

technique

This new section is open for technicians to explore the unusual, the difficult, the innovative methods by which perfusion meets the challenge of the hour and produces the ultimate goal — a life saving technique.

Perfusion for Repair of Aneurysms of the Transverse Aortic Arch

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Aneurysms of the transverse aortic arch present a technical challenge to the thoracic surgeon and extracorporeal perfusionist. The purpose of this communication is to present a perfusion technique that we have found to be safe and reliable for complete repair of these aneurysms. This technique, having been used for repair of the transverse aortic arch associated with cystic medial necrosis, trauma, syphilis, and arteriosclerotic aneurysms, has given us a means of prosthetic replacement of the transverse arch while maintaining a physiologic perfusion.

Aneurysms of the transverse portion of the aortic arch involve the innominate, left carotid, and/or left subclavian arteries. Although the surgical management of these aneurysms presents a technical challenge to the thoracic surgeon, success also depends upon physiologic perfusion of the cerebral, coronary, and systemic circulations. The circuitry needed and the conduct of the perfusion present a challenge to the extracorporeal perfusionist as well. The purpose of this communication is to present a perfusion technique that we have found to be safe and reliable.

Perfusion System

The perfusion circuit and technique described here is for repair of aneurysms that involve all three major vessels of the aortic arch. The perfusion system utilized for this repair evolved after consideration was given to blood flow within the systemic circulation, the cerebral circulation, and within the coronary circulation of an anesthetized patient. Under these conditions, cardiac output is approximately equal to 2400 ml/min/m² of body surface area (B.S.A.).₁ Cerebral blood flow is approximately fifteen percent of the cardiac output or 360 ml/min/m² of B.S.A.,₂ and the coronary blood flow is approximately five percent of the cardiac output or 120 ml/min/m² of B.S.A.₃ Blood flow to the remainder of the systemic circulation is approximately eighty percent of cardiac output or 1920 ml/min/m² of B.S.A. In all of our perfusions we duplicate blood flow as it occurs normally in the anesthetized patient.

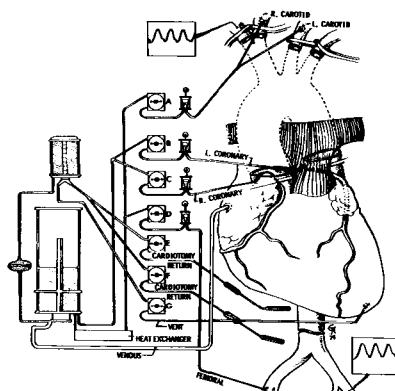


Figure 1 — Schematic showing the circuitry used for perfusion of the aortic arch.

The perfusion circuit is outlined in Figure 1. In order to establish total cardiopulmonary bypass a single ½ inch venous cannula is placed in the right atrium connected to ½ inch PVC tubing for venous return to the disposable bubble oxygenator. After oxygenation with 100% O₂ the blood is returned to the patient's aorta via a heat exchanger and a bubble trap through 3/8 inch PVC tubing to a #26 French Bardic Cannula to the femoral artery. Cardiomy suctioning is accomplished through two ¼ inch PVC tubing sets with a 3/8 inch boot through the roller pump. The larger boot allows the pump rollers to turn at a slower rate in an effort to help reduce hemolysis. Decompression of the left ventricle is accomplished by placing a vent through the apex of the left ventricle. A ¼ inch PVC tubing with a 3/8 inch pumphead boot is positioned in the pumphead and attached to the vent. The cardiomy suckers and the vent are connected to a rigid cardiomy reservoir which has an in-line cardiomy filter for return to the venous portion of the oxygenator.

Oxygenated blood for the cerebral perfusion circuit is taken from the oxygenator with ¼ inch PVC tubing. After passing through a roller pump it goes to a bubble trap with an anaeroid pressure manometer where cerebral perfusion line pressure is monitored. A ¼ inch perfusion line then leaves the bubble trap and goes to a ¼ x ¼ x ¼ inch "Y" connector which has two 16 French Bardic cannulas for infusion to the carotid arteries.

The coronary perfusion circuit is identical to that used for cerebral perfusion except that two circuits are used so that each coronary artery can be selectively perfused.

The prime consist of lactated Ringers with 5% Dextrose and whole blood containing 30 mgm of Heparin. Buffering the prime to a pH of 7.40-7.46 is done with NaHCO₃ as needed. The total asanguinous priming volume is kept to 40 ml/kg or lower. The use of blood in the prime is determined by the patient's hemoglobin value and added as needed. Once total mixing is achieved during bypass a hematocrit of 20% is considered optimum.

The heat exchanger system is a combination of a Sarns 65 ml metal heat exchanger and the integrated heat exchanger in the Harvey oxygenator hooked in series.

Arterial pressure lines are inserted in the right radial artery for monitoring of the

perfusion pressure in the innominate artery and into the femoral artery for monitoring of body perfusion pressure. The volemic state is determined from a central venous line in the left subclavian vein and by monitoring of urine output.

Technique of Perfusion

The use of this technique may best be illustrated with a case example. A 42 year old male was admitted to UTMB with a dissection of the ascending, descending, and transverse aortic arch with dissection extending just above the renal arteries associated with cystic medial necrosis. Dilatation began just above the aortic valve and it was obvious that dissection had extended into the innominate artery up to the right subclavian artery (Fig. 2). Due to the possibility of a blowout of the ascending aorta and the severe occlusion of the branches of the aorta it was decided that surgery was immediately indicated. The patient had an estimated blood flow rate of 4800 ml/min. The total cerebral blood flow was calculated at approximately 720 ml/min, estimated bilateral carotid blood flow was 514 ml/min, and estimated carotid blood flow was 257 ml/min. The coronary blood flow was also calculated and found to be approximately 240 ml/min with a left coronary blood flow of about 204 ml/min and an estimated right coronary blood flow of 36 ml/min.



Figure 2 — The aneurysm is shown before being repaired. Dilatation begins just above the aortic valve and extends into the descending aorta involving the carotid arteries, and subclavian arteries.

The prime consisted of 2700 ml of Ringers Lactate with 5% Dextrose, 450 ml ACD blood with the platelets removed which contained 30 mgm Sodium Heparin, and 64 meq of NaHCO_3 , and a total priming pH of 7.40. 1 gm. of Solu-Medrol is given 30 minutes before the initiation of bypass, and an initial Heparin dose of 3 mgm/kg is given prior to insertion of the bypass catheters which is followed by 1/8 of the initial dose every $\frac{1}{2}$ hour until Heparin reversal with Protamine (1.3 x total Heparin dose) after the termination of bypass.

100% O_2 is used for oxygenation and is used at .7 - .8 of the blood flow for most bypass procedures with the Harvey Hybride Oxygenator.

Cardiopulmonary bypass was established gradually by releasing venous occlusion and starting the arterial pumphead until 50% of total flow was reached with a mean femoral artery pressure of 70 mm Hg. The water in the heat exchanger circuit was

reduced to 9°C and hypothermia to 30°C was accomplished in 4 minutes. The left ventricular vent is inserted and total flow to 4800 ml/min was established. Total cardiopulmonary bypass was achieved with electrical fibrillation of the heart. PO₂ levels are kept between 120-180 mm Hg and the PCO₂ range between 30-40 mm Hg even during hypothermia to 30°C.

The right carotid artery was cannulated and perfusion was begun at 100 mm Hg pressure and the carotid artery proximal to the cannulation site was then clamped. The left carotid artery was cannulated and perfusion was maintained at 100 mm Hg and the left carotid artery was clamped proximal to the cannula. A total carotid blood flow of 510 ml/min was achieved at a pressure of 100 mm Hg. The carotid blood flow was subtracted from the total body flow of 4800 ml/min resulting in a body flow of 4390 ml/min. This body flow rate was then achieved.

The aorta distal to the left subclavian artery was occluded. The ascending aorta was opened and the coronary ostia were cannulated with a small mayo coronary artery cannula in the right coronary artery and a medium mayo coronary artery cannula in the left coronary artery. Coronary perfusion was established at 110 mm Hg and a flow of 200 ml/min. The systemic perfusion was maintained at a flow rate of 4190 ml/min with the institution of coronary perfusion.

Once the perfusion was determined to be adequate, the branches of the aorta were transected and substitution of the aortic arch was accomplished with a dacron prosthesis (Fig. 3) initially sutured to the distal end of the aorta. This prosthesis was tailored at the table with an ascending limb of 30 mm woven dacron connected to a section of 25 mm woven dacron. The branches were constructed from two separate dacron bifurcation prosthesis with a 16 mm common trunk going to two 8 mm limbs. The intima and media were sutured together before attachment of the prosthesis. The left subclavian artery limb was anastomosed after successful evacuation of air from the prosthesis. The clamp used on the descending aorta was then moved proximal to the left subclavian artery and flow to this artery was accomplished through the retrograde flow from the aorta. Next the left carotid artery was anastomosed and perfusion of this branch was discontinued by clamping the cannula while perfusion of the right carotid was maintained. The clamp on the aorta was moved proximal to the left carotid artery and its flow was re-established with retrograde perfusion. The right carotid limb was then joined and perfusion to this branch was discontinued and the arteries were decannulated. The systemic flow increased to 4600 ml/min. The branches of the arch were then perfused by retrograde aortic perfusion from the femoral artery line. After air was removed from the remaining prosthesis in the ascending aorta the prosthesis was sutured with a continuous suture to the ascending aorta and the coronary perfusion was discontinued. The patient was then warmed to 37°C in 8 minutes with a maximum water temperature of 42°C. After electrical defibrillation there was excellent cardiac action and the bypass was decreased to 50% of total body flow (2400 ml/min) by occluding the venous line and the left ventricular vent was removed. The prosthesis was intact and functioning (Fig. 4) when Protamine was administered and the chest was closed.

The arterial pressure was 120/70, venous pressure was 12 mm Hg, and the urine output during bypass was 1600 ml. The total perfusion time was 2 hours 19 minutes with 1 hour 36 minutes of cerebral perfusion and 1 hour 42 minutes for perfusion of the coronary arteries. Since blood loss was minimal (600 ml total) no additional blood was required. The diuresis induced by Mannitol and hemodilution increased the

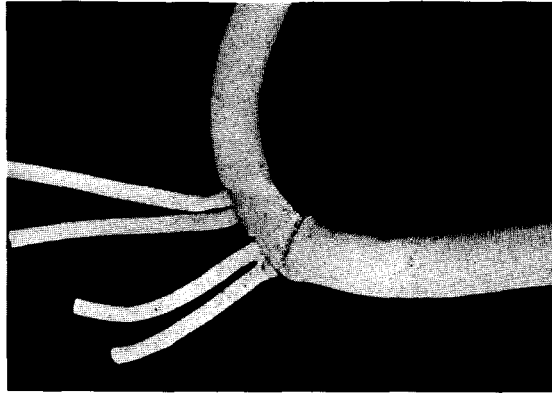


Figure 3 — Dacron prosthesis which was substituted for the aortic arch containing the four limbs of the transverse arch.

urine output requiring the addition of 1500 ml Ringers Lactate with 5% Dextrose during the perfusion. Post-perfusion fluid replacement was entirely from the remaining blood in the oxygenator and was monitored by using the arterial and venous pressure. This replacement was estimated at 700 ml of blood used for volume replacement.

Discussion

The systemic, coronary, and cerebral tissues were evaluated separately from a pressure/flow relationship to determine the guidelines to be used for the perfusion.

Systemic Perfusion

The system perfusion is accomplished by the criteria used for a routine bypass procedure. Flow is calculated from B.S.A. (m^2) multiplied by the basal resting anesthetized cardiac index of 2.4 L/min/m^2 of B.S.A.

$$\text{Total flow} — \text{C.I.} (2.4 \text{ L/min/m}^2) \times \text{B.S.A.} (m^2),$$

Arterial pressures are monitored from the right radial artery and the femoral artery. These pressures are used for evaluation of systemic perfusion until the aortic arch is isolated from the systemic perfusion and its branches are selectively perfused at which time the radial artery pressure is used to evaluate innominate artery perfusion. Systemic perfusion is conducted primarily on the basis of flow. If the cardiac output is

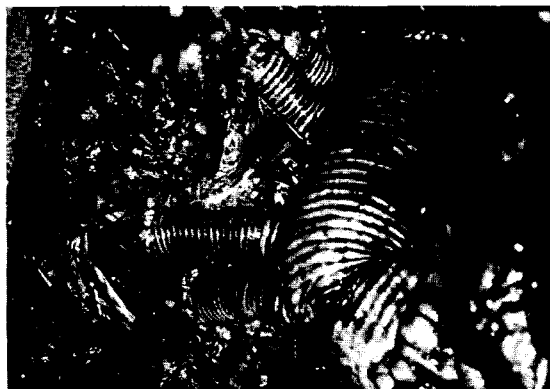


Figure 4 — The completed prosthetic aortic arch replacement intact and functioning.

normal and the perfusion pressure is normal then the resistance of the vascular bed is assumed to be normal. The perfusion pressure is maintained at 60-90 mm Hg (mean) initially by slight flow adjustments or volume additions. Vasoactive drugs are used if these adjustments do not maintain the pressure. The venous pressure is maintained at approximately 10 (range 5-18) mm Hg. The urine output is monitored and maintained at 30-35 cc/hr is hemoglobinuria is present. Additional fluid and/or mannitol is given if the urine output is unsatisfactory.

PO₂ levels are kept between 110-180 mm Hg and the PCO₂ range between 30-40 mm Hg even during hypothermia to 30°C. During hypothermia PCO₂ and PO₂ values are corrected for temperature by the use of a standard temperature compensating blood gas nomogram. The pH values are corrected by use of the formula:

$$\text{Corrected pH} = (.0147) (T + \text{noncorrected pH}) \\ \Delta T = \text{Change in Temperature } (^{\circ}\text{C})$$

Cerebral Perfusion

The cerebral tissue is primarily supplied with blood by the two internal carotids and to a lesser extent the two vertebral arteries collectively known as the circle of Willis. The flow percentage of these arteries varies from patient to patient due either to their congenital development or sclerotic changes. Clamping of even one of the carotids for 3-5 minutes is enough to cause irreversible ischemic changes especially in older persons with advanced atherosclerosis as the collateral circulation is insufficient in sustaining cerebral circulation. The estimated cerebral blood flow was derived from the normal cerebral blood flow of 15% of the resting cardiac output. This value is fairly constant due to the autoregulatory action of CO₂ concentration on the cerebral circulation. (Excess CO₂ in the cerebral blood dilates the vessels and increases the flow while decreased CO₂ constricts the vessels subsequently reducing the flow emphasizing the need to maintain normal pCO₂ and pH values in blood leaving the oxygenator.)

To accurately determine the flow needed for each carotid, angiography of the cerebral vasculature could be used to illustrate dominance of each carotid as a percent to total cerebral blood flow and then to compute the percentage of flow for each carotid. However, we feel confident in using a total carotid flow value of 80% of the total cerebral blood flow.

Example: Bilateral carotid blood flow = $\frac{80\% (\text{Total cerebral blood flow})}{100}$

100

Once this factor is derived we felt that in order to maintain adequate cerebral perfusion then a pressure/flow relationship must exist since the cerebral circulation is vasoactive. To monitor the perfusion pressure of the innominate and left carotid arteries a pressure manometer was mounted on a bubble trap. An additional pressure tracing was displayed from the right radial artery in order to further evaluate innominate perfusion.

In practice the carotid/innominate perfusion pressure recorded from the bubble trap is maintained at 100 mm Hg at all times with careful monitoring of flow to the calculated flow value. The 100 mm Hg pressure is sufficient in maintaining an actual pressure of 90 mm Hg due to a 10 mm Hg pressure gradient across the 16F Bardic cannula. The flow in the innominate artery will obviously exceed the calculated flow due to the takeoff of the right subclavian until the subclavian is clamped. The left

subclavian artery is not perfused due to adequate collateralization of the arm. These calculated values are not intended to be exact absolute values, but are used as guides to qualitate the perfusion while influencing variables are always considered, such as hypothermia, pharmacology, obesity, etc. The flow requirement of the coronary arteries is about 5% of the resting cardiac output and of this the left coronary artery derives 85%. The flow calculation was based on these percentages.

$$\text{Estimated coronary blood flow} = \frac{(5\%) (\text{cardiac output})}{100}$$

$$\text{Estimated left coronary blood flow} = \frac{(85\%) (\text{ECBF})}{100}$$

$$\text{Estimated right coronary blood flow} = \frac{(15\%) (\text{ECBF})}{100}$$

The coronary artery bed is also vasoactive responding to increased or decreased O₂ requirements and will dilate or constrict in response to oxygen debtor excess. A perfusion pressure of 100 mm Hg was used for both coronary arteries and monitored with the flow rate computed for each coronary. The pressure gradient across a coronary catheter approaches 20 mm Hg so a pressure of 110 mm Hg will give an actual pressure of 90 mm Hg in the coronary artery. The left coronary artery is normally perfused without any perfusion to the right coronary artery in patients with normal or dominate left coronary arteries that have adequate collateral flow to the right coronary artery.

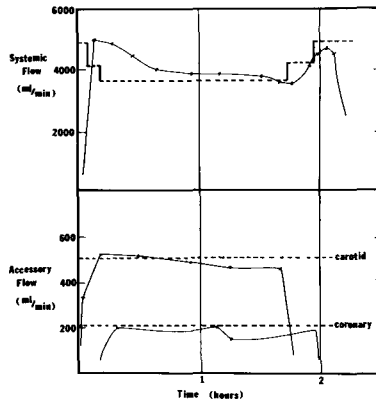


Figure 5 — A graph showing the calculated flow values as compared to what was derived from the clinical perfusion.

This method of perfusion and its modifications have been successfully used on various combinations of aortic arch branch vessel anomalies either pathologic or traumatic, cystic medial necrosis of the ascending aorta with aortic valve replacement, and Marfan's Syndrome. The increased complexity of the circuit requires the perfusionist to remain in absolute control of the perfusion during each phase of the procedure. The calculations used to determine flow values were consistent with those values derived from the perfusion. (Fig. 5). The patient showed no neurological deficit and returned to an alert state shortly after returning to the Intensive Care Unit.