

CLINICAL CARDIOPULMONARY BYPASS UTILIZING NORMOTHERMIA, NORMOTENSION AND "HIGHFLOW"

Kent A. Vasko and Richard A. DeWall

INTRODUCTION

Since the advent of clinical open cardiomy procedures utilizing heart-lung bypass with a mechanical system, few advances have been made in equipment. The conceptual designs of Gibbon¹, Bjork², later extended by Kay and Cross³, DeWall⁴, and other have either stood or failed the test of vigorous application during the preceding 15 years. Two of the above systems have been adopted for greater application than the others. It should be said before proceeding that the accidental discovery of heparin by McClean in 1916⁵ and the means of isolation and purification by Howell and Holt⁶ made the possibility of any system a reality.

The next development in extracorporeal perfusion was the selection of blood substitutes, a point on which there still remains considerable debate. Many solutions are used with success but it seems that hemodilution, either partial or complete, consistently results in the least number of problems. Hematologists and blood bank personnel continually express concern over undefined reactions with blood examined carefully by current techniques. Balanced electrolyte solutions, dextran and five percent dextrose in water, have their advocates. Recent results in this laboratory are indicative of a real gain in electrolyte and volume stability with the use of a serum protein-electrolyte solution⁷, however, the present cost may be prohibitive for routine use. An excellent review of blood substitutes has recently been written by Gruber⁸.

There are many ways to conduct a perfusion such as those expressed by Gollan⁹ or Donald¹⁰ to mention only two commonly employed out of many. Our experience has been that no single formula is adequate, and, in fact, no two patients can be perfused in the same manner. We have not found the use of complex priming solutions with many additives to have special virtue but rely upon 5% dextrose in water for priming. A patient should be in metabolic balance prior to a perfusion, however a good perfusion can compensate for some acid base imbalance due to poor cardiac output from a sick heart and any anesthesia problems. Inadequate perfusion of the biological system leads to every variety of metabolic or physiological problems one may encounter, the most disastrous of which is probably the disseminated intravascular coagulation syndrome¹¹. Conversely, adequate perfusion results in normal physiology.

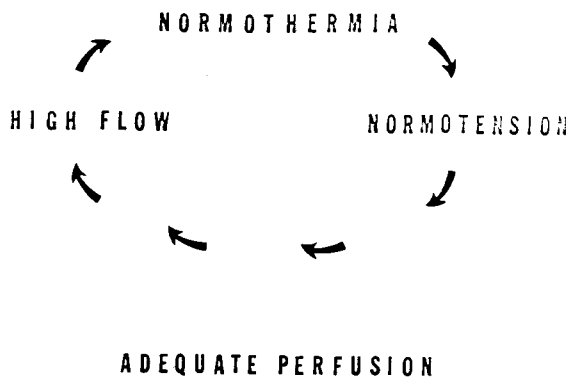
Cox Heart Institute, Kettering Medical Center, Dayton, Ohio
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OUR PRESENT PERFUSION METHOD:

Our current approach to perfusions which has been employed during the past eighteen months is what we have elected to term a "perfusion triad" (figure 1). A fourth dimension of pulsatile blood pumping might be considered by some but presently the evidence is not sufficient to warrant conversion to this form of pumping. The attainment of adequate perfusion, as reflected by maintenance of renal function (no less than 50 ml per hour of urine output and preferably 100 ml per hour), normal electrolyte values and normal blood gases (pH, pCO₂, pO₂, and calculated buffer base excess or deficit) measured at least every fifteen minutes or more often as conditions warrant, can be attained by the technique which follows.

We utilize a standard conventional bubble oxygenator for all cases¹². The only variation being between that of patient size (adult, pediatric, infant). The priming solution used is five percent dextrose in water. In diabetics, ten units of regular insulin is added to each liter of five percent glucose in water used in the prime. Additional insulin is added when needed based upon periodic blood glucose determinations. Heparin is added to the priming solution at a rate of 100 units for each 500 m. of priming solution. Mannitol is added as a "one-time" dose of 12.5 gms. Any further diuresis if desired, is achieved by the use of furosemide in single doses of 20 to 40 mgm intravenously or directly into the extracorporeal system.

The only rationale for the use of Mannitol is that of providing some osmotic diuresis in the occasional patient in which the systemic arterial pressure is low prior to or during the onset of perfusion because of low cardiac output, anesthetic effects, or inadequate blood volume. Central venous pressures are monitored on all patients. Transfusions are begun immediately after the catheter is placed to drive to venous pressure to at least 15 cm water. This provides for a physiologically functional blood volume regardless if the patient is hypo-normal or hypervolemic. At the onset of perfusion, priming volume is infused from the oxygenator as rapidly as necessary to maintain systemic pressure. This means a temporary drop in reservoir volume but is well worth the extra effort when compared to the difficulty in recovering from even a transient drop in pressure which leads to generalized vasoconstriction and sequestration. Once the peripheral bed is shut down due to hypotension there follows an agonizing period of trying to reopen the peripheral vascular bed to achieve adequate perfusion. Venous pressures during perfusion are kept in the range of 10 cm water.



- 1 Normal Blood Gases
- 2 Normal Electrolytes
- 3 Urinary Output
- 4 Normal Metabolic Functions
- 5 Low Morbidity

Figure 1. The "triad" of perfusion techniques with a summary of results.

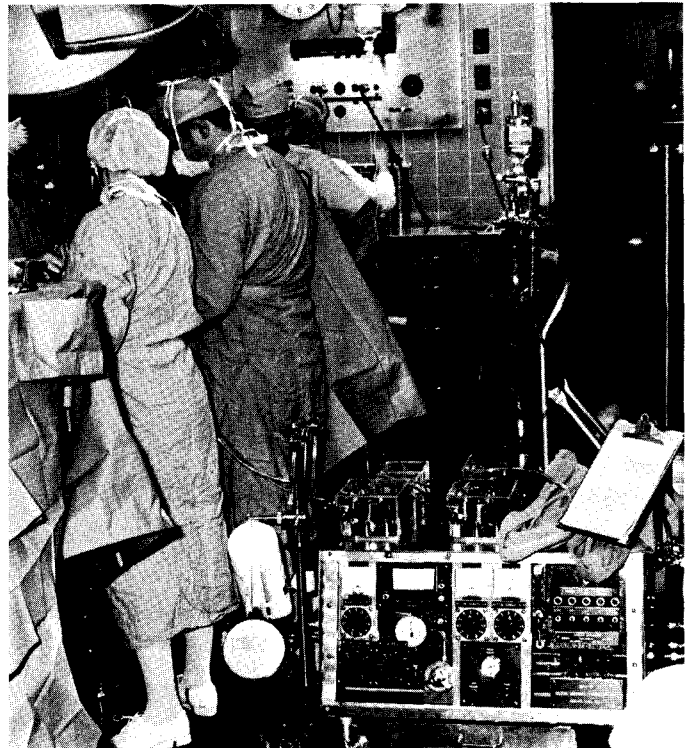


Figure 2. Relative position of perfusion system to patient to obtain smallest volume and transit time.

BLOOD REPLACEMENT:

Volume deficiencies are especially common in those patients undergoing surgery for coronary heart disease probably due to a low output state and resultant reduction in functional or "physiologic" vascular space. These patients have been functionally hypovolemic well in excess of the difference between predicted and calculated blood volume. They have routinely required as much as four or five units of blood above that which was expected to be necessary for the desired pressure-flow relationship. Regardless of the actual quantity we simply add as much blood volume as is necessary to achieve this as long as venous catheters are unobstructed and caval drainage is adequate. Hypovolemia of the coronary patients has been observed by Johnson et al¹². His report indicates that patients with impaired myocardial function (measured dP/dt) are usually not hypovolemic while those with normal function more frequently are.

All additional whole blood is added by the anesthesiologist to prevent the sudden introduction of a large bolus of poorly filtered and often very viscous ACD blood into the systemic circuit. For each unit of ACD blood added we add 2000 units of heparin and 20 mellequivalents on NaHCO³.

HEPARINIZATION:

Patient heparinization is carried out at a dosage of 300 units per kilogram just prior to cannulation. Ten percent of the initial dose is added each hour to compensate for metabolic degradation. Variations in the recommended doses of heparin replacement are widespread. The disappearance of heparin is dependent on many factors including concentration. At levels of 4 milligrams/kg the rate of disappearance is said to be 50 percent per hour¹⁴. Perhaps a realistic approach is that of adding enough additional heparin to maintain a partial thromboplastin time at or above sixty seconds¹⁵. Although the ratios vary from author to author, it has been found that, in our technique, addition of ten percent of initial dose per hour will accomplish this provided that all additional ACD blood is taken into consideration. At the end of perfusion protamine sulfate is administered slowly at a dose calculated to be one-half of the initial heparin dose. Later another quarter dose may be added. No further agents are employed

to us that "polypharmacy" with regard to reestablishing coagulability has probably resulted in more frequent and serious post perfusion bleeding than if the above protamine dose alone is given. It may even be argued no protamine is required¹⁶.

EXTRACORPOREAL CIRCUIT:

The volume of the extracorporeal circuit is kept as low as a comfortable operating level will permit and the system is placed as close to the table as possible (figure 2). This may be somewhat confining for the personnel on that side but the achievement of the smallest possible extracorporeal volume and shortest transit time in the circuit are felt to be valuable enough to offset any discomfort. The priming volume in the circuit is 16 ml/kg. of body weight plus 25 ml in addition to fill the coronary perfusion system when it is used. The venous "line" is filled at the table from the patient. Connectors with luer sidearms are employed on the positive pressure sides of the arterial and venous sides for sampling. A hydraulically operated venous clamp* (figure 3) is used to control venous return.

The onset of perfusion is a critical period in achieving adequate flow while maintaining pressure. The venous clamp is opened slowly and infusion from the arterial reservoir controlled as described. The superior and inferior vena cavae are fully occluded by the conventional tape snares. At the time of occluding the superior cava a careful appraisal of venous return as indicated by reservoir volume should be carried out. A fall in volume (decrease in venous return) is indicative of inadequate drainage of the superior vena cava. This may also occur if the head is lowered during the procedure. This is important in any technique but especially so in high flow procedures as arterial blood delivery to the upper body will quickly result in a net increase over venous return blood. This poses not only the obvious mechanical problem of venous return to the system but is potentially very hazardous to the patient.

* Olson Medical Products, Ashland, Massachusetts

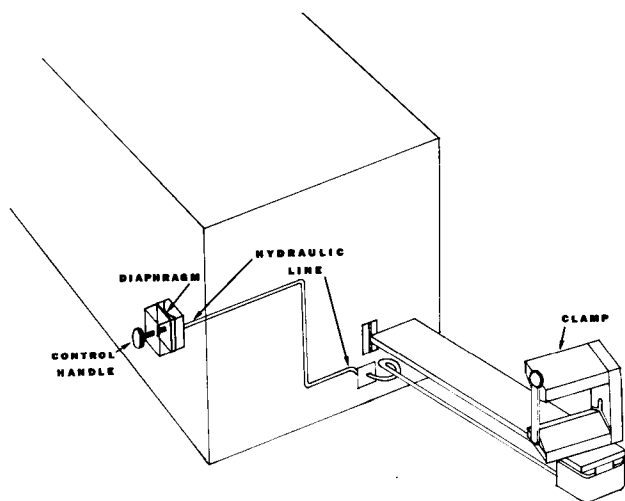


Figure 3. Diagram of hydraulic clamp system used to control venous return.

PHYSIOLOGIC AND METABOLIC CHANGES:

Once total bypass is achieved, the flow rate is adjusted to whatever level is necessary to maintain a systolic pressure over 70 mm Hg with good metabolic stability based on measurements of arterial and venous blood pH, pO_2 , pCO_2 and calculations of arterial venous differences and buffer base excess or deficit. Urine output is measured. It has been found that systolic pressure below 70 mm Hg usually results in abrupt cessation of urinary output while pressures from 70 to 100 mm Hg, produce a linear increase in output. Above that pressure, little, if anything, is gained in renal function. The importance of this lies in the fact that a central arterial pressure near 70 mm Hg must reflect the critical closing pressure in the renal vasculature.

One metabolic change that may occur in any procedure but has been noted in several patients undergoing coronary artery surgery is an increasing pH of blood with otherwise normal arterial and venous blood gases. This may be accompanied by a sagging arterial and venous pressure in the fact of very high flow rate and an adequate blood volume. A request for a potassium determination will very likely reveal a hypokalemia, a potassium below 3.5 meq/l. The administration of forty or more milliequivalents of potassium chloride will result not only in stabilization of pH but result in an increase in vascular tone as reflected by an increase in both arterial and venous pressures and in venous return. A similar situation may also be seen in which hypokalemia is accompanied by decreased pH. If the patient will not respond to what is otherwise a stable and presumably adequate perfusion the cause may be hyperglycemia. This has

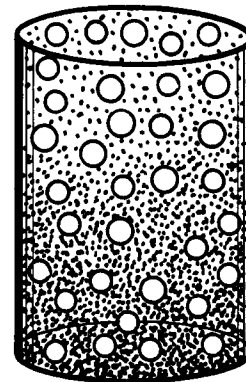
been seen in patients in which other evidence of diabetes has not been previously noted and is probably due to strict dietary enforcement because of their heart disease but becomes apparent during perfusion especially after receiving large amounts of ACD blood, and glucose containing solutions.

"COMING OFF" THE PUMP:

The cessation of extracorporeal circulation is by simply gradual (rather than abrupt) withdrawal of extracorporeal support by (1) allowing part of the venous return to enter the cardiopulmonary circulation and withdrawal of left ventricular decompression, (2) reduction in support by reducing venous return while maintaining volume stability in the reservoir (or transfusion of part of the volume to the patient), and (3) final cessation of all external support. This process usually requires a period of ten to fifteen minutes. The abrupt termination of support at the end of a procedure is probably as physiological as completing a parachute drop by removing the parachute two or three hundred feet above the ground.

CONCLUSION:

During the preceding eighteen months, the above technique has been employed in all patients undergoing open cardiomy at this institution and another local hospital with excellent results both during and following perfusion. Physiologic and metabolic balance should and can be maintained in all perfusion.



BIBLIOGRAPHY

- Gibbon, J.H., Jr.: An oxygenator with a large surface-volume ratio. *J. Labor. Clin. Med.* 24:1192, 1939.
- Bjork, V.O.: Brain perfusion in dogs with artificially oxygenated blood. *Acta Chem. Scand.* 96:1, 1948.
- Kay, E.B. and Cross, F.S.: Direct vision repair of intracardiac defects utilizing a rotating disc oxygenator. *Surg. gynec. Obstet.* 104:701, 1957.
- DeWall, R.A. and Lillehei, C.W.: Design and clinical application of the Helix reservoir pump-oxygenator system for extracorporeal circulation. *Post Grad. Med.* 23:561, 1958.
- McClellan, J.L.: The thromboplastic action of cephaline. *Am. J. Physiol.* 41:250, 1916.
- Howell, W.H. and Holt, E.: Two new factors in blood coagulation-Heparin and pro-antithrombin, *Am. J. Physiol.* 47: 382, 1918.
- Vasko, K.A., DeWall, R.A., and Bonnabeau, R.C.: A serum protein-electrolyte solution as perfusate for cardiopulmonary bypass. *Proceedings Central Society for Clinical Research*, 43:27, 1970.
- Gruber, V.F.: *Blood replacement*, published by Springer, Berlin-Heidelberg-New York, 1969.
- Gollan, F.: *Physiology of cardiac surgery*, 96 pp. Chas. A Thomas, publ, Springfield, Illinois, 1959.
- Donald, D.E. and Moffitt, E.A.: The relation of blood flow and blood volume during extracorporeal circulation in man. *Surg. Forum* 7:264-267, 1957.
- Deykin, D.: The clinical challenge of disseminated intra-vascular coagulation. *New Eng. J. Med.* 283:636, 1970.
- DeWall, R.A., Najafi, H. and Roden, T.: A hard shell temperature controlling disposable blood oxygenator. *JAMA* 197:1065, 1966.
- Johnson, W.D., Flemma, R.J., Manley, J.C., and Lepley, D., Jr.: The physiologic parameters of ventricular function as affected by direct coronary surgery. *J. Thoracic and Cardiovasc. Surg.* 60:483, 1970.
- Galletti, P.M. and Brecher, G.A.: *Heart-Lung bypass*. Grune and Stratton Publishers, New York and London, 1962.
- Pierce, E.C. II: *Extracorporeal circulation for open-heart surgery*. Chas. C. Thomas Publisher, Springfield, Illinois, 1969.
- Castaneda, A.R.: Must heparin be neutralized following open-heart operations? *J. Thorac. Cardiovasc. Surg.* 52:716, 1966.