
Estimation of Colloid Osmotic Pressure During Hemodilutional Cardiopulmonary Bypass

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Abstract

Patients undergoing cardiopulmonary bypass (CPB) using hemodilution are subjected to large reductions in colloid osmotic pressure (COP). The purpose of this investigation was to determine the course of COP during CPB and to compare these values to critical ranges for COP as cited in the literature.

The prime consisted of a mixture of the crystalloid (Lactated Ringer's) and a variety of colloids. Samples were taken of the prime, and blood drawn prior to, during, and after CPB. The COP of each sample was measured, and also estimated by three (3) different techniques.

During CPB, patient's COP were reduced by 30–60%, placing them within the published critical ranges for COP. Since patients did not suffer the predicted consequences of large reductions in COP, it is apparent the previously accepted critical ranges for COP must be re-evaluated for the CPB patient.

In the process of this investigation, a simple pumpside method for COP estimations was developed.

Introduction

Concern for the determination of colloid osmotic

pressure (COP) during cardiopulmonary bypass (CPB) arises from the many articles indicating various adverse effects resulting from the reduction of colloid osmotic pressure in the critically ill patient. Changes in either the pulmonary capillary pressure or in the colloid osmotic pressure have been shown to be a cause of pulmonary edema.^{1,2,3,4} The values derived from the colloid osmotic pressure minus the pulmonary capillary pressure can serve as a good index for the development of pulmonary edema and for the prognosis of recovery.^{1,2,3} In each case it is the difference between the colloid osmotic pressure and the capillary pressure that determines these effects.

During cardiopulmonary bypass both the perfusate pressure and the colloid osmotic pressure are subject to change. While the reduction of the colloid osmotic pressure leads to tissue edema with its associated acidosis, shunting, etc., it also allows for increased glomerular filtration rate.⁵ Because of this, the perfusate pressure and its colloid osmotic pressure should be considered in the management of the patient undergoing cardiopulmonary bypass.

Because of the complexity and cost of directly measuring colloid osmotic pressure, it is desirable to find a simple method for estimating the colloid osmotic pressure of the perfusate during cardiopulmonary bypass. Several equations relating colloid osmotic pressure to total plasma protein can be found in the literature.^{1,6,7} This study's purpose is to follow the course of colloid osmotic pressure during cardiopulmonary bypass and to find a less complex method for determining the perfusate's colloid osmotic pressure.

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Methods and Materials

Two instruments, the Automatic Clinical Analyzer^a (ACA) and the American Optical Refractometer^b (AOR), were chosen to determine total plasma protein (TPP). Prior to the start of the clinical investigation, a comparison of the readings in gm/dL between the ACA and the AOR was done using bovine albumin standards^c of 4, 6, 8, and 10 gm/dL. The Student T Test was used for statistical analysis.

Since the prime was to contain a 1.2% concentration of a non-protein osmotic agent, Hespan,^d a second test was performed to determine if either of the two instruments was sensitive to the presence of Hespan.

Clinically, 10 adult patients undergoing cardiopulmonary bypass were used in this investigation. There were four valve replacements, five coronary artery bypass grafts, and one combination valve replacement and coronary artery bypass graft. Each patient received a heparin loading dose of 300 units/kg of body weight. In 6 cases, the heart-lung machine was primed with 2,000 ml of Lactated Ringer's, 500 ml of Hespan and 1,500 units of heparin. In 4 cases, 250 ml of Lactated Ringer's were replaced with one unit of packed red blood cells. If additional Lactated Ringer's was needed while on bypass to maintain volume, then 100 ml of 25% normal serum albumin was given for each liter of Lactated Ringer's used.

The pre-bypass sample was drawn 5 minutes after the heparin loading dose was given. The first on-pump sample was drawn 5 minutes after the initiation of bypass. All other on-pump samples were drawn every 30 minutes. One hour after the termination of bypass, the post-pump sample was drawn using a heparinized syringe.

Each sample underwent the following analyses:

1. Hematocrit, to show dilutional effects
2. Total plasma protein using the American Optical Refractometer
3. Total plasma protein using the Automatic Clinical Analyzer

^a Dupont Clinical Systems Division, Wilmington, DE 19898

^b American Optical Company, Buffalo, NY 14240

^c New England Reagent Laboratory, East Providence, RI 02914

^d A solution of 6% Hydroxyethyl Starch in 0.9% Sodium Chloride Injection stated by the manufacturer to have approximately the colloidal properties of human albumin. American Critical Care, Division of American Hospital Supply Corporation, McGaw Park, IL 60085

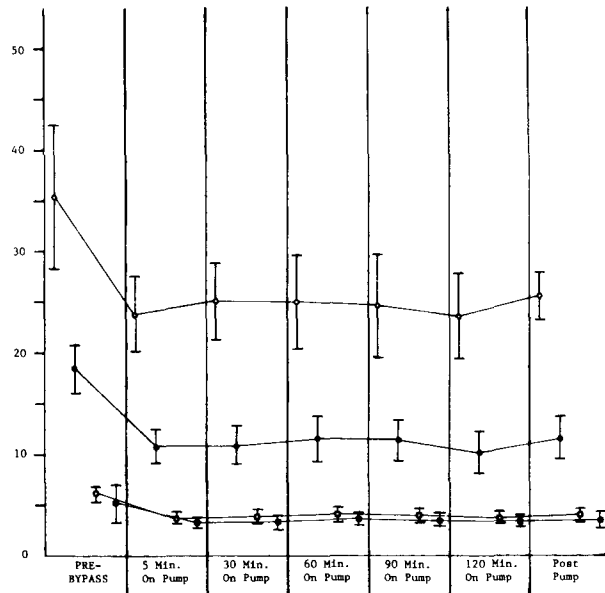


FIGURE 1. Changes Per Sample Interval In: Hematocrit (O) in percent, Colloid Osmotic Pressure (●) in mm Hg, Total Plasma Protein determined by the American Optical Refractometer (□) in gm/dL, Total Plasma Protein determined by the Automatic Clinical Analyzer (■) in gm/dL.

4. Colloid osmotic pressure using the Instrumental Laboratory Weil Oncometer, Model 186^e

The colloid osmotic pressure was then estimated from the total plasma protein data and correlated to the measured colloid osmotic pressure. This data was subjected to regression and correlation analysis.

Results

In the *in vitro* comparison of the American Optical Refractometer and the Automatic Clinical Analyzer, there was no significant difference at the 0.05 level in their readings for the bovine albumin standards. However, in each of the determinations made on Hespan, the Automatic Clinical Analyzer gave total plasma protein readings of 0.0 gm/dL while the American Optical Refractometer consistently read 4.3 on the gm/dL scale.

Figure 1 presents the mean \pm standard deviation for the parameters measured at each sample interval during the clinical investigation. The greatest change in all readings occurred during the first 5 minutes after

^e Instrumental Laboratory Inc., Lexington, MS 02173

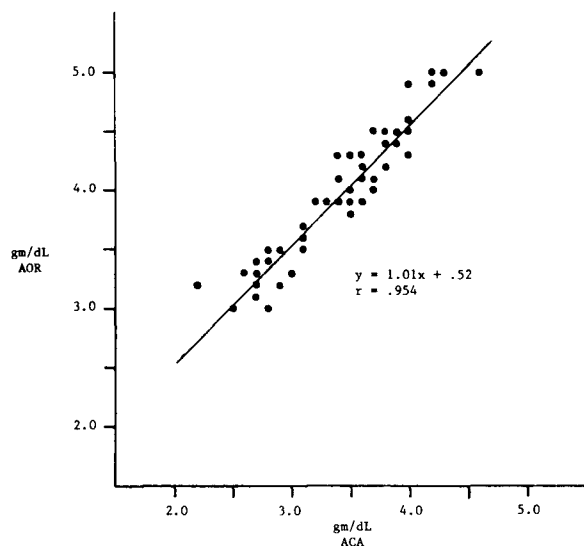


FIGURE 2. Total Plasma Protein (TPP) Readings Obtained From The American Optical Refractometer (AOR) vs Total Plasma Protein Obtained From The Automatic Clinical Analyzer (ACA)

the initiation of bypass. These reductions were obviously due to the hemodilutional effects of going on bypass as indicated by the change in the hematocrit. The colloid osmotic pressure dropped an average of $41.3 \pm 5\%$. Similar reductions were observed in the total plasma protein. In all cases, the colloid osmotic pressure remained below a mean of 12.5 mmHg throughout bypass and one hour post-pump.

As might be expected, the values for total plasma protein as determined by the American Optical Refractometer consistently read slightly higher than the values determined by the Automatic Clinical Analyzer. Figure 2 presents the relationship of the total plasma protein readings of the two instruments.

Figure 3 represents the relationship of the colloid osmotic pressure (COP) to the readings for the total plasma protein (TPP) as determined by the American Optical Refractometer (AOR) and the Automatic Clinical Analyzer (ACA). In both instances the colloid osmotic pressure is a linear function of the total plasma protein.

Discussion

Because of the results obtained in the *in vitro* comparison of the American Optical Refractometer and the Automatic Clinical Analyzer, it is apparent that the refractometer is sensitive to the presence of the non-

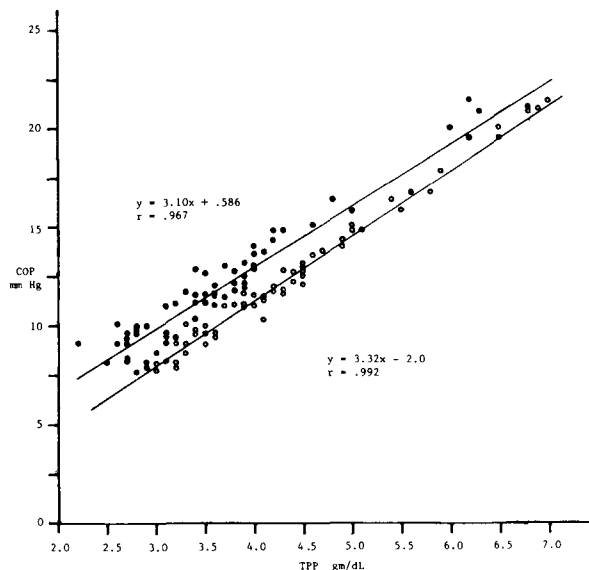


FIGURE 3. Colloid Oncotic Pressure (COP) vs Total Plasma Protein Determined By The American Optical Refractometer (O), And Total Plasma Protein Determined by the Automatic Clinical Analyzer (●).

protein osmotic agent, Hespan, whereas, the Automatic Clinical Analyzer is not. Since Hespan is a non-protein, the readings from the refractometer in gm/dL are used as relative values and not as a reading of the actual protein content of the sample.

The consensus of several investigators^{1,3,5} is that if colloid osmotic pressure is allowed to fall to a level less than 17 mmHg, the risk of pulmonary edema increases and the prognosis of recovery decreases. When the colloid osmotic pressure is less than 13 mmHg, the situation is very grave. It was noted earlier in this study that the mean colloid osmotic pressure of the patient group was less than 12.5 mmHg throughout bypass and post-pump. However, all patients recovered without complications.

The reason for their recovery is twofold. First is the aggressive patient management post-operatively with diuretics; osmotic agents such as fresh frozen plasma, albumin, and Hespan; positive end expiratory pressure; and antihypertensive drugs. Secondly, most patients presented for cardiopulmonary bypass do not have multi-system complications such as renal failure or respiratory disease. Whereas, the critically ill patient may exhibit several complications which make for difficult control of protein synthesis, total body fluid, tissue edema, lymphatic drainage and/or blood pressure.

Conclusions

1. The use of the American Optical Refractometer provides an inexpensive and reliable method for the determination of total plasma protein concentration and the subsequent estimation of colloid osmotic pressure. The American Optical Refractometer, besides being easy to use and requiring a very small sample size, is also sensitive to the presence of non-protein osmotic agents.

2. Colloid osmotic pressure can be reliably estimated from the American Optical Refractometer reading by multiplying the total plasma protein (TPP) reading by 3.32 and then subtracting 2.0.

$$\text{COP} = (3.32 \times \text{TPP}) - 2.0$$

3. Since patients undergoing cardiopulmonary bypass tolerate the acute depression of colloid osmotic pressure attendant with hemodilutional primes so well,

a redefinition of optimal levels for colloid osmotic pressure while on bypass is needed.

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