Perfusion During Open-Heart Surgery

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PERFUSION DURING OPEN-HEART SURGERY

Since the description of the Azygos factor by Andreasen and Watson in 1951,[1] perfusion criteria have been much debated. Early investigators fluctuated between a high and low flow rates and the debate continues today.[2, 3, 4, 5, 6] Hypothermia has been both widely acclaimed and generally repudiated.[7, 8] Anoxic arrest of the heart[10, 11, 2, 12] versus coronary perfusion[9] is yet another question of intense debate. This latter question takes on even more significance when confronted with an already severely damaged myocardium as seen in the candidate for coronary artery bypass graft surgery. Vigorous hemodilution is acclaimed by many, others advocate the maintenance of high hematocrit to avoid sacrificing oxygen carrying capacity. In an attempt to resolve some of these questions a critical review of our perfusion data during a 22 month period was undertaken.

MATERIALS AND METHODS

Between January 1, 1972, and October 31, 1973, 3,195 adult patients underwent total cardiopulmonary bypass for surgical correction of various types of cardiac defects. One thousand eight hundred nine of these patients underwent coronary artery bypass graft surgery. All patients were perfused through the ascending aorta or femoral artery with a roller pump and using a disposable bubble oxygenator. Carbon dioxide in oxygen was the oxygenating gas and no volatile anesthetic was administered during cardiopulmonary bypass. Extracorporeal filtration was utilized only in the cardiotomy return line. Five percent Dextrose in lactated Ringer's (20 ml/kg) was the only solution used to prime the perfusion circuit. Heparin 25 mg/l was added to the prime and 3 mg/kg was administered to the patients. Flow rates were maintained optimally between 40 and 60 ml/kg/min as the minimum acceptable perfusion rate. Decompression of the left ventricle was accomplished by a left atrial vent. Moderate (30-32° C esophageal) systemic hypothermia was induced by extracorporeal cooling at the onset of bypass and the myocardium was cooled topically with saline slush. Hypothermia was utilized in all operative procedures involving aortic valve disease, two or more aorto-coronary bypass grafts, or resection of left ventricular aneurysm. Ischemic arrest was then instituted by clamping the ascending aorta. Perfusion was terminated as early as possible after the aortic clamp was released after surgical repair and heparin was reversed with protamine sulfate as soon as venous cannulae were removed. We were unable to relate any perfusion characteristics to mortality.

DISCUSSION

Perfusion pressure: For most of the bypass period in all patients, perfusion flow ranged between 40 and 60 ml/kg/min and at this flow arterial pressures measured in the radial artery ranged between 40 and 60 mmHg. Not rarely perfusion pressure approached and at times exceeded 100 mmHg without apparent cause especially toward the end of the bypass period. When approaching 90 mmHg, treatment was instituted to avoid excessive back bleeding into the heart and additional blood trauma by a high flow through the coronary return system. Hypertensive perfusion always responded transiently to trimetaphan (Arfonad) or isoproterenol (Isuprel)

and less reliably to phentolamine (Regitine). For a longer effect, chlorpromazine (Thorazine) was usually effective.

Excessively low perfusion pressure was usually associated with low perfusion rate and most commonly occurred at the onset of bypass. The commonest cause of low perfusion rates was inadequate venous return from malposition of the caval catheters. If adjustment of caval catheters and lowering the blood reservoir level in the oxygenator failed to provide adequate flow, additional lactated Ringer's was added to the oxygenator and the volume translocated to the intravascular compartment to provide increased venous return. At times 5-6 liters of electrolyte solution representing the sum of prime volume, intravenously administered solution and added prime was required to achieve satisfactory flow rates.

High perfusion rates per se obviously do not necessarily indicate high tissue perfusion. Rates in excess of 80 to 100 ml/kg/min may simply represent arterial-venous shunting as in tetralogy of Fallot. Even in the absence of such obvious shunting, there is no assurance that high pump flow rates lead to high perfusion of organs requiring high flow by virtue of sensitivity to oxygen lack. Indeed the converse is possible. We have been unable to correlate post-operative neurological defects (slow awakening, delerium, or neurological deficit) with low perfusion flows or pressures except in a few exceptional circumstances. Shumway's group[8] reported excellent results with perfusion rates of 35 ml/kg/min, as has Zudhi and associates[13] with perfusion rates not exceeding 20 ml/kg/min, both utilizing moderate systemic hypothermia. At flow rates used in our patients, the output of urine was steady during bypass without the addition of mannitol or diuretics, but only in response to the large water load provided before and during bypass. Urine production was approximately 250 ml during one hour of perfusion.

Hemodilution: With the increasing shortage of stored blood and the rising incidence of hepatitis after blood transfusion, as high as 51% of patients undergoing open-heart surgery[14] in one report, hemodilution as a means of blood conservation assumes an even more appealing aspect. Added advantages include the lower resistance to flow of low hematocrit blood suggesting better capillary and tissue perfusion and the capability of operating upon patients whose religious beliefs interdict blood transfusion. Hematocrit values as low as 15 were observed during bypass in our patients and this value was considered our lowest acceptable degree of hemodilution. This dilution to less than half normal was not associated with postoperative coagulation problems, water intoxication, or congestive failure from excessive electrolyte solution. The excess water was rapidly diuresed early in the post-bypass period particularly if furosemide (Lasix) in 20-40 mg doses was given at the end of operation. The mean hematocrit during bypass in our patients was 24.5%, which represented a 56.1% reduction from pre-operative hematocrit.

Ischemic Arrest: Ischemic arrest was achieved by clamping the ascending aorta after core cooling to 30° C esophageal and topically cooling the myocardium with saline slush. The ischemic time ranged from 16 to 122 minutes, the average being 48.6 minutes. Griepp and Shumway[8] however reported aortic cross clamp times from 21 to 138 minutes in a similar group of patients and could not relate cross clamp time to mortality, requirement for post-operative inotropic support, duration of post-operative ventilation, duration of intensive care, or hospital stay. Reul, et al[15] in a study of 493 coronary bypass patients concluded that fatal myocardium complications were related to pre-existing disease rather than duration of aortic occlusion or ischemic arrest. Coronary perfusion was not used in our patients because of its attendant complications including myocardial hemorrhage, coronary artery dissection, dislodgement of arteriosclerotic material, and myocardial infarction. Similarly continous prolonged electrical fibrillation was not used because of possible sub-endocardial hemorrhagic necrosis.[16] Ischemic contracture of the heart ("Stone

Heart")[17] was not observed in this group of patients.

Hypothermia: Rapid cooling was begun as soon as bypass was instituted by a venous line heat exchanger and a 4° C cooling reservoir.[18] Cooling to an esophageal temperature of 30° required about 5 to 15 minutes and neither serious arrhythmias nor hypotension appeared during this relatively rapid cooling. Cooling rates seldom exceeded 1° per minute. On rewarming the water temperature in the reservoir was never allowed to exceed 42° C with a resulting blood-water temperature gradient of not more than 12° C, and in most instances the gradient was less than 8° C owing to the cooling of the water in the warming reservoir by the blood.

Filters: A depth type dacron wool filter* was employed in the cardiotomy return line. Since the major portion of blood trauma occurred in the coronary suction system, which also returns most of the biological debris to the circuit, filtration in this sub-system was considered mandatory. We selected the depth type filter because it is more effective in removing this biological debris than is the grid type filter.[19]

We have not used arterial line filtration because of our concern for further blood trauma by passing fragile erythrocytes at high velocities through small holes. Plasma hemoglobin determinations do not reflect sub-lethal damage and subsequent short life spans of those injured, but still viable, erythrocytes.[20]

Oxygenators: Six different bubble oxygenators were used in this group of patients: Travenol, Rygg, an experimental bag type, Bentley, Harvey, and Galen. Mortality in our patients was not related in any way to the type of oxygenator used. Each oxygenator was satisfactory when employed in a manner which recognized its individual operating characteristics and limitations. For example one was extremely efficient in CO_2 removal while another tended to retain CO_2 and still another was slower in rewarming capacity. One oxygenator may well appear to be inferior in performance when operated under conditions most suitable for another oxygenator. For example, we found that the optimal blood to gas flow ratio was higher when using the Bentley oxygenator, lower in the Travenol, and lowest in the Harvey when maintaining an arterial PO_2 between 100 and 200 mmHg as the criterion. The Bentley would certainly appear to be grossly unsatisfactory in oxygenating capacity if it were operated with the Harvey blood to gas flow ratio.

Some of the problems encountered at times during this study apart from the specific individual operating characteristics include: inadequate oxygenating capacity (even at blood flow rates less than 5 l/min) of all the oxygenators used, inadequate defoaming capability in all except the Rygg and Travenol, blood to air leaks in all oxygenators, fibrin and frank clot formation despite adequate heparinization in all oxygenators, and inadequate rewarming capacity in the Bentley. Floating particulate matter in several of the oxygenators prompted our investigation of particulate contamination. Average particulate contamination as high as 130,000 particles larger than 20 micron per oxygenator was demonstrated in oxygenators as received from the factory. As a result of findings each oxygenator is now rinsed and the prime filtered through a 5 micron filter** prior to use.

Although we found no correlation between mortality from operation and any perfusion characteristics we reviewed, we recognize the limitations of such data. A careful review of morbidity, more detailed analysis of the course of perfusion, as well as details of surgical technique and post-operative care might enable us to identify complications ascribable to perfusion alone. In the absence of such detailed information and from the absence of gross correlations in this study, we believe the perfusion system and technique described here is safe and effective.

SUMMARY

We have reviewed the perfusion characteristics of 3,195 consecutive patients

*Pioneer Filters, Incorporated, Beaverton, Oregon.
**Millipore Corporation, Bedford, Massachusetts.

undergoing cardiopulmonary bypass for surgical correction of various types of cardiac defects. We could not correlate mortality in this group with duration of ischemic arrest, degree of hemodilution, urine output, perfusion rates, perfusion pressures, or oxygenators used. Based on this experience our criteria for adequate perfusion of these patients include perfusion rates of 40-60 ml/kg/min, perfusion pressure between 40 and 60 mmHg, acceptable arterial and venous blood gas values, some urinary output, and the presence of EEG activity.

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