Total arch replacement with selective antegrade cerebral perfusion and mild hypothermic circulatory arrest

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Introduction

This article describes the surgical techniques demonstrated in our video, "Total arch replacement (TAR) with selective antegrade cerebral perfusion (SACP) and mild hypothermic circulatory arrest" (*Video 1*).

The aortic arch is the most common location for the development of aortic aneurysms. These aneurysms are often located close to the brachiocephalic vessels, and atheromatous plaque and thrombus are often present both in the aneurysm and in the nearby aorta. In addition, the brachiocephalic branches, especially the left subclavian artery, frequently have atheromatous plaque at the orifices. Despite recent progress in endovascular treatments, mural thrombus and atherosclerotic debris in the aortic arch are frequently problematic. Therefore, endovascular repair cannot be considered as the first-line intervention for arch aneurysm without establishing secure preventive measures against atheroembolism caused by catheterization. The open replacement of the whole aortic arch with brachiocephalic vessel reconstruction using prosthetic grafts remains the gold standard procedure for the management of this condition. Historically, open aortic arch surgery for aortic arch aneurysm has been invasive. We believe that four factors make open arch repair difficult: (I) possible brain injury due to inadequate protection; (II) a deep, narrow operative field in the distal aorta and the left subclavian artery; (III) hemorrhage and transfusion; and (IV) possible myocardial damage due to prolonged ischemia. Therefore, we have used hypothermic circulatory arrest with SACP rather than other brain protective methods, and developed a method to optimize the operative field.

Our procedure for arch aneurysm is simple and standardized. We use systemic cooling until 25 to 28 ℃ at tympanic membrane temperature, followed by SACP with balloon-tipped catheters and myocardial protection by intermittent retrograde blood cardioplegia. Anastomoses are sequentially constructed at the distal arch, the proximal root, the left subclavian artery, the left carotid artery, and the right brachiocephalic artery.

Most of these procedures are routinely completed within 3 hours. Patients even over 80 years old can mobilise on the ward and resume oral diet on postoperative day one. Fast-tracked recovery is certainly achieved with this surgical procedure.

Operative techniques

Monitoring arterial lines, temperatures and surface cooling of the head

The patient is positioned in supine and general anesthesia is induced. Bilateral radial arterial lines are monitored and temperature probes are introduced for the tympanic membrane, bladder and rectum. The head is covered with an ice helmet for surface cooling immediately after induction of anesthesia. Trans-esophageal echocardiogram is monitored throughout the procedure.

Selection of arterial cannulation sites and institution of cardiopulmonary bypass

Following a median sternotomy, the ascending aorta and the proximal aortic arch is carefully evaluated by epiaortic ultrasound. The arterial cannulation site is determined according to preoperative computed tomography (CT) and intraoperative epiaortic echographic findings. Our preferred site is the ascending aorta. If the ascending aorta and aortic arch are severely atherosclerotic, we often use the right axillary artery for arterial cannulation. In case of hemodynamic instability such as ruptured arch aneurysm, the femoral artery is used.

Two venous cannulae are inserted into the superior and inferior vena cava and cardiopulmonary bypass (CPB) is instituted. A left ventricular vent cannula is inserted through the right superior pulmonary vein and systemic cooling is started immediately. Systemic cooling is considered adequate for circulatory arrest when the tympanic temperature falls to 25 to 28 ℃. The target body temperature is dependent upon a number of factors, including aortic pathology and the complexity of the distal anastomotic site. If the lower body circulatory arrest time is expected to exceed 30 minutes, cooling is performed to 25 ℃ for protection of the lower body organs including spinal cord and kidney, but cooling is stopped at 28 ℃ if completion within 30 minutes is expected. We do not clamp the ascending aorta to avoid aortic manipulation until hypothermic circulatory arrest, except in concomitant cardiac valve procedures with normal ascending aortic wall. During the systemic cooling phase, distal coronary anastomosis is performed if required.

Circulatory arrest at 25 ℃ of tympanic membrane temperature

CPB is terminated at a tympanic temperature of 25 to 28 ℃, at which point the aorta is opened. In most cases, when the tympanic temperature reaches 25 ℃ (which takes approximately 10 to 20 minutes), the core temperature (bladder or rectum) is still at 30 to 32 ℃. Lower body perfusion distal to the descending aorta is resumed after the distal aortic anastomosis.

Myocardial protection

The myocardium is protected by retrograde intermittent infusion of cold blood cardioplegia via the catheter inserted directly into the coronary sinus by right atriotomy and pursestring. Repeat doses are infused every 20 to 30 minutes until coronary reperfusion is resumed.

Selective antegrade cerebral perfusion

SACP is used routinely in our total arch replacement. Three brachiocephalic branches are divided at the level of good/healthy arterial wall. If any atheromatous emboli are expected, a short period of retrograde cerebral perfusion is performed prior to SACP. A 14-Fr balloon-tipped cannula is inserted into the brachiocephalic artery and 12-Fr cannulae are inserted into the left common carotid and the left subclavian arteries. SACP flow is 10-12 mL/kg/min with a perfusate temperature of 25 to 28 ℃. The brain oxygen saturation is monitored using INVOS 5100C (Somanetics, Troy, Mich.), and bilateral radial artery pressure.

Aortic arch dissection and creation of the distal aortic stump

The distal aortic area is often deep and narrow. We begin to dissect the aortic wall from the dorsal aspect of the arch, where the peri-adventitia plane is easily identified. The ligamentum arteriosum is divided and separated between the main pulmonary artery and the minor curvature of the aortic arch. Use of the ESTECH retractor (Estech, San Ramon, CA, USA) effectively facilitates adequate exposure of this deep operative field. We often enter the left pleural cavity to approach the distal aortic arch segment in order to free the surrounding tissue.

The distal segment of aorta is transected at the level of normal diameter and the adjacent soft tissue is carefully undermined. Small arterial branches to esophagus and bronchi are identified, clipped and divided if needed. In some cases the distal aortic stump may be at the level of the left pulmonary vein. It is reinforced with a 1.5 cm Teflon felt strip fixed outside the distal aorta with about four 4-0 Prolene sutures. These sutures are gently pulled up to make the distal aortic segment more shallow.

Distal aortic anastomosis and reperfusion of the distal aorta

A sealed quadrifurcated Dacron graft (Gelweave Four Branch Plexus™ graft, Vascutek, Inchinnan, England) is our preferred prosthesis for aortic arch reconstruction. The graft is sized to match the diameter of the distal aortic stump. With excellent exposure of the surgical field as shown in the video, the distal aortic anastomosis is constructed with a 3-0 Prolene (SH needle) continuous running suture. We commonly sew approximately 5 to

6 crimps, and sometimes more, in depth of the graft, which is inserted into the native aortic stump. Each bite is approximately 6 to 8 mm in advance, as we believe the wider the bite the better, especially in poor quality aortic walls. The 'elephant trunk' technique is not routinely used unless necessary. Bioglue can be applied externally after completion of the anastomosis, completing hemostasis. One of the plexus branches is then connected to arterial line of CPB and the prosthesis is clamped proximally. Antegrade perfusion of the distal aorta is then resumed. Systemic rewarming is started at this point.

Proximal ascending aortic anastomosis

Next, the proximal ascending aorta is wrapped with a 1.0 cm Teflon felt strip reinforcement approximately 1 cm above the sinotubular junction. The anastomosis is performed with a 4-0 Prolene continuous running suture. After completing this, coronary circulation is re-started.

Brachiocephalic branch reconstruction

Finally, the three arch vessels are reconstructed using 5-0 Prolene continuous running sutures from the left subclavian artery to the brachiocephalic artery. In this video, the left vertebral artery was anomalously arising from the aortic arch, between the left carotid and the left subclavian arteries. Accordingly, it was reimplanted into the graft branch for the left subclavian artery. In almost all cases, when reconstruction of arch vessels is completed, the bladder temperature reaches 35 ℃ and the heart is contracting sufficiently to allow for weaning from CPB.

Hemostasis is confirmed using the ESTECH retractor. All anastomoses and dissected areas - even in very deep surgical fields - are visualized and additional suturing can be easily performed if required. Complete hemostasis is achieved in many cases. We currently perform the procedure without requiring blood transfusions to account for losses.

Comments

In the present article, we present recent five-year clinical outcome of consecutive 105 TAR patients (1). The patients were 85 males and 20 females with a mean age of 73 years (range, 41 to 88 years). Eighty-one patients with chronic lesions underwent elective surgery and 24 patients underwent emergency surgery. Thirty six patients underwent concomitant cardiac procedures: coronary artery bypass graft (n=27), aortic valve replacement (n=5), aortic valve replacement + mitral valve replacement (n=1), and aortic valve replacement + coronary artery bypass grafting (n=3). Of all cases, the mean operation time, CPB time, coronary ischemic time, lower body circulatory arrest time, and SACP time were 277±83, 164±40, 92±33, 58±22, and 95±28 minutes, respectively. Hemorrhage requiring re-sternotomy occurred in five patients (5%) and acute renal failure requiring new dialysis occurred in two patients (2%). The mean duration of mechanical ventilation time was 20±11 hours. Prolonged intubation (>48 hours) was required in five patients (5%), and prolonged intensive care unit stay (>72 hours) in eight patients (8%). Thirty-day mortality occurred in only one ruptured emergent case (1%). Permanent neurological dysfunction (PND) occurred in three patients (3%) and temporary neurological dysfunction (TND) occurred in three patients (3%).

The SACP technique, which extends the safe time limit for arch surgery, has now gained acceptance (2-4). As SACP allows for a higher temperature setting during distal anastomosis, we have begun to use milder levels of hypothermia based on a tympanic temperature of 25-28 ℃. In almost all cases, when the tympanic temperature reaches 25 ℃, which takes approximately 10-20 minutes, the core temperature is still at 30-32 ℃. Core temperature based on bladder or rectal temperature has generally been used as the minimum setting and the safety of using tympanic temperature as the minimum setting is controversial. Zierer and colleagues (5) showed that SACP in combination with mild hypothermia (core temperature of 30 ℃) offers sufficient cerebral protection and may be safely applied to aortic arch surgeries requiring SACP time of 90 minutes or more. In previous studies using antegrade cerebral perfusion during arch surgery, the incidence of TND was 2-13.3% and that of PND was 2% to 6.6% (6,7). In our experience, the incidence was 2.8%. We report a low incidence of neurological deficit and suggest that the application of this perfusion and temperature management protocol to aortic arch surgery is safe.

The major concern associated with lower body circulatory arrest under mild hypothermia is end-organ protection. The safe limit of circulatory arrest time under mild hypothermia for protection of the spinal cord is unknown. In our series, we experienced no cases of paraplegia. We inserted the SACP cannulae into all three arch vessels, and achieved blood backflow from the intercostal arteries inside the descending aorta. This blood backflow may contribute to the protection of the spinal cord.

Another concern is renal damage. Motomura and colleagues report an incidence of acute renal failure requiring dialysis of 7% in a recent series of 4,707 patients undergoing thoracic aortic surgery (7). In our series, the incidence of renal failure requiring new dialysis was only two cases (2%), an incidence comparable to standard cardiac surgery. These data support the safety of our surgical strategy of SACP with lower body circulatory arrest under mild hypothermia.

In our surgical sequence, CPB was restarted from the side branch of the graft and rewarming initiated immediately after completion of distal anastomosis. This early rewarming protocol with SACP is also controversial. During arch vessel reconstruction, the heart-beat and progress of rewarming were sufficient to allow weaning from CPB so that CPB could be discontinued immediately after reconstruction of the brachiocephalic artery. This sequence of reconstruction procedure minimizes CPB time and coronary ischemic time.

The safety of SACP with mild to moderate hypothermia for protection of the brain and visceral organs has been questioned. In the present report, our excellent surgical results support the use of SACP under mild hypothermia.

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