

blood pressure 40/20 torr, and heart rate 240/min. A third blood-gas analysis showed: $P_{CO_2} = 35$ torr, $P_{O_2} = 164$ torr, $pH = 7.22$. The temperature then rapidly returned to normal. Blood pressure remained low, however, and barely increased after repeated doses of ephedrine, 1 mg/kg, intravenously.

Three hours after decamethonium we attempted to recreate events by restarting halothane, 2 per cent, and giving a second dose of decamethonium, 1 mg. But the temperature remained between 37 and 37.5 C. Subsequently the blood pressure became barely perceptible, the EKG turned grossly irregular, and the animal died. Unlike the 30 minutes or more of postmortem flaccidity seen in identically anesthetized animals, this cat developed extreme rigor within 10 minutes. This is similar to the reported case of malignant hyperthermia in the dog which developed rigor mortis within 2 minutes after cardiac arrest.

The clinical protocol described here follows that reported for the malignant hyperpyrexia syndrome in man and swine. To be

sure, the syndrome must be extremely rare in the feline, as we have not seen it in the well over 500 cats anesthetized in like manner before. In fact, cats decrease their body temperature by several degrees Celsius when breathing halothane.⁴ While the time course of the hyperthermic response would seem to incriminate decamethonium, we cannot with certainty exclude halothane or the halothane-decamethonium sequence as the precipitating factor.

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Estimating Allowable Hemodilution

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Deliberate hemodilution with noncellular colloid volume expanders avoids the risks and expense of replacing surgical blood loss with whole bank blood. The limit to such replacement is usually set by concern for oxygen transport as measured by hemoglobin or hematocrit. Some patients tolerate isovolemic hemodilution to hematocrit values as low as 25 per cent. For a given patient for whom one knows

the preoperative blood volume, the hematocrit, and the extent to which one will permit hemodilution, serial hematocrits would guide replacement when large volumes are replaced. In the absence of repeated hematocrit or hemoglobin measurements, a variety of rules of thumb, of varied rational and physiologic bases, which are intended to guide the anesthesiologist's decision to begin whole blood replacement, are in use. A common one neglects the continuous decrease in hematocrit. This "oversimplified" rule increasingly underestimates the true hematocrit as loss continues, and can be improved upon. Our work consists of three parts: a) a model of the blood volume, permitting prediction of an allowable loss for a given decrement in hematocrit; b) a clinical verification of the

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Received from the Department of Anesthesia, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19104. Accepted for publication July 12, 1974. Supported in part by USPHS Research Center Grant 5-P01-GM-15430-06, and Research Training Grant 5-T01-GM-00215-15 from the National Institute of General Medical Sciences, National Institutes of Health.

model in a variety of patients; c) a simplification of the predicting equations, easily memorizable for use in the operating room.

THEORETICAL DILUTION EQUATION

The model used for calculating an allowable blood loss that will result in a given decrease in the hematocrit assumes a normal blood volume that is well mixed in a short time compared with the blood loss (*i.e.*, the blood loss per minute is a small fraction of the cardiac output). As blood is lost, it is replaced with colloid solution concurrently and equally. Where minor differences between loss and replacement exist in practice, we assume a contraction or expansion of the blood volume over the period of time involved.†

Approaching the problem from a mathematical point of view, let

- H = hematocrit
- V = estimated blood volume
- L = blood loss = noncellular replacement
- t subscript indicating time
- o subscript indicating initial conditions

A small change in hematocrit from the initial hematocrit should equal a small change in blood volume from the initial blood volume. Writing the differential equation:

$$dH/H = dL/V$$

Integrating over limits from initial conditions to any t yields:

$$V (\ln H_o - \ln H_t) = L_t \quad (1)$$

Equation 1 may be rewritten narratively as:

Blood loss = estimated volume \times the natural logarithm of the ratio of initial to final hematocrit.

This equation permits rapid calculation of the blood loss for a desired hemodilution.

† Clearly, insufficient volume replacement results in further erythrocyte loss at a more rapid rate per volume of surgical blood loss than if normal volume were maintained and the erythrocytes diluted. On the other hand, over-replacement dilutes the erythrocytes, causing a lower rate of loss per surgical blood loss, but itself has considerable attendant dangers.

CLINICAL CORRELATION

This mathematical model was verified in clinical practice. Fifty patients, selected with the expectation of major blood loss, were studied. The patients included adults and children of both sexes, undergoing open-heart, orthopedic, vascular, general, ear, nose and throat, and gynecologic surgical procedures. Control hematocrits were obtained preoperatively. Blood loss was determined from that collected in suction tubes and bottles, weighed on sponges, and estimated to be on the surgical field, drapes, and floor by an experienced staff anesthesiologist. Estimated blood volume was calculated using Moore's formula, which considers body habitus and sex.¹ Central or peripheral venous hematocrits were obtained several times while blood loss was being replaced with noncellular volume expanders. The blood loss was replaced as accurately and concurrently as possible. Three patients were given Dextran-40, 47 patients were given plasma protein fraction, and all patients received some crystalloid fluids. The equations assume replacement concurrent with loss. To account for actual differences between loss and replacement at the time of hematocrit sampling, the predicted hematocrit was calculated on a programmed Wang Series 720 Calculator simulating blood loss and replacement by an iterative technique. The volume of replacement was taken to be equal to the infused Dextran or plasma protein, plus 15 per cent of the volume of crystalloid fluids administered with two hours of the hematocrit sample. Fifteen per cent was taken as an average ratio of plasma volume to extracellular fluid volume.

The measured results were compared with predicted results. Fifty patients provided 83 instances for comparison. The mean difference in volumes per cent between actual and predicted hematocrits was 0.28 ± 0.21 (SE). The standard deviation of the mean difference was 1.46 vol per cent, indicating that 95 per cent of the observed results were within four hematocrit points of the predicted results. This difference, which is within the error of the measurement of hematocrit, is of little clinical significance, and indicates that the model accurately follows real conditions. Thus, one

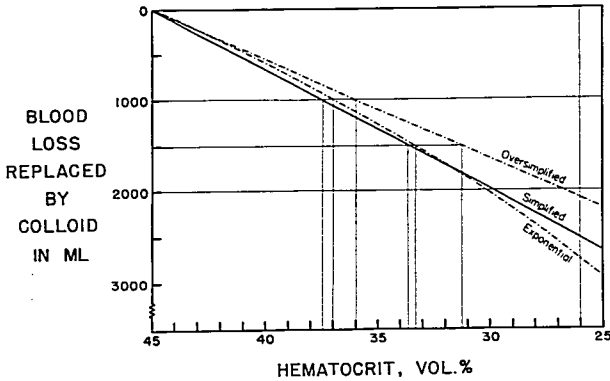


FIG. 1. Calculation of decreasing hematocrit during replacement of blood loss by equal volume of colloid suspensions may be accomplished by an exponential equation (broken line) or by simplified approximation (curved solid line), or an "oversimplified" assumption that all blood lost has the initial hematocrit. The example shown is for an initial blood volume of 5 liters. The two curved lines are in close agreement for reasonable degrees of hemodilution, but the "oversimplified" line suggests greater hemodilution throughout. For example, as indicated by the thin horizontal line at a loss of 1,500 ml, the curves agree within 1 vol per cent but the straight line "oversimplified" value is in error by more than 2 vol per cent.

may use the dilution equation with confidence.

A SIMPLE PREDICTIVE EQUATION

The form of equation 1 does not lend itself to easy calculation because of the natural log functions. It may be rewritten using a Taylor series expansion for the logarithmic terms, dropping the cubic and higher terms, which are numerically negligible for the range of values considered clinically. The equation is rearranged to obtain:

$$L = V (H_0 - H_1) (3 - \bar{H}) \quad (2)$$

In this equation, \bar{H} indicates the mean hematocrit calculated by averaging the initial and final hematocrits. The hematocrits must be written as decimal fractions (*i.e.*, 0.45 and not 45 per cent).

Equation 2 may be narratively written:

Blood loss = estimated blood volume
× change in hematocrit × the
difference between 3 and the
average hematocrit.

The error introduced by equation 2 is small

for estimated blood volumes of 500 ml to 8.5 l, initial hematocrits from 25 to 50 vol per cent, and final hematocrits down to 24 per cent. The difference in results in final hematocrits in all the above circumstances is less than 1.2 vol per cent and is independent of the estimated blood volume.

A sample calculation illustrates the use of this formula: Suppose a patient with an estimated blood volume of 5 l has an initial hematocrit of 45 vol per cent. His physician decides he could tolerate a hematocrit of 34 vol per cent and prescribes albumin and saline replacement for blood loss. From equation 1 he calculates the allowable blood loss before transfusion as prescribed by equation 1:

$$\begin{aligned} \text{Allowable loss} &= 5,000 (\ln 45 - \ln 34) \\ &= 1,401 \text{ ml} \end{aligned}$$

Alternately, he could calculate from equation 2:

$$\begin{aligned} \text{Allowable loss} &= 5,000 \times (0.45 - 0.34) \\ &\quad \times \left(3 - \frac{0.45 + 0.34}{2} \right) \\ &= 1,432 \text{ ml} \end{aligned}$$

Thus, the difference in calculated allowable blood loss is small. The actual hematocrit would be 33.8 instead of the target 34 vol per cent if the small extra hemodilution were permitted.

In physiologic ranges the differences between results of equation 1 and equation 2 are clinically negligible. As an example, the figure shows the equations for an estimated blood volume of 5 l and an initial hematocrit of 45 vol per cent. In general, the simplified equation modestly overestimates the hematocrit early in isovolemic replacement, and underestimates it later, a conservative error. The oversimplified calculation increasingly underestimates the hematocrit.

The decision to risk whole blood transfusion should be made on a rational basis. In a surgical procedure entailing considerable blood loss, the physician may decide his pa-

tient will tolerate hematocrit dilutions to 30 vol per cent without significant impairment of oxygen transport to the tissue. When intraoperative hematocrits are not readily available, the decision to stop replacing with noncellular volume expander and commence replacement with bank blood is difficult to make on logical grounds. Rules of thumb are often inaccurate. A sound mathematical model for hemodilution has been verified. The development of equation 2 provides an easily remembered, convenient and useful formula for guiding the anesthesiologist. This should save many patients from the risks and expense of unnecessary whole blood transfusion.

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A Scavenging Device for Venting Methylmethacrylate Monomer Vapor

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Methylmethacrylate, a self-curing acrylic cement, has been used in orthopedic surgery and to a lesser extent in dentistry and neurosurgery for several years.¹ This cement is made by mixing a powder (a mixture of polymethyl methacrylate, methylmethacrylate-styrene copolymer and barium sulfate USP†) with liquid methylmethacrylate monomer. After mixing, the texture becomes doughy and in 7–10 minutes is suitable for insertion into a patient. During the mixing of the cement, methylmethacrylate vapor is emitted. Some operating room personnel have complained of headaches and vomiting either during or after exposure to the vapor. Further, the vapor is flammable, and it is appropriate for devices to be constructed to vent this vapor. We have designed a scavenging device that has been

used successfully in our operating rooms for the past six months.

METHOD AND MATERIALS

Certain physical and chemical properties of methylmethacrylate monomer vapor are of importance when considering methods of venting. The vapor is about 3.5 times as heavy as air (vapor density 3.45).² For comparison, the vapor density of diethyl ether is 2.6. At room temperature, the vapor is flammable (flash point 50 F) and is classified as a moderate fire hazard by the National Fire Protection Agency (NFPA) and as a dangerous fire hazard by the Interstate Commerce Commission. Again for comparison, the flash point of ethyl alcohol is 55 F. The lower explosive limit of methylmethacrylate vapor is 2.1 per cent when mixed with air. The lower explosive limits of diethyl ether and ethyl alcohol when mixed with air are 1.8 per cent and 3.2 per cent, respectively. The odor threshold for methylmethacrylate vapor is 0.21 ppm, and it has a

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Accepted for publication July 12, 1974.

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