Classic Pages of the Journal of ExtraCorporeal Technology

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Michael Vinas submitted an original technique article to JECT in 1990 that is this quarter’s classic article. For those of us who follow the development of perfusion technology communications on the Internet, we know that Michael was prolific. Over his career, Michael worked at Vanderbilt University Medical Center, Oral Roberts University, Johns Hopkins Medical Center, Bellevue Hospital in New York City, and recently at Jamestown Regional Medical Center in Tennessee. Sadly, with Michael’s passing this year, the perfusion industry will be a little less interesting and less creative.

One of Michael’s pet subjects was the post-dilutional hematocrit (Hct). Long before the large database evidence was published, we learned that the operative Hct nadir is highly associated with undesired cardiopulmonary bypass (CPB) outcomes (1–3), and Vinas taught us to how to avoid low hematocrits.

It will take the reader some patience and quiet time with your programmable calculator or an Excel™ spreadsheet to appreciate the algorithm published in this classic JECT article. One of the goals for Vinas’ equations was to facilitate the estimation of allowable pump prime before hitting a low Hct target. His predicting equations are the tools that DeFoe, Groom, the Northern New England Heart Study Group, and other authors recommend that we use to avoid subjecting patients to low CPB hematocrits (3).

Prior to Vinas, in JECT, Fletcher published a hemodilution model with an equation and clinical data (4). After 1990, Acsell, Searles and their coworkers published more tools for perfusionists to employ to help avoid excessive hemodilution (6–7). In the same year (1990), Shill presented a technique to use the patient’s own blood to displace the crystalloid prime in the CPB circuit (5).

For more than 10 years, the JECT has provided us with useful clinical tools to help take care of our patients. Vinas’ 1990 article is a classic example of a method that is still useful today. With the rapid evolution of electronic perfusion records, computerized heart lung machines and PDAs, Michael’s algorithm and the context for its use can easily live on.

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References

The Volume Allowance Formula as a Guide to Non-Haemic Solution Administration

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Abstract
We have developed a formula sequence which calculates the predicted blood volume, hemodialitational hematocrit and conjunctively figures the amount of non-haemic solution margin allowable before reaching a minimally acceptable or 'target' hematocrit in the adult patient.

Another application of the formula calculates the value for the amount of prime reduction to prevent the addition of blood to the ECC priming volume. The formula also provides the figures for the amount of blood to add to the prime of the extracorporeal circuit in order to maintain a target hematocrit.

Introduction
Many institutions have escalating concerns toward the administration of blood products. Complications such as hepatitis, AIDS, antibody-antigen reactions, etc. could be contained with a conservative blood product administration program and would mean savings in medical supply and administrative costs.

The practice of blood conservation, especially in the field of extracorporeal circulatory technology, necessitates the need for various computations, which include predicted blood volume and approximate hematocrit adjusted for hemodilation with known amounts of non-haemic solutions. We have enhanced the application of these formulas to include a volume allowance calculation which allows the perfusionist to quantify the amount of non-haemic solution that may be administered before reaching a target or minimally acceptable hematocrit.

Methodology
It is our practice that all patients subjected to extracorporeal circulation during open heart surgery, as a routine, are evaluated for predicted blood volume, red cell mass, adjusted hematocrit values influenced by hemodilation, and blood product requirements, if necessary.

As a rule, unless contraindicated, an average adult patient is usually allowed to hemodilute to 20-21% HCT before there is a concern to hematransfuse. More debilitated patients may require 25-30% hematocrits. As an addendum to these calculations, we developed a volume allowance formula. This formula provides us with valuable information as it pertains to the conduct of perfusion, the priming volume of the extracorporeal circuit, non-haemic solution and/or blood product administration requirements, if indicated.

In example 1, we present a hypothetical 70 kg adult male with no pathological disorders other than mild to moderate atherosclerotic plaque formation in the coronary arteries, a pre-bypass hematocrit of 38% and a prime volume of 1800 ml.

For our example, we will employ the Texas Heart Institute predicted blood volume formula of 70 ml/kg (1), which correlates favorably with our own hemodialitational survey. We will also employ a revision of Edward C. Berger's anticipated hematocrit calculations (2).

The volume allowance calculation assumes reasonable pathophysiology, systemic and pulmonary vascular resistance, colloidal oncotic pressure, osmotic pressure, and electrolyte values within a reasonable range. It is assumed that rehydration from the NPO status will have been achieved via anesthesiology during the pre-bypass phase as is generally our experience and an updated hematocrit prior to extracorporeal circulation.

Example 1
Step 1: Calculate the predicted blood volume.

\[ 70 \text{ kg} \times 70 \text{ ml/kg} \]
\[ 4900 \text{ ml-predicted blood volume (PBV)} \]

Step 2: Compute the patients red cell mass (RCM1).

\[ 4900 \text{ ml-PBV} \times 0.38 \text{(Fractional Hematocrit (HCT1))} \]
\[ 1862 \text{ ml RCM1} \]

Step 3: Figure the hemodialitical hematocrit (HCT2).

\[ 0.28 = \frac{1862 \text{(RCM1)}}{6700 \text{(PBV+Prime= Total System Volume)}} \]

\[ 0.28 \times 100 = 28\% \text{(HCT2)} \]

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Step 4: Calculate the RCM at target or minimally accepted hemodilutional hematocrit value.

\[ \frac{6700 \text{ TSV (Total System Volume)}}{0.21} = 1407 = \text{RCM2} \]

Step 5: Figure the RCM difference and divide by the target hematocrit expressed as a decimal.

\[
\begin{align*}
1862 - \text{RCM1} \\
- 1407 - \text{RCM2} \\
455 = & \text{RCM difference}
\end{align*}
\]

\[ 455 \times 21 \text{ ml volume allowance} \]

The various steps in the volume allowance calculation may be condensed and expressed in the following equation:

\[
[((\text{Kg x 70}) \times (\text{HCT1/100}) \times (\text{TSV x (HCT2/100)})]/(\text{HCT2/100})
\]

or

\[
[\text{RCM1} - \text{RCM2}]/\text{HCT2}
\]

Our ongoing hemodilutional research tentatively reveals that predicted blood volumes, compared to a computer regression model, may vary on an average of ±20% after standard deviation, especially for the average adult female population; therefore, the volume allowance value should be discounted by administering half the calculated value, then reevaluating the hemodilutional status with an updated hematocrit.

The volume allowance formula is especially appreciable in the smaller, more anemic patient. For example, a female patient weighing 50 kg with a pre-bypass hematocrit of 32%, an extracorporeal circuit volume of 1500 ml and a minimum acceptable hematocrit of 21% would present the following:

Example 2

\[
\begin{align*}
1120 \text{ RCM1} \\
- 1050 \text{ RCM2} \\
70 \text{ RCM difference}
\end{align*}
\]

\[ 70 \text{ delta RCM} = 333 \text{ ml volume allowance} \]

\[ .21 \text{ (Fractional HCT2)} \]

In Example 2, the patient should be entitled to approximately 333 ml of non-haemic solution(s) before reaching the target hematocrit or minimal accepted hematocrit. Half this amount should be administered and a reevaluation undertaken. Also, the relatively small volume allowance should alert the clinician that blood products may need to be administered and should be immediately accessible.

The formula may be adjusted to provide a value for blood administration. For example, if the patient had a hematocrit of 28% and required a prime volume of 1800 ml, the RCM1 would calculate to be 980 ml and the adjusted hematocrit figure to be 18.5%.

Example 3

\[
\begin{align*}
980 \text{ RCM1} \\
-1112 \text{ RCM2} \\
- 133 \text{ delta RCM}
\end{align*}
\]

\[ -133 = 633 \text{ ml prime reduction} \]

\[ .21 \text{ HCT2} \]

Analytically, if the volume allowance formula figures a negative number, the formula becomes a volume reduction instrument indicating the amount of prime to reduce to obtain the desired hematocrit without the addition of blood.

If the amount of prime can not be altered, then the absolute value of delta RCM is taken for the amount of RBC's to administer.

It has been our experience that an average unit of packed red blood cells (PRBC) preserved with ADSOL contains a volume of approximately 300 ml with a hematocrit approaching 50%. CPD-A units differ by having an approximate hematocrit of 70% but are usually reconstituted before administration. The RCM difference divided by 150 should provide the needed number of ADSOL units versus 210 for non-reconstituted CPD-A units of PRBCs. Therefore:

\[
\begin{align*}
133 = .9 \text{ ADSOL units-PRBC} \\
150
\end{align*}
\]

\[
\begin{align*}
133 = .6 \text{ CPD-A units-PRBC} \\
210
\end{align*}
\]

Calculations such as those presented in this article may be tedious with a hand-held calculator and subject to operator error; therefore, it is strongly recommended to incorporate a computer for assistance.

We have provided a token computer program written in BASIC computer language applicable with an IBM compatible computer. The program is also compatible with an EPSON HX-20 portable computer. The program incorporates error trapping to prevent input data that is not compatible to routine situations.

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100 IF KG<35 OR KG>120 THEN 70
110 ' CLS
120 CLS
130 GOSUB 790
140 INPUT "HCT (%)"; HCT1
150 IF HCT1<25 OR HCT1>50 THEN 120
160 ' CLS
170 GOSUB 790
180 INPUT "PRIME (ML)"; PRIME
200 IF PRIME<1200 OR PRIME>3000 THEN 170
210 ' CLS
220 GOSUB 790
240 INPUT "DESIRED HCT (%)"; HCT2
250 IF HCT1<HCT2 THEN 120
260 IF HCT2<21 OR HCT2>38 THEN 220
270 CLS
280 ' REM CALCULATION SECTION
300 BLDVOL=KG*70
310 RCM1=BLDVOL/(HCT1/100)
320 TSV=BLDVOL+PRIME
330 ADJHCT=(RCM1/TSV)*100
340 ' CLS
350 ' CLS
360 RCM2=TSV/(HCT2/100)
370 RCM3=RCM1-RCM2
380 VOLALLOW=RCM3/(HCT2/100)
390 ADJHCT=INT((ADJHCT+10+.5)/10
400 VOLALLOW=INT(VOLALLOW)
410 REDUCE=ABS(VOLALLOW)
420 ' CLS
430 PRBC=RCM2-RCM1
440 ADSOLUNIT=PRBC/150
450 ADSOLUNIT=INT((ADSOLUNIT*10+.5)/10
460 CPDAUNIT=PRBC/210
470 CPDAUNIT=INT((CPDAUNIT*10+.5)/10
480 ' REM DATA OUTPUT SECTION
500 ' CLS
520 GOSUB 790
530 PRT"DATE= "; DATES
540 PRT"TIME= "; TIMES
550 PRINT
560 PRT"BLOOD VOLUME (ML)= "; BLDVOL
570 PRT"ADJUSTED HCT. (%)= "; ADJHCT
580 PRT"VOL ALLOW. (ML)= "; VOLALLOW
590 ' IF VOLALLOW>0 THEN 690
610 ' CLS
620 PRT"REDUCE PRIME (ML) "; REDUCE
630 PRINT
640 PRINT" <OR>
650 PRINT
660 PRINT"PRBC NEEDED="; PRBC

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670 PRINT"ADSOL UNIT(S)= ";ADSOLUNIT
680 PRINT"CPD-A UNIT(S)= ";CPDAUNIT
690 ' FOR I=1 TO 3
710 PRINT" 
720 NEXT I
730 ' PRINT;TAB(28)"<DEPRESS ANY KEY TO RESUME>
740 PRINT;TAB(28)"VOLUME ALLOWANCE PROGRAM"
750 A$=INKEY$: IF A$="" THEN 750 ELSE 50
760 ' END
780 ' CLS
800 ' CLS
810 PRINT;TAB(29)"VOLUME ALLOWANCE PROGRAM"
820 FOR I=1 TO 4
830 PRINT
840 NEXT I
850 RETURN
860 END

Abbreviations

ADHJCT = Adjusted hematocrit
ADSOL = ADSOL units of packed red blood cells
BLDVOL = Patient blood volume
CPDA = CPD-A units of packed red blood cells
HCT1 = Patient hematocrit
HCT2 = Desired hematocrit
KG = Kilogram
PRBC = Packed red blood cells needed
PRIME = Priming volume of the extracorporeal circuit
REDUCE = The amount of prime to reduce sans blood
RCM1 = Red cell mass of the patient
RCM2 = Red cell mass of the total system
RCM3 = delta RCM1-RCM2
TSV = Total system volume (BLDVOL+PRIME)
VOLALLOW = Volume allowance of non-haemic solution(s)

Conclusion

Formulas that calculate patient blood volume and adjusted hemodilution hematocrits provide a guide to non-haemic volume allowance as well as minimum blood administration. These are recommended utilities for those institutions that are actively engaged in the conservation of blood administration as a reduction to possible complications associated with the use of blood and blood byproducts, as well as institutional cost containment. The volume allowance equation is an enhancement to these formulas and provides values concerning allowance of non-haemic solution or ECC prime reduction.

References