your procedure time. By knowing the collection efficiency (CE) of your apheresis machine, you can calculate the number of blood volumes to be processed to obtain specific results. You can calculate whether you need one procedure to obtain specific results or more. It's not always needed to process 3× the TBV. In this way, it can be avoided that the donor/patient is needless long connected to the apheresis device. By calculating the CE of each device, you can also compare the various devices for quality control reasons, but also nurses/operators. J. Clin. Apheresis 30:38–42, 2015.

Key words: extra corporeal volume; total blood volume; collection efficiency

INTRODUCTION

For the stem cell transplant program of the hospital you are working, the hematologist is requesting a hematopoietic stem cell product with 4×10^6 CD34 positive cells per kilogram of the patients' body weight from a male autologous donor (height 1.80 m, and bodyweight 88 kg) suffering from multiple myeloma. In the meanwhile, a 39-year-old woman was presented at the emergency unit with a platelet count of 20,000/μL (20×10^9/L), an hemoglobin level of 6.0 g/dL (3.6 mmol/L), and a lactate dehydrogenase (LDH) level of 1,080 U/L. The diagnosis of thrombotic thrombocytopenic purpura (TTP) was suggested, and therefore emergently a total plasma exchange (TPE) with at least one total plasma volume (TPV) is requested.

For a correct, but also safe performance of these requested apheresis procedures without harming donors and or patients, various calculations are needed. In this article, covering calculations in apheresis, we will discuss how to calculate the total blood volume (TBV), the TPV, the body surface area (BSA), and the extra corporeal volume (ECV). Besides that, we will discuss the collection efficiency of the apheresis machines, and in relation to that, how to calculate the number of TBVs to process to collect a specific number of cells with an apheresis machine. Finally, we will describe the hematocrit in relation to the hemoglobin levels.

CALCULATION METHODS

Total Blood Volume

Let's start with the TBV of a human being. If you ask people what the TBV of a human is, many will answer this is approximately 5 L. However, this cannot be right for everybody. Looking round in the world, you will understand that there must be a big difference between a tall and a small man, and a very obese man will have a totally different blood volume compared to a tiny woman. And also for babies and young children

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Abbreviations used: AC, anticoagulant; BMI, body mass index; BSA, body surface area; CBC, complete blood count; CE, collection efficiency; CE_1, collection efficiency type 1; CE_2, collection efficiency type 2; ECV, extra corporeal volume; Hb, hemoglobin; Hct, hematocrit; RBC, red blood cell; T, thrombocyte count; TBV, total blood volume; TPE, total plasma exchange; TPV, total plasma volume; TTP, thrombotic thrombocytopenic purpura

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For Males = $(0.3669 * Ht^3) + (0.03219 * Wt) + 0.6041$

For Females = $(0.3561 * Ht^3) + (0.03308 \times Wt) + 0.1833$

* Ht = Height in Meters
* Wt = Body weight in kilograms

Fig. 1. Nadler's formula to calculate the TBV of a human being based on gender, height, and weight.

TABLE I. Gilcher's Rule of Fives

	Blood volume (mL/kg of body weight)			
	Obese	Thin	Normal	Muscular
Male	60	65	70	75
Female	55	60	65	70
Infant/child	—	—	80/70	—

TABLE II. Total Blood Volume in Relation to the Age

Age group	Approximate blood volume (mL/kg)
Premature infant, at birth	90–105
Term newborn infant	80–90
Children > 3 months	70–75
Adolescents and adults	
Male	70
Female	65

you can't say that they will have a TBV of ~5 L. Because of the differences between the various human beings, various formulas to calculate a more accurate TBV are published. Well known are Nadler's formula and Gilcher's rule of fives [1,2], but the approximate TBV can also be calculated with various other formulas. Nadler's formula (see Fig. 1) is complicated, taking into account the height, weight, and gender of a person. It should be noted that this formula cannot be used for children. It's also important to know that most apheresis equipment is using Nadler's formula to calculate the TBV. That's also the reason that the machine is asking to include gender, height, and weight of the donor or patient prior to a procedure into the parameter settings of the machine.

For children, Linderkamp et al. [3] published already in 1977 model for the prediction of the blood volume of the child depending on the age and gender of the child varying from ~80 mL/kg for the newborn to 70–75 mL/kg for the 11–14 years old child.

In Gilcher's rule of fives, first of all a choice for male, female, or child need to be made. After that, you need to take into account the physics of the person. There is a choice for obese, thin, normal, or muscular. The reason for the difference is secondary to the difference in vascularization between adipose tissue and muscle tissue. Depending on the group your patient is belonging, the TBV must be calculated by multiplying the patient's body weight with the number as given in Table I.

In other calculation methods, the age of the person is the starting point. Similar to the formulas discussed above, the weight is multiplied with a number as given in Table II. For adolescents and adults, a difference between men and women is made. An adult man weighing 80 kg will have a TBV of 80 multiplied with 70, and therefore ~5,600 mL. The female with the same weight will have a TBV of 80 multiplied with 65, so ~5,200 mL.

In the last calculation method discussed here, the body mass index (BMI) is taken into account. Based on the BMI the bodyweight of the person needs to be multiplied with a number as given in Table III to achieve the TBV.

To calculate the BMI, the body weight in kilograms should be divided by the square height in meters (Fig. 2). So when you are 75 kg and having a 1.70 m, you need to divide 75 by square 1.7, and will get a BMI of 26 kg/m^2.

Extra Corporeal Volume

When somebody is talking about the ECV, he or she is talking about the volume of blood which is outside of the body. This is not only the anticoagulated blood which is in the disposable, but also the volume of the collected blood component and the volume in the tubes collected, for instance for laboratory tests. For the safety of the donor or patient, it is suggested that the ECV should be maximally 15% of the TBV. Therefore you absolutely need to know what, besides the TBV, the volume of the disposable you're using is. Working with Cobe Spectra (Terumo BCT), you have to know that some specific disposable sets have a volume of 285 mL. Assume that you will collect 300 mL. The ECV of the patient or donor will be therefore at least 285 + 300 mL is 585 mL. It must be realized that 585 mL is 15% of 3,900 mL. Therefore, one should be alert to perform procedures with this disposable in children and smaller persons, having a lower TBV than 3,900 mL.

Total Plasma Volume

To calculate the TPV of a person, the TBV and the hematocrit (Hct) are needed (see Fig. 3). The Hct is the volume percentage of red blood cells (RBCs) in the TBV. Females normally have an Hct between 36 and 46% (0.36–0.46 L/L). In males this is a little higher namely 44–53% (0.44–0.53 L/L). When there is, for instance, an Hct of 35%, the blood will consist of 35% of RBCs and ~65% of plasma.

TABLE III. Method to Calculate the Total Blood Volume (TBV) in Relation to the Body Mass Index (BMI)

	BMI < 18.5	BMI 18.5–24.9	BMI 25–29.9	BMI >30
Blood volume	80 mL/kg	70 mL/kg	65 mL/kg	55 mL/kg

$$BMI = Wt / Ht^2$$

* Ht = Height in Meters
* Wt = Body weight in kilograms

Fig. 2. Formula to calculate the body mass index (BMI).

$$TPV = TBV * (1 - Hct)$$

Fig. 3. Calculation method for the total plasma volume (TPV).

By knowing the TBV and the Hct, the TPV of the patient can be calculated. Since the plasma volume of the patient is higher in patients with a lower Hct, a higher volume of plasma need to be exchanged and therefore more units of plasma or plasma replacement fluids are needed. In case the patient has a TBV of 5,000 mL and has an Hct of 50% there will be 2,500 mL of plasma, and in case of an Hct of 30% 3,500 mL. This will give a difference of 1,000 mL, which is really influencing the duration of a plasma exchange procedure.

Also in a plasma collection in blood donors, the Hct is influencing the procedure, especially the procedure time. In blood donors, a fixed volume of plasma is collected with a plasmapheresis procedure. In the donor situation, usually discontinuous apheresis systems are used. In these systems, the plasma will be separated from the blood cells and stored in the plasma collection bag. Prior to the return of the cells to the donor, they are stored temporarily in a reservoir. Let's assume that this reservoir can contain 200 mL. Of course, the blood in the reservoir isn't purely cells, but has an Hct of ~80%, so there will be approximately 160 mL of RBCs in the completely filled reservoir. In case the donors' Hct is 50%, you can collect ~120 mL of plasma before a complete filling of the 200 mL reservoir. At that time we will have processed 320 mL of anticoagulated whole blood, because 50% of this 320 mL is 160 mL of RBCs. With this 200 mL of blood with an 80% Hct in the reservoir, you need to process 400 mL of anticoagulated whole blood in donors with an Hct of 40%, because 40% of 400 mL is again the same 160 mL of pure RBCs in the reservoir.

So when the donors' Hct is higher, you need to process more donor blood to achieve the same collection volume since the relative plasma volume in donors with a higher Hct is lower. Therefore you will have a longer procedure time. On the other hand, in patients we will collect not a fixed volume of plasma, but for instance one TPV. Therefore, there will be a longer procedure in patients with a lower Hct, and also a higher volume of replacement fluids is needed.

Collection Efficiency

When there is a need to collect a specified number of cells with an apheresis procedure, for instance 4×10^6 CD34 positive cells per kilogram of the patient's body weight, you would like to know how much of the donor's/patient's blood you need to process. Therefore, it is good to know the collection efficiency (CE) of the machines you are using. This parameter can also be used for quality aspects of your collection but also within your collection facility. For instance, the various collection machines, but also the various operators can be compared to each other.

In principle, the CE is the number of cells that is collected from the total number of cells processed by the apheresis machine. To simplify this, when for instance 100 cells are processed by the machine and 50 of 100 cells are collected in the storage bag, we have a CE of 50%.

In Figures 4 and 5, two formulas to calculate the CE for a platelet collection are given. Of course the same formulas can be used for all different blood cells, for instance for CD34 positive cells. In the formula given in Figure 4, you need to know the platelet count prior and after the apheresis procedure and of course also the number of platelets in the collection bag. Further you need to know the processed absolute blood volume, but note, this is the processed volume without the anticoagulant (AC) volume. With all these data, the efficiency with this machine for this procedure can be calculated accurately. Usually, this collection efficiency is named the CE_1.

When the post-count of the platelets isn't known, the 2nd formula (see Fig. 5) can be applied. However, since the cell count during a procedure can change, the CE calculated with the formula given in Figure 5 is less accurate than calculation given in Figure 4. Usually, this collection efficiency is named the CE_2.

It's totally not needed to process always 3× the TBV volume or always standard 15 L of the donor's or patient's blood. Knowing the mean CE of your machines in a cell specific collection, you can also calculate what volume of blood should be processed to collect a specific number of specified cells. With the formula as given in Figure 6 you can calculate this for instance for CD34

$$\frac{T_{product}}{((T_{pre} + T_{post}) / 2) * (\text{Processed volume} - \text{AC volume})} * 100$$

Fig. 4. Formula to calculate the collection efficiency 1 (CE_1).

$$\frac{T_{product}}{T_{pre} * (\text{Processed volume} - \text{AC volume})} * 100$$

T = thrombocyte count

Fig. 5. Formula to calculate the collection efficiency 2 (CE_2).

$$TBV = \frac{CD34_{needed} \text{ x body weight patient}}{CD34_{donor} \text{ x collection efficiency}}$$

Fig. 6. Calculation methods for the TBV to be processed to collect a specific number of CD34 positive cells.

TABLE IV. CBC Results of Patient John Smith

Hemoglobin	9.7 g/dL	5.9 mmol/L
Hematocrit	19%	0.19 L/L
Platelets	159,000/μL	159×10^9/L
Leukocytes	8,800/μL	8.8×10^9/L
CD34 positive cells	23.6/μL	23.6×10^6/L

positive cells. For instance, the hematologist is requesting 3×10^6 CD34 positive cells per kg of the patients' body weight, which is 65 kg. So you collect in total $3 \times 65 = 195 \times 10^6$ CD34 positive cells. The CD34 cell count in the donor is 35×10^6/L and a mean CE of your machine is 45%. Therefore to collect sufficient CD34 positive cells, you need to process $195/(35 \times 0.45) = 12.381$ mL of uncoagulated blood of the donor. By using these kinds of formulas and calculating the volume to be processed it can be seen in advance that one procedure will not be sufficient and that a second and/or third procedure is needed.

Hemoglobin and Hematocrit

Hemoglobin (Hb) is the iron-containing oxygen-transport protein in the RBC. Depending on the center or country your working, the units you're working with for the Hb level in human being can vary. Some work with gram per deciliter (g/dL) and others with millimols per liter (mmol/L). It's not that difficult to know what the Hb will be when for you usual unit is not used, because 1 g/dL equals to 0.6206 mmol/L, and the other way around, 1 mmol/L equals to 1.61 g/dL.

Besides the Hb, we also have the hematocrit (Hct). The Hct is the volume percentage of the RBCs or in other words the volume being taken by the RBCs.

Sometimes you only know the Hb, but for many apheresis procedures you also need to know the Hct. Hb and Hct are two different items, but there is a relation between Hb and Hct. When the Hb is shown in g/dL, your Hct will be approximately 3× the Hb. The calculation for the Hb in mmol/L is more difficult. You can calculate the Hct by multiplying your Hb by 10, than divide by 2 and from this outcome you should subtract 2.

Let's make this some what more concrete. You have a Hb of 16.1 g/dL (10 mmol/L).

To calculate the Hct, you multiply the 16.1 by 3 and you will have a result of 48%.

Is your Hb in mmol/L, you need to multiply this 10 mmol/L by 10 and divide the outcome of 100 by 2 (=50) and subtract 2, and also here your Hct is 48%.

SUMMARY

In summary, in this article, we discussed the TBV of a human being and the awareness that this varies per person. We learned to calculate the TPV from the TBV based on the hematocrit. We mentioned the total body mass index and the importance to know what the extra corporeal blood volume during a procedure is. Further we calculated the CE of the apheresis machine and from that the total volume to be processed to achieve a specific number of cells with an apheresis procedure. Finally we mentioned the calculation of the hematocrit from the known hemoglobin level.

Having said all this, we go back to our patients. Mr. John Smith is a multiple myeloma patient. An adequate number of CD34 positive cells needs to be collected for a hematopoietic stem cell transplant. He will be his own donor. Using Nadlers' formula, you can calculate that Mr. Smiths' TBV is approximately 5,600 mL. Based on the outcome of the complete blood count of this morning (see Table IV), you will calculate that with your machines (mean collection efficiency of 45%) you need to process ~33 L (almost 6× the TBV) of the donors' blood to achieve the 4×10^6 CD34 positive cells per kilogram of the patient's body weight. So you need at least two consecutive collection procedure days to achieve the requested goal.

Our second patient is Mrs. Jones. Using Nadlers' formula, you can calculate, based on the height and the body weight, that Mrs. Jones' TBV is ~4,300 mL. You already heared from the physician that the hemoglobin level is 6.0 g/dL (3.9 mmol/L). With the formula described above, you know now that the hematocrit will be ~18% (0.18 L/L), and therefore the TPV will be ~3,500 mL. Therefore, in the plasma exchange procedure for this TTP patient you need to exchange between 3.5 and 5 liters of plasma [4].

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