Masters of Cardiothoracic Surgery

Continuous perfusion "Branch-first" aortic arch replacement: a technical perspective

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Introduction

The following video, along with the in-depth perspective article published elsewhere in this issue, aims to take you through the significant steps and the theoretical aspects of aortic arch replacement using the "Branch-first" continuous perfusion technique (*Video 1*).

In essence the procedure consists of 5 major steps:

(I) Establishment of cardiopulmonary bypass using femoral inflow and moderate hypothermia;
(II) Serial disconnection and reconstruction of each arch branch (proceeding from innominate to left subclavian) using a trifurcation arch graft with a perfusion side arm port (TAPP graft, Vascutek Ltd., Renfrewshire, Scotland, UK). Following completion of the innominate anastomosis, the perfusion side arm port is used for selective antegrade cerebral perfusion for the remainder of the procedure;
(III) Clamping of the proximal descending aorta and construction of the distal arch anastomosis;
(IV) Completion of aortic root reconstruction;
(V) Connection of the common stem of the trifurcation graft to the ascending aortic graft.

Collateral network and individual proximal arch branch clamping

A basic principle of the "Branch-first" technique is the richness of the collateral network that exists between the 3 arch branches and between the arch branches and the upper and lower body. Apart from the circle of Willis, there are a number of extra-cranial collateral channels that augment cerebral perfusion during individual clamping of each branch vessels (1,2). These collateral channels include:

(I) Those between the external and internal carotid arteries;
(II) The right and the left carotid arteries;
(III) The upper and lower body;
(IV) The subclavian and carotid arteries.

These extracranial collaterals allow for a short period of occlusion of one branch while the other two branches perfuse its territory. Typically with this technique, anastomotic times for each individual branch vessel are performed in approximately 10 minutes and we rarely see changes in ipsilateral cerebral oxygenation during this period. On the infrequent occasion that this does occur, alteration of systemic or head circuit flows generally brings cerebral oxygenation back to baseline levels.

Operative technique

Preparation

Pre-operative investigations include: computerised tomographic angiography (CTA) of the thoracic and abdominal aorta, and transesophageal echocardiography (TEE). Coronary angiography is performed where appropriate and if the acuity of the situation allows. In patients with a history of cerebrovascular disease, clinical findings of carotid bruits, significant blood pressure difference between left and right arms (>20 mmHg systolic) or suspicion of atheroma of the ascending aorta or aortic arch on TEE or CT scan, further imaging studies are performed when possible. These may include: carotid and trans-cranial Doppler (TCD) ultrasonography, and magnetic resonance angiography (MRA) or CTA of the cerebral circulation. Intra-operative cerebral monitoring is performed by a combination of electroencephalogram bi-spectral index (BIS) monitoring, near-infrared spectroscopy (NIRS) and TCD. In addition, patients have bilateral radial and left femoral arterial lines for assessment of pressures in all arterial territories.

Positioning and draping

The patient is prepped and draped widely, allowing access to both groins for femoral cannulation. The neck is also prepared and left exposed. In the case of difficult access to the branch vessels it is important to have the ability to extend the incision along the anterior boarder of left sternocleidomastoid muscle as this greatly improves access, in particular to the left subclavian artery. The chest is now opened by standard midline sternotomy.

Division of the thymus and mobilization of the innominate vein

To facilitate exposure of the arch and the branch vessels the thymus is divided in the midline for its entire length in both the anterior mediastinum and the root of the neck. The innominate vein is mobilised by dividing all tributaries in the mediastinum. Dividing all tributaries of the vein gives it substantial mobility during the arch reconstruction, allowing it to be slung and retracted to an appropriate position where necessary. This enhanced mobility ensures that the innominate vein does not need to be ligated or divided during the course of the operation. This is important as preservation of the innominate vein ensures optimal left cerebral venous drainage and avoids the possibility of left hemispheric venous engorgement and venous hypertension, which may be a source of cerebral injury in some patients.

Femoral arterial cannulation

The patient is now systemically heparinized and cardiopulmonary bypass is instituted via femoral arterial inflow and central cavo-atrial drainage. Using a Seldinger technique, the artery is punctured, a guide wire is inserted and its position is confirmed in the descending thoracic aorta using TEE. The artery is then dilated and an EOPA arterial cannulae (Medtronic Inc, Minneapolis, MN, USA) inserted, flushed, de-aired and connected to the arterial circuit. It is important not to advance the femoral arterial cannulae too far as this may lead to the tip being positioned high in the common iliac artery with the loss of pelvic to lower limb collaterals, which are important in reducing the risk of leg ischemia or compartment syndrome. Femoral arterial cannulation early in the procedure allows control of systemic perfusion and allows optimal control of flow during periods of manipulation and clamping of the branch vessels. As the arch itself is intact during the entire period of the arch reconstruction and de-branching perfusion of both the heart and vital organs is maintained via the main arterial femoral cannula. Cardiac ischemic exclusion time is therefore limited and the need for circulatory arrest during arch reconstruction negated.

Mobilization of the branch vessels

The arch branches are now exposed for a length of 3-4 cm using a "no touch" technique. Minimizing direct manipulation of the branch vessels is important as it reduces the potential for atheroembolism and subsequent embolic cerebral injury. Surrounding tissues should be dissected away from the vessel and it is important to avoid direct manipulation of the vessel itself. Proceeding in a systematic fashion from the innominate artery proximally to the left subclavian artery distally provides enhanced exposure of each subsequent distal branch vessel by allowing the preceding vessel to be retracted out of the way and also by greatly improving mobility of the arch.

The TAPP graft

We currently use a modified trifurcation arch graft with a side arm perfusion port (TAPP graft, Vascutek Ltd., Renfrewshire, Scotland, UK). The addition of the side arm to this graft has made significant contributions to the evolution of the technique. In particular, it has removed the need for axillary artery cannulation as a means of providing antegrade cerebral perfusion which simplifies the conduct of the operation. Whilst axillary artery cannulation is associated with low morbidity, there are definite risks of axillary artery injury, dissection or brachial plexus injury, as well as the increased operative time associated with the additional operative steps. This is especially undesirable during emergency cases and can be technically difficult in obese patients and those with fragile or small-calibre axillary arteries.

Measuring the TAPP graft

It is important to emphasise at all times that the graft is stretched and measured under tension and when possible, during pressurisation prior to division of the limbs. This ensures that the graft is tailored to optimal length and avoids problems that can otherwise occur with kinking, twisting or suboptimal lie and positioning of the graft at the completion of the reconstruction.

Innominate artery reconstruction

The innominate artery is clamped just proximal to its bifurcation and about 1 cm distal to its origin from the arch, and transected between the clamps. The distal stump is then anastomosed to the first limb of the 3-branched graft in an end-to-end fashion. Notice that the heart is still beating during construction of this anastomosis and the patient is on full flow femero-atrial cardiopulmonary bypass. Cerebral perfusion is therefore maintained by contralateral flow through the left common carotid artery and the previously described associated collateral channels. As mentioned we rarely see changes in cerebral oxygenation during this phase of the reconstruction.

Institution of antegrade perfusion via the side arm port of the TAPP graft

We now attach a "1/4 to 3/8" connector to the 8 mm side arm perfusion port of the graft. This is secured with a cable tie and silk tie. After the innominate artery anastomosis is completed the graft is de-aired. At the completion of each anastomosis to the graft it is important to ensure that the branch vessel is adequately back bled to remove both air and any potential debris from the limbs. The side arm of the trifurcation graft is now connected to a separate cerebral head circuit which is used for antegrade flow. Use of a separate circuit for cerebral perfusion allows us to alter cerebral flow and perfusion independent of systemic flows. This enables precise control of cerebral flow which can be adjusted according to changes in cerebral oxygenation or right radial arterial pressure, (which now serves as a surrogate measure of innominate and hence right carotid arterial pressure). Cerebral perfusion flow rates of approximately 1 litre per minute (0.8-1.4 L/min) are generally used. The proximal innominate stump is now ligated. Alternatively, ligation of the proximal stump can also be undertaken prior to the innominate anastomosis which provides improved access to the distal innominate stump if the anastomosis proves difficult.

Left common carotid artery anastomosis

Completion of the innominate anastomosis removes tension from the arch, increases its mobility and enhances access and exposure to the left common carotid artery. The left common carotid is now fully mobilized. The limb of the graft is again stretched under tension prior to division to ensure that there is no redundancy which may lead to kinking. A similar process is followed for the anastomosis of the second limb of the branched graft to the carotid artery. The carotid artery is clamped and divided and the anastomosis is also completed in an end-to-end fashion. During this phase of the reconstruction continuous right-sided antegrade cerebral perfusion is running via the side arm of the branched graft. This augments left-sided cerebral perfusion via the described collateral channels. Again this anastomosis typically takes approximately 10-minutes to complete and we rarely see any change in cerebral oxygenation during this step. After flushing out air and potential debris from the graft and carotid stump, clamps are removed, therefore allowing restoration of antegrade flow to the left carotid artery via the perfusing side arm of the trifurcation graft. From this point in the procedure both the left and right carotid arteries have continuous antegrade cerebral flow controlled by a separate head circuit. This ensures that for the remainder of the operation the potential for significant cerebral hypoperfusion is limited. The proximal left carotid stump is now ligated. The trifurcation graft can now be laid out away from the immediate operative field, therefore allowing enhanced exposure to the residual arch.

Left subclavian anastomosis

The patient presented in this video did not require re-implantation of the left subclavian artery. If required, completion of the anastomosis of the third limb of the branched graft to the left subclavian artery is performed in the same manner as the preceding two anastomosis. In practice we have found that subclavian reconstruction is required in just over 40% of our arch reconstructions. In circumstances where a large arch aneurysm interferes with access to the left subclavian artery, we utilise a number of manoeuvres to facilitate its reconstruction. These include:

(I) A short (1-2 cm) extension of the neck incision along the anterior border of the left sternocleidomastoid muscle can greatly improve exposure to the left subclavian artery;

(II) Temporarily decreasing the distal perfusion pressure which reduces the turgidity of the arch and avails more space;

(III) Delaying the left subclavian reconstruction until the descending aorta is clamped (which does not impose a significant addition to left subclavian ischaemic time) and the arch resected, thus leaving ample room for left subclavian anastomosis.

At this stage all arch branches are perfused via the branched graft, which can be laid easily out of the field over the patient's neck. It is important to note that during this whole process the circulation was not interrupted to either the heart or the distal organs. Also of note is that all three arch branch anastomoses are readily in view and complete hemostasis from these sites can be ensured with ease.

Distal arch anastomosis

The completely de-branched arch is now readily mobilised, ready for clamping and the anastomosis of the arch graft to the distal arch. This can be assisted by temporary reduction in distal perfusion to increase the manoeuvrability of the arch and proximal descending aorta. Also, division of the ligamentum arteriosum allows the recurrent laryngeal nerve to "drop away" from the aortic wall, thus protecting it from possible injury. The descending aorta can be "clamped" in a number of ways. Our preferred technique is to directly clamp at the distal end of mobilisation, allowing for a simple end-to-end anastomosis at the junction of the arch and descending thoracic aorta. Clamping of the descending aorta ensures continuing perfusion of the abdominal organs and spinal cord via the femoral artery cannula. If the aneurysm is large, or the aorta is of poor quality, or access for clamping is still not available, control of the descending thoracic aorta can be achieved in a number of other ways:

(I) Intra-luminal control can be achieved with a balloon occlusion catheter, or

(II) Less frequently the distal descending aorta can be accessed and clamped through the posterior pericardium, behind the heart.

If a balloon occlusion catheter is used femoral flows often need to be slightly reduced to avoid displacement of the catheter. These manoeuvres are especially useful in patients with chronic dissections and in re-operations where distal clamping proves difficult. In these more complex patients, if periods of distal circulatory arrest are required they may be combined with antegrade perfusion via the side arm in the balloon occlusion catheter along with moderate hypothermia. Also in cases where a femoral cannula could not be used, direct antegrade body perfusion can be achieved via a side port in the balloon occlusion catheter.

This is the first time in the operation where the heart is excluded from circulation. Myocardial protection is initiated and maintained at this stage by a combination of antegrade and retrograde blood cardioplegia or by antegrade and retrograde custodial histidine-tryptophan-ketoglutarate cardioplegia solution.

The remaining ascending aorta and arch is excised. Depending on the procedure being performed, either the proximal root reconstruction or the distal arch reconstruction can be performed first. Also some cases, such as a valve-sparing David procedure combined with an arch replacement, may require separate grafts for the proximal and distal reconstruction with a graft-to-graft anastomosis. In the case presented the patient required remodelling of the sinotubular junction and replacement of the aorta to the level of the left subclavian artery. This was performed with a single Dacron graft with a pre-attached single side arm graft (Ante-Flo Prosthesis, Vascutek Ltd., Renfrewshire, Scotland, UK). Again, the graft is stretched prior to division and this ensures optimal length of the graft and avoids kinking or redundancy in the graft following completion of the reconstruction. Once again, the potentially hazardous distal arch anastomosis is easily in view and complete hemostasis can be ensured before moving on to the next stage.

After completion of this anastomosis, distal body flow can be changed from femoral to the sidearm of the Ante-Flo graft, and a clamp applied to the main arch graft immediately proximal to it. This is important in cases of aortic dissection where it is critical to re-establish antegrade flow in the true lumen to avoid pressurisation of the false lumen, which may lead to malperfusion or can cause disruption or troublesome bleeding at the distal arch suture line. Alternatively femoral cannulation can be continued and the side arm of the Ante-Flo graft can be used as a de-airing port later in the operation. The required aortic root reconstruction can now proceed as necessary, and the anastomosis between the arch graft and root is completed.

Anastomosis of the TAPP graft to the ascending aortic graft

Finally, the trunk of the branched graft is passed posterior to the innominate vein and positioned for the anastomosis to the ascending graft in end-to-side fashion to complete the reconstruction. Even at this stage there is no interruption to cerebral perfusion as the anastomosis is performed proximal to the perfusing side arm. Again, care is required in trimming the branched graft to the correct length. If the limbs of the graft are too long there is the potential for kinks or twists which may lead to stenosis or increase the risk of thromboembolism or occlusion of the limbs. In practice, careful trimming of the length of each limb following pressurisation of the preceding anastomosis ensures that this is not a significant issue. Also placing the TAPP graft on the proximal outer curvature of the ascending graft allows for optimal lie of the TAPP graft and reduces the possibility of twisting or kinking once the chest is closed. Importantly, placing the TAPP graft proximally on the ascending graft and hence moving the common stem origin of the branch vessels proximally allows for a favourable landing zone should second stage endovascular reconstruction of the residual native descending thoracic aorta be required. In this patient, as the ascending aorta and arch were being replaced for aneurysmal disease rather than for dissection, we continued femoral perfusion and used the side arm of the ante-flow graft as a de-airing port.

Surgeons used to a more traditional island technique may find at this point in the operation a number of key anastomosis are inaccessible and anastomotic bleeding is difficult to control. As can be seen even at this stage we find it easy to individually and systematically interrogate each anastomosis and ensure both quality and hemostasis, with any anastomotic bleeding easily corrected. This is one of the major advantages of this technique.

As the reconstruction is now complete a retrograde "hot-shot" is administered, right atrial and right ventricular pacing wires are placed, the cross clamp is removed, de-airing manoeuvres undertaken and routine procedures for separation from cardiopulmonary bypass and de-cannulation are performed. Following femoral de-cannulation we make special effort to ensure there is a satisfactory pulse distal to the point of cannulation in the common femoral artery. We have a low threshold for open exploration or completion angiography if there is any concern about distal perfusion prior to leaving the operating room. For this reason we have experienced no limb-related problems with femoral cannulation in our aortic practice.

Comments

We believe the "Branch-first" technique has a number of clinically significant advantages when compared to more traditional methods of arch surgery:

(I) There are no periods of global circulatory arrest;

(II) Cardiac perfusion is maintained during the entire phase of the arch branch reconstruction, therefore limiting cardiac ischemic time and improving postoperative myocardial function;

(III) Distal organ perfusion is maintained throughout the whole operation, limiting the potential for liver, renal, gastrointestinal and spinal cord injury;

(IV) As there are no periods of global circulatory arrest and both cerebral and distal organ perfusion are maintained throughout the procedure, there is no need for deep hypothermia and its associated spectrum of disadvantages, including coagulopathy, alterations in normal cerebro- and cardiovascular responses during hypothermia and rewarming, and the prolongation of CPB times;

(V) Removing the time pressures associated with circulatory arrest reduces some of the pressure placed on the surgeon, allowing for an unhurried and more technically precise anastomosis even in the most technically demanding of arch reconstructions;

(VI) The use of the TAPP graft with a side arm for antegrade perfusion eliminates the need for pre-emptive axillary arterial cannulation and simplifies the steps in operation.

In addition, implanting each individual branch vessel to a trifurcation graft has a number of advantages over a more traditional island technique:

(I) All sutures lines are more easily accessible allowing optimal haemostasis;

(II) As the suture line for each branch is performed more distally, and removed from the diseased arch, they are often constructed in less diseased and easier to work with arterial tissues;

(III) Following completion of the arch branch reconstruction the branches are relocated out of the immediate operative field, resulting in greater mobility of the de-branched arch and increased ease of access for completion of the distal aortic anastomosis;

(IV) Moving the common stem of the trifurcation graft proximally provides a large and anatomically favourable landing zone should further second stage endovascular treatment be required on the more distal native aorta.

We believe that the "Branch-first" technique for aortic arch replacement is a worthy alternative to more traditional methods of arch replacement, and can be utilized in even the most complex of arch reconstructions. In our experience, adopting this technique as our standard operative approach has led to reduced coagulopathy, improved neurological outcomes and reduced incidence of end organ dysfunction and injury in the perioperative period.

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