A Model for Estimating Post-Dilution Hematocrit with Minimal Blood Loss

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Abstract

A hematocrit estimator model (HEM) for post dilutional hematocrit prior to cardiopulmonary bypass is presented. The estimator model was tested on 75 adult patients, whose ages range from 36–81 years with a median age of 62.4, undergoing cardiopulmonary bypass.

The estimator model allows an accurate and efficient determination of the hematocrit, after the patient receives large volumes of non-heamic fluid, based on a retrospective analysis of our patient database.

Introduction

Aside from the avoidance of homologous blood transfusion with its adverse side effects, there are other desirable effects from hemodilution, such as a reduction in viscosity and yield stress,[1] improved microcirculation, reduced hemolysis,[2] and decreased post operative bleeding.[3] Excessive hemodilution can result in impairment of oxygen transport[5,6] and decline in 2,3 DPG.[7] The intrinsic hazards of donor homologous blood, such as the possibility of disease transmission and induced coagulopathies, demand that the hemodiluted state be controlled within acceptable limits.[8]

An estimator model has been developed to allow an easy and accurate method for the estimation of post-dilutional hematocrit created by cardiopulmonary bypass, fluid challenge, or fluid resuscitation of patients with multisystem trauma and shock.[9] The estimator model assumes that during the pre bypass period, blood loss is minimal (less than 250 ml) and the transcapillary water movement into the interstitial body fluid compartment is negligible.[10]

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Figure 1 is based on the basic estimator model Eq. One.

$$HCT_{post} = (EBV \times HCT_{pre})/(D + EBV) \qquad \text{Eq. 1}$$

The variables in the hemodilution model are specified as:

HCT_{post} = post dilutional hematocrit
HCT_{pre} = hematocrit predilution (%)
EBV = Estimated Blood Volume (ml)
D = Dilutional volume of Fluid (ml) (pump prime + cardioplegia + anesthesia fluid)

With addition of dilutional volume D to the EBV, the final blood volume of the patient becomes: FBV = EBV + D

Using EBV + D as the final blood volume assumes negligible transcapillary diffusion of plasma water across capillary membranes based on Starling forces. Patients in congestive heart failure and patients receiving blood prior to the first CPB hematocrit or blood prime were not used to create the estimator equation.

By computer simulation this information can be useful in planning for the administration of whole blood or packed red blood cells (RBC) to increase the oxygen carrying capacity in the hemodiluted patient.

Method

Seventy-five adult patients, undergoing cardio-pulmonary bypass with non-haemic prime, were studied. Each patient was given a crystalloid-colloid prime, containing varying amounts of Plasmalyte-A, with volumes ranging from 2200 to 4133 ml. The priming solution consisted of:

200 ml albumin 25%
25 gm Mannitol
Plasmalyte-A
10,000 units sodium heparin

Patients were heparinized with 300 units per kilogram and Activated Clotting Times (ACT) were maintained at greater than 400 seconds. Hypothermic autologous blood/crystalloid cardioplegia was used on all cases.

Hematocrit values were measured on a Technicon H1 CBC analyzer.[a] Baseline (post-induction) hematocrit values were obtained approximately 20 minutes prior to bypass. All fluids given by the anesthesia team, after the baseline hematocrit and prior to the first CPB hematocrit, were estimated and added to pump prime and the crystalloid portion of the cardioplegia solution for entry into the estimator equation (D in Eq. 1). About twenty minutes after initiation of CPB and five minutes after the initial dose of cardioplegia was given, blood samples for the hematocrit measurement were drawn from the bypass circuit.

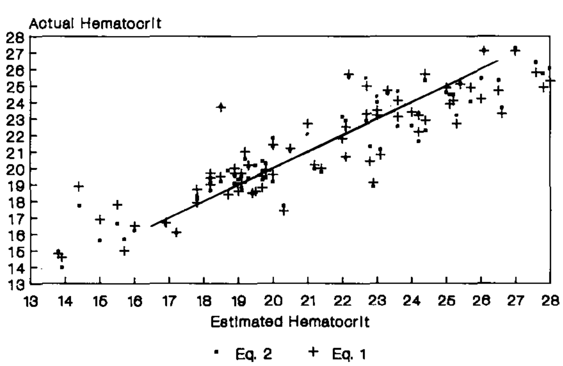
Results

The statistical results relating the actual and the computed hematocrits, derived from Eq. 1, were calculated using standard formulae from statistics.[14] By computer simulation, a regression chart depicting the HEM values from Eq. 1 vs. actual values of 75 patients is shown in Table 1.

When the basic equation (Eq. 1) was compared to the actual HCT_{post}, the 75 patients had a correlation coefficient of .84 and a standard error of the estimate of .07. The constants 6.89 and .687 were derived from the Y intercept and the slope, respectively. A multi-variate analysis was also performed relating HCT_{post} to height (HGT), weight (WGT), dilutional volume, and pre bypass hematocrit. The regression coefficient for each variable HGT (centimeters), WGT (kilograms), dilutional volume

Table 1

Hematocrit Estimator Model
75 random patients real vs predicted



a Technicon, Tustin, CA, 92680

(D), and HCT_{pre} were built into the original equation (Eq. 1). Thus predicting Eq. 1. becomes;

$$HCT_{post} = (A \times HGT) + (B \times WGT) + (C \times D) + (D \times HCT_{pre}) + \text{const.} \qquad \text{Eq. 2}$$

The use of a multi variate regression analysis indicates the relative importance of each independent variable based on the historical data collected to perform the regression analysis.The variables A, B, C, D, are the coefficients for each of the independent variables which were respectively .02802, .0867, −.00353, .575 (HGT, WGT, D, HCT_{pre}) with a constant of .6215.

When the predicted HCT_{post} from Eq. 2 is compared to the actual HCT_{post}, a correlation coefficient of .90 results with a standard error of y estimate = 1.56. The HCT_{post} values are statistically the same (Student t-test) as the values derived from Eq. 1 and Eq. 2 ($p = .4307$ and $t = .1751$). Comparison of Eq. 2 values with HCT_{post} values yielded $p = .4758$ and $t = -.0610$. The degrees of freedom in both tests were 71.

Equation 2 was programmed in Microsoft BASIC[b] into a pocket computer. The program listing is shown below. There may be slight differences in syntax because of the different dialects of BASIC.

```
100 REM VOLUME ESTIMATOR & TARGET HEMOGLOBIN ESTIMATOR
110 INPUT "HEIGHT"; A : A = A * .02802 : REM .02802 IS THE COEFFICIENT
120 INPUT "WEIGHT"; B : B = B * .0867 : REM .0867 IS THE COEFFICIENT
130 INPUT "PRE HCT"; C : C * −.00353 : REM −.00353 IS THE COEFFICIENT
140 INPUT "DILUTION"; D : D = D * .575 : REM .575 IS THE COEFFICIENT
150 POSTHCT = A + B + C + D + .6215 : REM .6215 IS THE CONSTANT
160 PRINT "ESTIMATED HEMATOCRIT"; POSTHCT
```

Discussion

The accuracy of the HEM is based upon the accuracy of the input data. The most significant source of error can be the inaccurate computation of blood volume from Eq. 3 employed in this method. The blood volume (EBV) may also be approximated by two different models, estimating the blood volume based on body surface area Eq. 4[13] or an estimation from weight, Eq. 5.

$$\text{Blood Volume} = \text{Plasma Volume} \times 100/(100 - .87 \times \text{Hct}) \qquad \text{Eq. 3}$$

$$EBV = .416 \times (\text{height cm})^{.3} + .039 \times (\text{weight kg}) - .03 \qquad \text{Eq. 4}$$

$$EBV = 70\text{ ml} \times KG \qquad \text{Eq. 5}$$

Isotope studies have shown that in the normal adult male under 40 years, approximately 60% of body weight is water, in young women 50%.[11] During aging, total blood volume and plasma volume increase slowly according to surface area, until adult blood volumes are reached.[12] Standards based on body surface area are usually considered to be more accurate than from body weight from the biological standpoint.

Weight referenced standards are usually considered to be more convenient to use.[4] Thus, it is recommended EBV be estimated as a function of the body surface area as specified in Eq. 4.

This method provides statistical evidence for using the adjusted model (Eq. 2) to numerically estimate the initial hematocrit after instituting cardiopulmonary bypass, cardioplegia induction, and/or fluid challenge.

In recent years there have been significant advances in computer-aided diagnosis and decision making for cardiopulmonary bypass. These advances are essentially modeling problems, as we gain more insight into ways in which perfusionists approach clinical management. It is increasingly feasible to assist perfusionists in this decision making process by employing computer-based models.

The use of the HEM provides accurate, quantitative prediction of the effects of hemodilution as well as aiding in the decision making process regarding the administering of blood or crystalloid solutions at the initiation of heart-lung bypass.

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Blood suctioned from a surgical field during cell salvage should be done with minimal suction pressures and with the goal of minimizing blood-air interfaces. Significant reduction of blood damage can be obtained by diluting blood with normal saline while suctioning it from the surgical field.Â when the minimal hematocrit was reached and transfused any remaining blood following completion of the case.Â Mathematical modeling is used here to analyze PABD. A model of PABD was constructed to simulate the transfusion of red cells once a predetermined minimum hematocrit was reached. Preoperatively deposited units not needed to maintain a hematocrit at this level were not transfused.