A Technique of Large Volume Hemodilution for Cardiopulmonary Bypass

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The use of blood substitutes for cardiac surgery has been documented many times since 1959. Some cardiac centers remain reluctant to employ this technique. It is our opinion that hemodilution can be used safely and with many advantages to the patient.

Total cardiopulmonary bypass in 100 patients ranging in age from three years to seventy-six years was undertaken at two hospitals in Minneapolis, Minnesota. Outlined herein are observations of the effect of large volume hemodilution on the patient's hematocrit, hemoglobin, urine output, body weight and plasma hemoglobin levels.

HISTORY

In the early years of CPB*, large volumes of homologous banked blood were used in cardiac surgery for various reasons: (1) Priming volume of CPB equipment was large (2) Blood handling equipment supplied by industry was substandard, resulting in elevated levels of plasma hemoglobin and bleeding tendencies (3) Poor understanding of atraumatic techniques of blood handling by surgical team increased blood damage and post CPB bleeding.

Hepatitis transmission, anaphylactic sensitization and transfusion reactions remain as hazards to homologous blood transfusions. Pulmonary insufficiency precipitated by microembolization of particulate matter found in banked blood has more recently received attention. Reul† in his studies found cellular debris in the pulmonary veins of patients who had received large amounts of homologous blood. This seems to imply that through the action of arteriovenous shunting mechanisms of the lung, some debris from banked blood may actually enter the systemic circulation.

Fortunately the technology of CPB has advanced to a level where little or no blood is necessary for most intracardiac procedures.

TECHNIQUE

Standard perfusion techniques with concomitant hypothermia at thirty degrees centigrade and the Bentley† disposable bubble oxygenator were utilized for all bypass procedures. Sarns‡ modular 180 degree roller pumps with occlusive settings were used to produce systemic perfusion rates of at least 2.2L/min/M2 for adults and 2.4L/min/M2 for children. These flow rates usually produced radial artery pressures in the range of 50-100 mmHg, and venous saturation from 60-70%.

Neither vasopressive agents or blocking agents were used to maintain systemic pressures or enhance flow rates. An aneroid pressure monitor§ was placed in arterial line of the CPB circuit to insure against position error of the aortic cannula and also to alert the perfusionist of abnormal pressures, possibly due to dissection at the site of systemic cannulation. We have also found this monitor to be a simple, economical and reliable indication of systemic pressure both before and after CPB.

During CPB, maintenance of pre-determined venous pressure was not considered, however, this pressure was measured to insure against obstruction of venous drainage to the oxygenator. Right atrial filling pressure after CPB was also measured from the

*CPB—Cardiopulmonary Bypass
†Bentley Oxygenator—Bentley Laboratories, Inc.
‡Sarns modular pump—Travenol Laboratories, Inc.
§Arterial pressure monitor—Travenol Laboratories, Inc.

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same catheter positioned in close approximation to the right atrium via a vein in the arm or leg.

For CPB, cannulae were placed in the usual manner. Emphasis was placed on standardized techniques for each type of cardiac repair.

A mixture of 100% oxygen and fluothane were used for blood oxygenation and to maintain anesthesia during CPB.

Hemodilution was accomplished in these patients using a commercially available balanced electrolyte solution with the pH adjusted to 7.4.* For adults, 43cc/kilo body weight was used and 20cc/kilo for children. A lesser degree of dilution was necessary when anemia was present.

**DISCUSSION**

When utilizing the technique of large volume hemodilution, diuresis is commonplace both during surgery and in the postoperative period. The average urine output during CPB was 275cc/hr. Immediately post CPB, hematocrit ranged from 20-30%. 9 Gms. was the lowest hemoglobin in this series. As urine output stabilized in the postoperative period, these parameters usually have returned to an acceptable range. If significant blood loss was encountered during surgery (500-1000cc) banked blood was administered. Finlayson¹⁰ has noted that most patients should be able to tolerate a loss of up to 20 per cent of their blood volume and, if the fluid volume is maintained, losses of up to 40 per cent of their red cell mass.

Translocation of non-hemic prime into the extravascular compartment is not to be disputed. However, this so called “water logging” of tissues does not appear to alter the outcome of patients, even those patients with severe congestive failure. The reduction of oncotic pressure with dilution most likely explains this translocation of fluid. Additional factors such as an increased capillary permeability resulting from damage to platelets and leukocytes,¹¹ cellular hypoxia and general stress to the organism should also be considered. It is suggested to maintain iso-osmolarity in prime solutions used for hemodilution to limit this movement of water.¹² There has been no significant alteration in preoperative and five day postoperative body weights indicating that the excess fluid load from hemodilution is excreted. Naturally, those patients with preoperative failure do lose weight in the postoperative period if hemodynamics are corrected.

The association of potassium depletion with CPB has been documented by various investigators⁶⁻⁷·¹² and replacement therapy should be considered to reduce the incidence of ventricular hyper-irritability. During CPB and in the immediate days following surgery a large loss of potassium occurs by diuresis. Hyperglycemia and hyperinsulinemia may also cause intracellular movement of potassium.¹⁶ A study by Clark and colleagues,⁷ in which whole body potassium was measured by use of a total body counter, showed a decrease in whole body potassium of about 200 MEq between the preoperative study and 48 hours later. Similar results were found by Pacifico, Kirklin and colleagues in their studies.¹ The administration of potassium during CPB is part of our protocol and also in the post-operative period. More aggressive therapy is indicated when arrhythmias are noted or when diuretics are administered, regardless of the plasma potassium results. Previous studies have shown potassium in the amount of 50 to 100 MEq/24 hours is excreted in the urine in the early days after open intracardiac surgery.⁵ ⁹

Venous blood returning to the CPB was easily oxygenated to 100 per cent saturation using 100 per cent oxygen in a ratio of three liters oxygen per liter of blood flow. During hypothermic periods this ratio could be reduced to 1-2 liters oxygen per liter of blood flow. In the majority of these cases the addition of CO₂ to the oxygenator was not necessary to maintain acceptable blood CO₂ levels. By regulating oxygen inflow to the oxygenator, physiologic blood oxygen saturation can be maintained without hyperventilation.

Hirsch and colleagues² measured oxygen consumption clinically and experimentally during CPB with total hemodilution. Oxygen consumption in their studies ranged from 1.2 to 3.3cc per kilogram per minute. Hemodilution ranged from 25cc to 52cc per kilogram with flow rates averaging 52cc per kilogram per minute at an esophageal

*Normosol-R Abbott, Plasmalyte 148-Baxter Travenol

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temperature of 33 degrees centigrade. This data compared favorably with those reported by Senning but the values are less than the theoretical values for man during whole body perfusion with blood prime at normothermic temperatures. Research carried out by Housman using hemodilution on 4-6 kilogram puppies indicated that regardless of the prime solution employed, adequate oxygenation, CO₂ exchange and tissue perfusion took place as long as the hematocrit remained above 15 per cent. In our series of 100 patients using hemodilution of 43cc per kilogram, hypothermia and flow rates of 2.2 to 2.4L/min/M² hypoxic acidosis was not observed.

Forty-eight of the cardiac procedures were successfully completed without the use of blood and a 2 per cent incidence of postoperative bleeding. We feel this low incidence is, in part, due to the minimal use of banked blood. The average volume of blood administered during surgery for this variety of both simple and complex cardiac lesions was 525cc.

In our experience, if special attention is given to proper placement of venous cannula, ventricular and pulmonary artery suction devices and aortic cannulation, little or no extra cardiac suction is needed. Improper planning for size and placement of cannula and suction devices is conducive to blood leaking into pericardium and thorax. This blood will mix with fat and other non-hemic substances which tend to lyse blood cells and possibly trigger the clotting mechanism resulting in bleeding problems due to intravascular coagulation. With the advent of the high quality of CPB filters* much of the debris is removed from suctioned blood, however, significant hemolysis to blood components cannot be reversed. Judicious use of suctioning devices and decreased usage of banked ACD blood were methods of reducing plasma hemoglobin levels in studies by Riley. When necessary, blood was returned to the CPB via cardiotomy suction. Blood damage was kept to a minimum by controlling the flow rate of the suction system, limiting the amount of free air to mix with the blood.

Blood remaining in the CPB circuit after the completion of bypass was stored in Fenwall blood bags* for volume replacement in the immediate post bypass period. Chromium 51* was used in vivo to tag this remaining blood. Results indicated the mean half life to be 14.6 days. Considering normal half life to be 30 days, we felt this blood should be saved and returned to the patient rather than being discarded. After CPB, the immediate storage of remaining CPB blood in transfusion bags facilitates the surgeons decannulation and administration of protamine sulphate, therefore, reducing blood loss. It should be noted that in the immediate post CPB period there is frequently significant hemodynamic variation from normal and, therefore, blood volume replacement should be based on right and/or left atrial filling pressures and not according to loss noted in suction bottles and sponges.

Significant problems with anemia have not been experienced, however, when indicated, blood or packed cells were administered in the post-operative period. The average decrease in hemoglobin concentration one week after operation was 1.8 gms. per cent. The average decrease in packed red cell volume was 7.1 per cent which is compatible with statistics from other centers.

CONCLUSION

We have found large volume dilution for CPB to be safe and to have inherent advantages when compared to total hemic CPB. Cost to the patients is reduced, as is the risk of contamination and other hazards of blood administration. The average volume of blood administered during surgery for this variety of both simple and complex cardiac lesions was 552cc. A low incidence of postoperative bleeding in this series (2%) is, in part, due to the minimal use of banked blood. Plasma hemoglobin levels of 8.7 mg per cent per hour indicate less trauma to blood traversing the CPB circuit could also be attributed to hemodilution. Enhanced perfusion and metabolism is another probable outcome of hemodilution, however, proof is lacking. There is no question that kidney function is enhanced and we have not experienced any detrimental outcome from this diuresis.

*CPB filters
Bentley
Swank
Johnson & Johnson

Chromitope sodium, Squibb
Fenwall Division of Travenol Labs.
JA-5N Blood Pack, 450 ml ACD
REFERENCES


