The cervical branch-first technique in complex redo sternotomies

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The cervical branch-first technique offers unparalleled advantage in neuroprotection from an early stage of complex reoperative aortic surgery
Title: The cervical branch-first technique in complex redo sternotomies

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Glossary
AV = Aortic valve
AVR = Aortic valve replacement
BF-TAR = Branch-first total aortic arch repair
CABG = Coronary artery bypass grafting
CCA = Common carotid artery
CPB = Cardiopulmonary bypass
ECMO = Extracorporeal membranous oxygenation
FET = Frozen elephant trunk
IA = Innominate artery
IJV = Internal jugular vein
LVOT = Left ventricular outflow tract
MVR = Mitral valve replacement
PV = Pulmonary valve
RVOT = Right ventricular outflow tract
SCA = Subclavian artery
TEVAR = Thoracic EndoVascular Aortic Repair
TV = Tricuspid valve
VA = Vertebral artery
Central picture legend

The cervical branch-first technique performed at the level of the neck.

Central message

The cervical branch-first technique enables continuous antegrade cerebral protection via a dedicated “head circuit” at the level of the neck before complex re-sternotomy is attempted.

Perspective statement

The cervical branch-first technique offers unparallel advantage in neuroprotection from an early stage of complex reoperative aortic surgery. It provides an independent circuit for complete antegrade cerebral perfusion, irrespective of suspension to circulatory flows to the rest of the body during complex re-entry into hostile chests.

Abstract

Background:

Branch-first total aortic arch repair has been a paradigm shift in the technical approach for uninterrupted neuroprotection during open aortic surgery. This technique is further modified to instigate hazardous sternal re-entry in patients with hostile mediastinal anatomy at risk of aortic injury.

Methods:

Intraoperative preparation and the illustrated operative technique of the cervical branch-first technique are described. The accompanying case series narrates the experiences and outcomes of four patients who underwent successful complex reoperative aortic surgery utilising this technique.
Results:
The indication for re-sternotomies included a 6th re-operation for recurrent mycotic aortic pseudoaneurysm; a 3rd re-operation for extensive infective endocarditis; a re-operation for complete Bentall graft dehiscence with contained aortic rupture; and a 3rd re-operation for residual type A dissection. All patients survived their proposed surgery. 2 patients were operated on in an emergent setting. 2 patients separated from cardiopulmonary bypass with the extracorporeal support. None suffered permanent neurological sequelae, gut ischaemia, peripheral arterial complications, or in-hospital mortality. 1 mortality due to decompensated heart failure was reported at 6-months postoperative.

Conclusion:
The cervical branch-first technique offers unparallel advantage in neuroprotection from an early stage of complex reoperative aortic surgery. It provides an independent circuit for complete antegrade cerebral perfusion, irrespective of suspension to circulatory flows to the rest of the body during complex re-entry into hostile chests. Our experience to date has demonstrated promising outcomes and further refinements will guide patient selection best suited for this technique.

Keywords: branch-first total aortic repair, complex redo sternotomy, redo open aortic surgery
Introduction

Branch-first total aortic arch repair (BF-TAR) has been a paradigm shift in the technical approach to open arch surgery, both in the elective and emergent settings. It utilises a staged reconstruction of the supra-aortic vessels using sequential clamping and reperfusion of each branch from a trifurcation graft with a perfusion side port (1). This allows uninterrupted antegrade cerebral perfusion, minimises distal organ ischaemic time, and reduces the risk of gaseous or particulate embolization inherent in branch cannulation for selective antegrade cerebral perfusion. This article describes further modification of this technique to ensure uninterrupted neuroprotection for complex reoperative aortic surgery at risk of aortic luminal breach during sternal re-entry. We report on our early experience with four patients. The Austin Health Office for Research department has waived informed patient consent. The protocol approval number is HREC/102088/Austin-2023 (9/24/23).

Operative technique

Monitoring

Intraoperative cerebral monitoring is performed as previously described (2). Bilateral radial and dorsalis pedal arterial pressure lines, cerebral oximetry, and transoesophageal echocardiogram (TOE) are used.

Preparation

Central venous catheters are inserted superiorly, close to the angle of the jaw to be well clear of the planned cervical incisions. External defibrillator pads are applied posterolaterally. The patient is positioned supine on the operating table and the skin is prepared and draped widely. Draping extends high on the neck to allow for incisions along the anterior border of the
sternocleidomastoid muscles, as well as potential for supraclavicular and infraclavicular incisions bilaterally for subclavian artery access if needed.

**Incision**

Two cervical incisions are made along the lower half of the anteromedial border of the sternocleidomastoid muscles and joined to the midline sternal skin incision (Supplementary Figure 1). The incision is deepened down to the carotid sheath, identifying the Internal Jugular Vein (IJV), Common Carotid Artery (CCA) and vagus nerve (Figure 2). On the right side, proximal mobilisation of the right CCA exposes sufficient length of the Innominate Artery (IA) and the proximal part of the right Subclavian Artery (SCA) for subsequent clamping and anastomosis. On the left side, sufficient length of the proximal part of the left SCA can often be mobilised, deep to the left IJV, without recourse to a separate left supraclavicular incision.

**Cardiopulmonary bypass (CPB)**

CPB is instituted using peripheral femoral arterial and venous cannulation, often in a closed fashion, utilising pre-closure with the Perclose ProGlide suture mediated closure system (Abbott, Belgium). Complete venous drainage is ensured using a multi-stage long venous cannula (Medtronic, USA) positioned with its tip in the superior vena cava under TOE guidance, with added suction as necessary. A dedicated “head circuit”, taken as an extra line from the main circuit, is utilised for cerebral perfusion. Core cooling begins after anastomoses of the IA and left CCA to the trifurcation graft of the “head circuit” and proceeds to a target temperature of 25°C. The cooling rate is initially quite slow until the cervical debranching is complete to avoid premature cardiac distension from aortic valve regurgitation or early ventricular fibrillation.
Arch debranching

Once established on CPB, the branch-first technique is performed akin to the well described BF-TAR (2), albeit in the neck. Great care is required in measuring graft length to avoid kinks. This is done by holding the confluence point of the trifurcation graft at the manubriosternal angle and cutting the appropriate stretched limb at the level of the proposed anastomosis (Figure 3).

The IA is clamped as proximally as possible in the suprasternal notch. It is often necessary to clamp the right CCA and SCA separately to ensure adequate length for end-to-end anastomosis of the distal innominate stump to the first branch of the trifurcation graft using 5-0 running prolene (Figure 4).

After de-airing and reperfusion of the reconstructed IA, end-to-end anastomosis between the left CCA and second branch of the trifurcation graft is performed in a similar fashion (Figure 5).

It is often not possible to reach to divide the left SCA proximal to its left Vertebral Artery (VA) and left internal mammary artery. Consequently, an end-to-side anastomosis is done between the third branch of the trifurcation graft and the left SCA (Figure 6). Nonetheless, a heavy silk suture is passed around the left SCA proximal to the left VA and internal
mammary artery and tied (Supplementary Figure 2). In cases where the left VA arises
directly off the arch, direct reconstruction from within the chest can be performed later.

Re-sternotomy

If not already reached, sternal re-entry is delayed until the core temperature approaches 25°C.
If ventricular fibrillation and significant ventricular distension occur during cooling, an apical
left ventricular vent can be inserted via a mini-thoracotomy (3). If the aorta is not breached
with re-entry, then routine adhesion mobilisation is performed, and cannulas for left
ventricular venting via the right superior pulmonary vein and retrograde cardioplegia
inserted. Alternatively, if the proximal aorta is inadvertently breached, progression to the
necessary next step can occur in haste and without the risk of cerebral circulatory arrest. At
this point, circulatory flows from the main bypass circuit are arrested, but maintaining
separate flows to the “head circuit”, and the aorta is entered (Figure 7). Once inside the aortic
lumen, distal control via balloon occlusion can be easily achieved by placing a large Foley
catheter distal to the aortic injury, allowing resumption of distal body perfusion
(Supplementary Figure 3).

If a coronary sinus retrograde cannula was successfully inserted prior to aortic breach,
retrograde cardioplegia is initiated and a search is made for the coronary ostia for direct
antegrade perfusion. Subsequent cardioplegia is repeated every 15-20 minutes by both
antegrade and retrograde routes during reconstruction. Once the appropriate anatomy is
exposed and adequate myocardial and cerebral protection are established, distal perfusion is
again arrested, and the Foley catheter removed to allow distal reconstruction, either by direct
anastomosis to a Dacron graft or via a Frozen Elephant Trunk (FET). With the latter completed, the main distal graft is de-aired and clamped, and circulatory flow is recommenced for distal reperfusion and slow core rewarming. The proximal reconstruction is then completed as necessary and the arch to root graft anastomosed. Finally, the common stem of the trifurcation graft is cut to length and anastomosed end-to-side to the new ascending aortic graft (Figure 8).

Results

Four patients with hostile reoperative mediastinal anatomy underwent uneventful complex sternal re-entries and aortic reconstruction using the cervical branch-first technique. The indication for re-sternotomies included a 6th re-operation for recurrent mycotic aortic root pseudoaneurysm after prior aortic root, ascending aorta, arch and FET procedures; a 3rd re-operation for extensive infective endocarditis after separate prior surgeries for types A and B aortic dissections; a re-operation following complete endocarditic Bentall graft dehiscence with contained aortic rupture; and a 3rd re-operation for residual type A aortic dissection after prior acute type A aortic dissection repair and, separately, coronary artery bypass grafting. All patients had evidence of adhesion between the aorta, aortic graft and/or false aneurysm to the posterior table of the sternum on CT scan. All patients survived their proposed surgery, and none suffered accidental aortic breach during sternal re-entry. Two patients were operated on in an emergent setting. Two patients separated from CPB with the support of extracorporeal membrane oxygenation (ECMO) but were subsequently weaned off without complications. None suffered permanent neurological sequelae, gut ischaemia, peripheral arterial complications, or in-hospital mortality. Table 1 summarises the patient characteristics.
and operation details. Salient clinical features of the four patients are described in further detail below.

Case 1

A 48-year-old female with Marfan’s syndrome and five prior aortic surgeries involving the total proximal aorta and arch (Table 1) as a complication of her connective tissue disorder and recurrent aortic graft infections, presented with Candida dubliniesis aortitis causing severe mycotic pseudoaneurysm involving the ascending aorta Dacron graft and aortic homograft. Her other significant past medical history included Takotsubo cardiomyopathy associated with mild left ventricular systolic dysfunction and previous thromboembolic cerebellar stroke without permanent neurological sequela. A pre-operative CT demonstrated the anterior ascending aortic pseudoaneurysm eroding into the posterior sternal table. Following a period of medical optimisation with prehabilitation and anti-fungal therapy, she underwent an elective reoperative aortic root and arch replacement. Repeat debranching of the supra-aortic vessels occurred at supra-sternal segments of native IA, left CCA, and left SCA utilising the cervical branch-first technique as described. The mediastinum was re-entered without aortic breach, albeit with minimal bilateral lung parenchymal injuries. Whilst technically successful, she required a short period of postoperative extracorporeal support that was weaned off successfully. Her postoperative recovery was complicated by acute respiratory and renal failures requiring temporary supports with a tracheostomy and haemodialysis. Apart from delirium, she suffered no permanent neurological dysfunction. She was discharged to rehabilitation following a 2-months hospital admission.

Case 2
A 60-year-old male with a prior mechanical Bentall procedure for an acute type A aortic dissection, and later a total arch replacement and insertion of a FET for residual type B aortic dissection, presented with severe Staphylococcus aureus bacteraemia complicated by mechanical aortic valve infective endocarditis, aortic root abscess, and seeding of infection into the pulmonary valve and right ventricular outflow tracts. A preoperative workup further demonstrated severe diffuse coronary artery disease. He underwent an emergency aortic homograft left and right ventricular outflow tract replacements and coronary artery bypass grafting. The mediastinum was re-entered safely, although an extended period on cardiopulmonary bypass was required for a technically challenging operation. He was transitioned onto ECMO, and his mediastinum was packed to manage severe coagulopathy prior to successful closure the following day. He was subsequently weaned off ECMO after one week. His postoperative care was further complicated by severe acute respiratory and renal failures requiring a prolonged ventilatory wean and haemodialysis, new biventricular failure requiring chemical inotropy, and complete heart block requiring insertion of a permanent pacemaker. He suffered postoperative delirium but not permanent neurological dysfunction. After 2 months of intensive care, he was admitted on the ward for a further 2 months. He represented 2 months following his discharge with acute pulmonary oedema in the setting of acutely decompensated biventricular failure and did not survive the event.

Case 3

A 66-year-old male with prior mechanical Bentall procedure and hemi-arch replacement with debranching of the IA and left CCA for an acute type A aortic dissection, and later an extra-anatomical left CCA to left SCA bypass and TEVAR for residual type B aortic dissection, presented in shock in the setting of a circumferential proximal Bentall graft anastomotic dehiscence and contained aortic root rupture due to presumed mycotic pseudoaneurysm. This
was associated with torrential prosthetic aortic valve paravalvular leak with a severely dilated left ventricle, severe mitral regurgitation due to reduced leaflet coaptation from annular dilatation, and moderate tricuspid regurgitation associated with severe pulmonary hypertension. A preoperative CT demonstrated the anterior pseudoaneurysm sac in contact with the posterior sternal table. He underwent an emergency reoperative mechanical Bentall procedure, mechanical mitral valve replacement, and tricuspid annuloplasty. Due to previous procedures involving the supra-aortic vessels, the IA was anastomosed to the “head circuit” trifurcation graft at a level close to the confluence of the right SCA and CCA, and the left CCA was anastomosed to the graft at a level below the extra-anatomical bypass, leaving the native left SCA unattended. This created an unconventional but complete head circuit. His mediastinum was re-entered safely. The prior proximal anastomosis on the sewing ring at the level of the valve conduit was found to be completely dehisced, with the Dacron graft anchored to the heart via intact coronary buttons. The operation proceeded unremarkably and he separated from CPB with minimal chemical inotropic support. He was successfully extubated on post-operative day 1 with no postoperative neurological dysfunction. He was discharged home 3 weeks later after a period of medical management for postoperative tachy-brady-arrhythmias.

Case 4

A 64-year-old male with prior coronary artery bypass grafting, complicated 6 weeks later by an acute type A aortic dissection necessitating an emergency ascending aorta replacement, presented with progressively worsening symptomatic aortic regurgitation and left ventricular failure. Preoperative investigations demonstrated residual complex aortic root, arch and descending aortic dissection, with the aneurysmal distal ascending aorta in close proximity to the posterior sternal table. His other significant past medical history included a left
nephrectomy for atrophic kidney and chronic kidney disease. He underwent an elective
reoperative aortic root and total arch replacement, and insertion of a FET. The mediastinum
was re-entered with an injury to the innominate vein, which was ligated without further
complication. The remainder of the procedure proceeded in an uneventful fashion, and he
was separated from CPB with minimal chemical inotropic support. His postoperative course
was unremarkable except for mild acute kidney injury, managed conservatively. He did not
suffer from postoperative neurological dysfunction and was discharged home on
postoperative day 11.

Discussion
Reoperative aortic surgery is associated with a two-fold increased risk of morbidity and
mortality compared to primary aortic surgery (4). This is particularly magnified when parts of
the aorta or aortic graft is adherent to the sternum. Standard approaches to these scenarios
include peripheral cannulation and deep hypothermia, so that if the aorta is breached on re-
entry, total circulatory arrest can be instituted while antegrade cerebral perfusion cannulas
can be inserted to maintain cerebral perfusion, especially as the complexity of aortic
reconstructions require a long time on circulatory arrest (5).

This approach has several shortcomings. Firstly, there is a real risk of left ventricular
distension and serious sub-endocardial ischaemia as cooling induces ventricular hypokinesis
and ventricular fibrillation, especially in the frequent presence of aortic regurgitation in this
patient cohort. An apical left ventricular vent through a short thoracotomy may ameliorate
this (3, 6), though is rarely totally effective and presents with its own significant risks.
Furthermore, large volume suction in the setting of significant aortic regurgitation can lead to
critical systemic hypoperfusion. Secondly, a significant time is required after aortic breach to
identify the anatomy and locate the arch branches for cannulation. A significant amount of air and local debris will likely already be present in the arch branches, which may inevitably embolise deeper into the cerebral circulation by the perfusion cannulas from direct cannulation. Lastly, attending to cardioplegia is further delayed with risk of significant ischemic myocardial injury.

Several case reports have previously described the successful use of selective antegrade cerebral perfusion to avoid catastrophic neurological injury upon re-entry into hostile mediastinum (6, 7, 8). To date, this is the only technique that describes the establishment of an independent, continuous, and complete antegrade cerebral circulation commenced prior to sternal re-entry. The described cervical BF-TAR modification continues the goals of the standard BF-TAR technique (1, 9, 10). In particular, the risk of cardiac distension is minimised by delaying core cooling until bilateral arch branch reconstruction to the “head circuit” is secured, so if ventricular fibrillation occurs, direct sternal-re-entry and rapid decompression can be performed without waiting for complete cooling. There are no periods of cerebral circulatory arrest, just as for standard BF-TAR. Similarly, myocardial and distal organ ischaemic times are reduced. Most importantly, the “head circuit” is autonomous from the primary operative field, and the operation proceeds in a calm and methodical fashion as there is unobstructed access to the full extent of the aorta with no time pressures, ensuring thorough and complete reconstruction.

Our success with the cervical branch-first technique was successfully extended in a case of first-time Bentall procedure in a patient with Takayasu’s arteritis with severe intraluminal obstruction of the proximal arch branches and dense para-aortic adhesions. The cervical approach allowed anastomoses to healthy distal arch vessels of normal calibre, bypassing the
intraluminal occlusion. This cervical approach can also be encouraged on patients presenting with severe proximal arch vessel atheroma at risk of embolization during its manipulation during cannulation.

Our results, though very preliminary, already suggest a very useful tool. No in-hospital mortality and no significant cerebral morbidity in such a high-risk cohort as described above, is certainly worthy of further investigation.

**Conclusion**

The cervical branch-first technique offers the opportunity to reproduce the excellent results experienced in the standard BF-TAR, in the case of complex reoperative aortic surgery with aorta adherent to the posterior sternal table. Our early results of no operative mortality or stroke in a group of four extremely high-risk patients merit further investigation and validation by other groups (Figure 1).

**References:**


<table>
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<tr>
<th>Age (years)</th>
<th>Sex</th>
<th>Indication for reoperation</th>
<th>Previous aortic surgery (indication)</th>
<th>Operation</th>
<th>Total bypass (mins)</th>
<th>Lower body CA (mins)</th>
<th>Postoperative complications³</th>
</tr>
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</table>
| 48         | F   | Recurrent aortic root Dacron graft & AV homograft mycotic pseudoaneurysm with sternal erosion | 1. Mechanical Bentall procedure  
2. Aortic root replacement (Dacron graft tear)  
3. Reoperative aortic root replacement (Candida endocarditis)  
4. Reoperative aortic arch replacement, debranching of IA, LCCA, LSCA, FET graft  
5. Reoperative ascending aortic + aortic root replacement with homograft (Bordatella endocarditis/root abscess) | Reoperative aortic root & arch replacements                                                             | 386                 | 86                   | ECMO  
Tracheostomy  
Haemodialysis         |
| 60         | M   | Prosthetic AV infective endocarditis, AV dehiscence, aortic root abscess with extension into RVOT & PV | 1. Mechanical Bentall procedure (acute type A dissection)  
2. Redo ascending, arch and descending thoracic aortic replacement (residual type B dissection) | Excision of mechanical AVR, aortic root, LVOT, RVOT, PV; PV, LVOT, RVOT homograft replacement; CABG² | 734                 | 0                    | ECMO  
Reoperation for bleeding POD 0  
Tracheostomy  
Haemodialysis  
PPM         |
<table>
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<tr>
<th>Age</th>
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<th>Diagnosis</th>
<th>Procedures</th>
<th>Length of Stay (days)</th>
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| 66  | M   | Complete endocarditic Bentall graft dehiscence with contained ascending aortic rupture | 1. Mechanical Bentall procedure, debranching of IA and LCCA, aortic arch replacement (acute type A dissection)  
2. LCCA-LSCA extra-anatomical bypass + TEVAR | 436  
3. Mechanical MVR; TV repair with annuloplasty² | None |
| 64  | M   | Severe AR, residual chronic type A dissection                              | 1. CABG  
2. Ascending aorta replacement (acute type A dissection)                      | 448  
60   | None |

CA=Circulatory arrest; AV=Aortic valve; RVOT=Right ventricular outflow tract; PV=Pulmonary valve; LVOT=Left ventricular outflow tract; CABG=Coronary artery bypass grafting; POD=Post-operative day; PPM=Permanent pacemaker; TEVAR=Thoracic endovascular aortic repair; TV=Tricuspid valve; FET=Frozen elephant trunk

1. Age at time of operation  
2. Emergency surgery  
3. Defined by the need for post-operative non-pharmacological management during the same admission
Legends

Figure 1. Illustrated operative technique and operative outcomes for the cervical branch-first technique in complex redo sternotomies

Figure 2. The V-shape cervical incision allows for access to the innominate artery, left common carotid artery, and left subclavian artery for supra-aortic debranching.

Figure 3. The distance of each graft from the manubriosternal angle to the level of the proposed anastomosis is measured at the stretched length of each graft limb.

Figure 4. The innominate artery is anastomosed to the first limb of the trifurcation graft.

Figure 5. The left common carotid artery is the next sequential branch anastomosed to the second limb of the trifurcation graft. Vascular clamps are applied between the first and second limbs to allow for the commencement of antegrade cerebral perfusion to via the innominate artery by the “head circuit”.

Figure 6. The left subclavian artery is anastomosed to the final limb of the trifurcation graft via an end-to-side anastomosis if adequate access to the left subclavian artery if not achieved.

Antegrade cerebral perfusion continues via the reconstructed innominate artery and left common carotid artery to the “head circuit”.

Figure 7. Continuous antegrade cerebral perfusion via the “head circuit” is established at the level of the neck before re-sternotomy is performed.

Figure 8. Reconstruction of the aorta is performed as necessary. The common limb of the trifurcation graft is anastomosed end-to-side to the ascending aorta graft as the final step of the aortic repair.

Supplementary figures:

Supplementary Figure 1. A V-shaped incision is made along the medial borders of sternocleidomastoid muscles bilaterally, adjoining the midline sternotomy skin incision.
**Supplementary Figure 2.** A heavy silk tie is used to occlude the left subclavian artery below the level of the left vertebral artery and left internal mammary artery.

**Supplementary Figure 3.** A large Foley catheter is placed beyond the aortic breach for balloon occlusion of the aortic lumen. Direct ostial cannulation is inserted for antegrade cardioplegia.

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