The cervical branch-first technique in complex resternotomy

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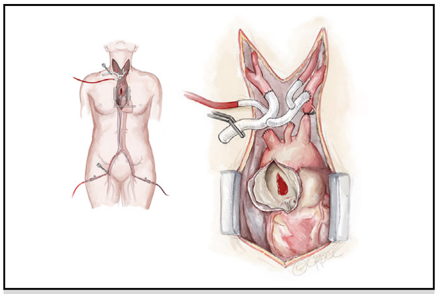
ABSTRACT

Background: Branch-first total aortic arch repair is a paradigm shift in the technical approach for uninterrupted neuroprotection during open aortic surgery. This technique is further modified to instigate hazardous sternal reentry 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 4 patients who underwent successful complex reoperative aortic surgery utilizing this technique.

Results: The indications for resternotomy included a sixth reoperation for recurrent mycotic aortic pseudoaneurysm, a third reoperation for extensive infective endocarditis, a reoperation for complete Bentall graft dehiscence with contained aortic rupture, and a third reoperation for residual type A dissection. All patients survived their proposed surgery. Two patients were operated on in an emergency setting. Two patients separated from cardiopulmonary bypass with extracorporeal support. None experienced permanent neurological sequelae, gut ischemia, peripheral arterial complications, or in-hospital mortality. One mortality due to decompensated heart failure was reported at 6 months postoperatively.

Conclusions: The cervical branch-first technique offers unparalleled 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 reentry into hostile chests. Our experience to date has demonstrated promising outcomes and further refinements will guide patient selection best suited for this technique. (JTCVS Techniques 2023;22:132-41)



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 resternotomy is attempted.

PERSPECTIVE

The cervical branch-first technique offers unparalleled 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 reentry into hostile chests.

Branch-first total aortic arch repair (BF-TAR) has been a paradigm shift in the technical approach to open aortic arch surgery, both in elective and emergency settings. It utilizes 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, minimizes 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 reentry. We report on our early experience with 4 patients. The Austin Health Office for Research department waived informed patient consent. The protocol approval number is HREC/102088/Austin-2023 (September 25, 2023).

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Abbreviations and Acronyms

BF-TAR	= branch-first total aortic arch repair
CCA	= common carotid artery
CPB	= cardiopulmonary bypass
ECMO	= extracorporeal membranous oxygenation
FET	= frozen elephant trunk
IA	= innominate artery
SCA	= subclavian artery
VA	= vertebral artery

OPERATIVE TECHNIQUE

Monitoring

Intraoperative cerebral monitoring was performed as previously described.[2] Bilateral radial and dorsalis pedal arterial pressure lines, cerebral oximetry, and transoesophageal echocardiogram were 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 (Figure E1). The incision is deepened down to the carotid sheath, identifying the internal jugular vein, common carotid artery (CCA), and vagus nerve (Figure 1). On the right side, proximal mobilization 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 mobilized, deep to the left internal jugular vein, without recourse to a separate left supraclavicular incision.

Cardiopulmonary Bypass

Cardiopulmonary bypass (CPB) is instituted using peripheral femoral arterial and venous cannulation, often in a closed fashion, utilizing preclosure with the Perclose ProGlide suture mediated closure system (Abbott). Complete venous drainage is ensured using a multistage long venous cannula (Medtronic) positioned with its tip in the superior vena cava under transoesophageal echocardiogram guidance,

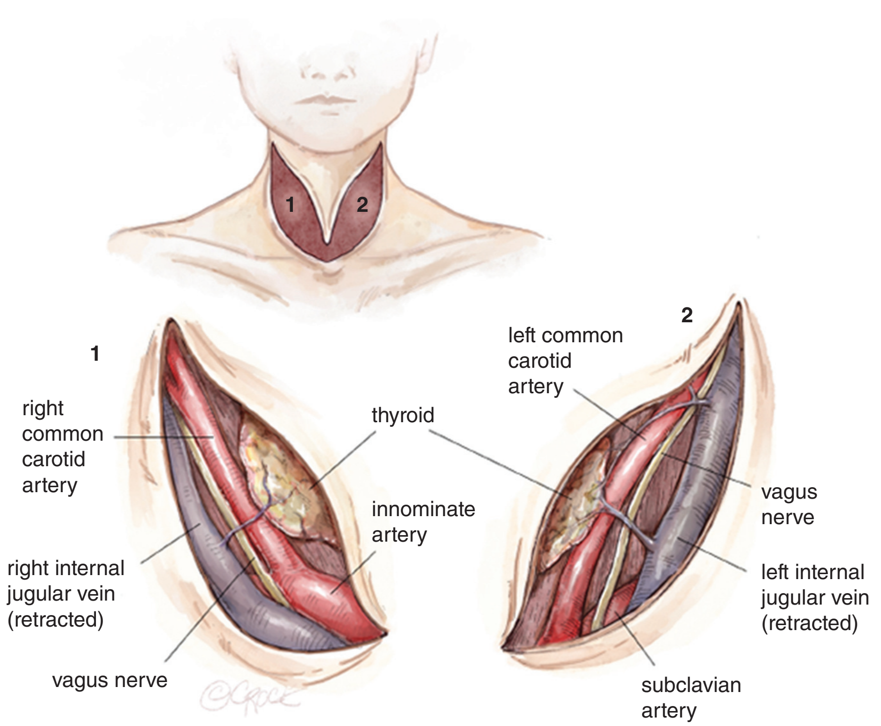

FIGURE 1. The *V*-shaped cervical incision allows for access to the innominate artery, left common carotid artery, and left subclavian artery for supra-aortic debranching.

with added suction as necessary. A dedicated head circuit, taken as an extra line from the main circuit, is utilized 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 2).

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 sutures (Figure 3). 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 4).

It is often not possible to reach to divide the left SCA proximal to the left vertebral artery (VA) and left internal thoracic artery. Consequently, an end-to-side anastomosis is performed between the third branch of the trifurcation graft and the left SCA (Figure 5). Nonetheless, a heavy silk suture is passed around the left SCA proximal to the left VA and internal mammary artery and tied (Figure E2). In cases where the left VA arises directly off the arch, direct reconstruction from within the chest can be performed later.

Resternotomy

If not already reached, sternal reentry 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 reentry, then routine adhesion mobilization 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 while maintaining separate flows to the head circuit, and the aorta is entered (Figure 6). 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 (Figure E3).

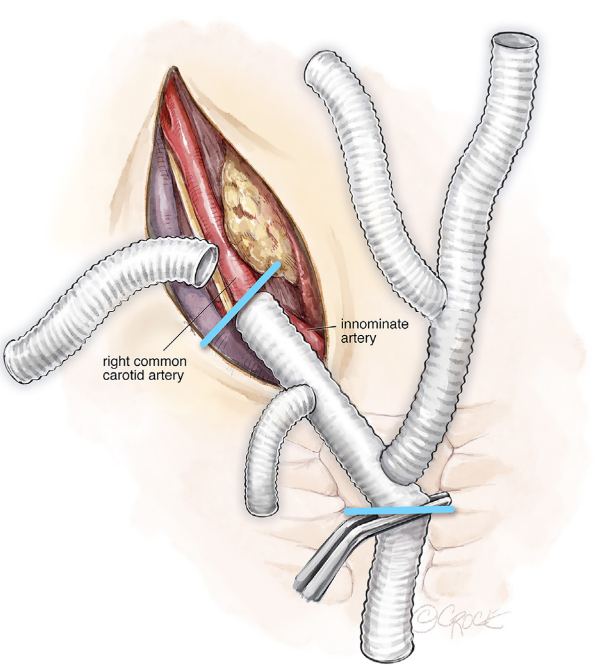

FIGURE 2. The distance of each graft from the manubriosternal angle to the level of the proposed anastomosis is measured at the stretched length of each graft limb.

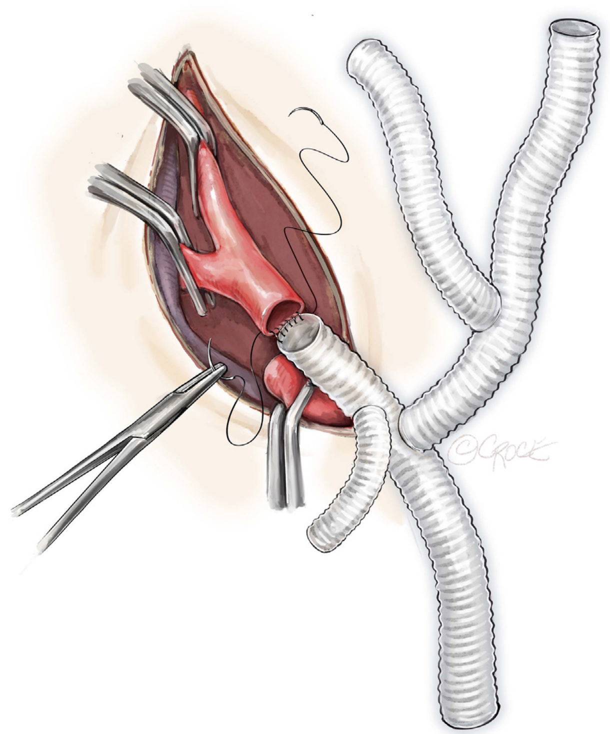

FIGURE 3. The innominate artery is anastomosed to the first limb of the trifurcation graft.

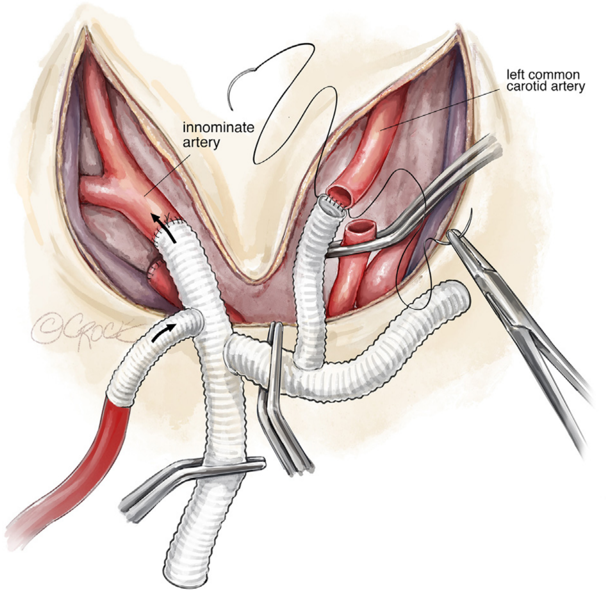

FIGURE 4. The left common carotid artery is the next sequential branch anastomosed to the second limb of the trifurcation graft. Vascular clamps are applied between the first and second limbs to allow for the commencement of antegrade cerebral perfusion via the innominate artery by the head circuit.

If a coronary sinus retrograde cannula was successfully inserted before 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 to 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 polyethylene terephthalate 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 7).

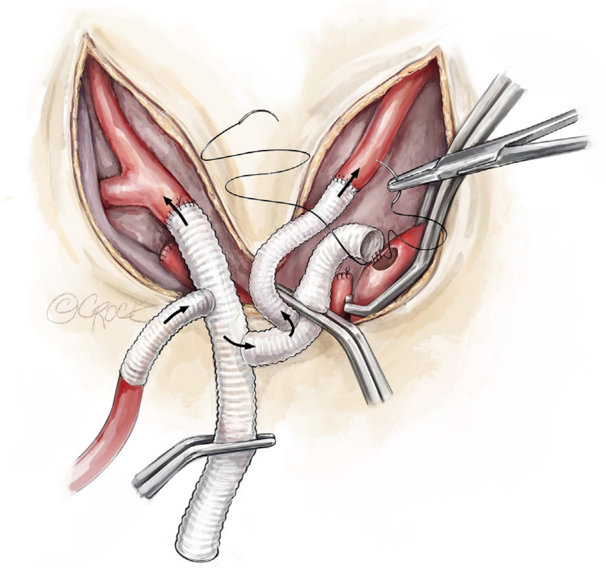

FIGURE 5. The left subclavian artery is anastomosed to the final limb of the trifurcation graft via an end-to-side anastomosis if adequate access to the left subclavian artery is not achieved. Antegrade cerebral perfusion continues via the reconstructed innominate artery and left common carotid artery to the head circuit.

RESULTS

Four patients with hostile reoperative mediastinal anatomy underwent uneventful complex sternal reentries and aortic reconstruction using the cervical branch-first technique. The indications for resternotomy included a sixth reoperation for recurrent mycotic aortic root pseudoaneurysm after prior aortic root, ascending aorta, arch and FET procedures; a third reoperation for extensive infective endocarditis after separate prior surgeries for types A and B aortic dissections; a first reoperation following complete endocarditic Bentall graft dehiscence with contained aortic rupture; and a third reoperation 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 computed tomography scan. All patients survived their proposed surgery, and none experienced accidental aortic breach during sternal reentry. Two patients were operated on in an emergency setting. Two patients separated from CPB with the support of extracorporeal membrane oxygenation (ECMO) and were subsequently weaned off without complications. None experienced permanent neurological sequelae, gut ischemia, peripheral arterial complications, or in-hospital mortality. Table 1 summarizes the patient characteristics and operation details. Salient clinical features of the 4 patients are described in further detail below.

Case 1

A 48-year-old woman with Marfan syndrome and 5 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 polyethylene terephthalate graft and aortic homograft. Her other significant past medical history included

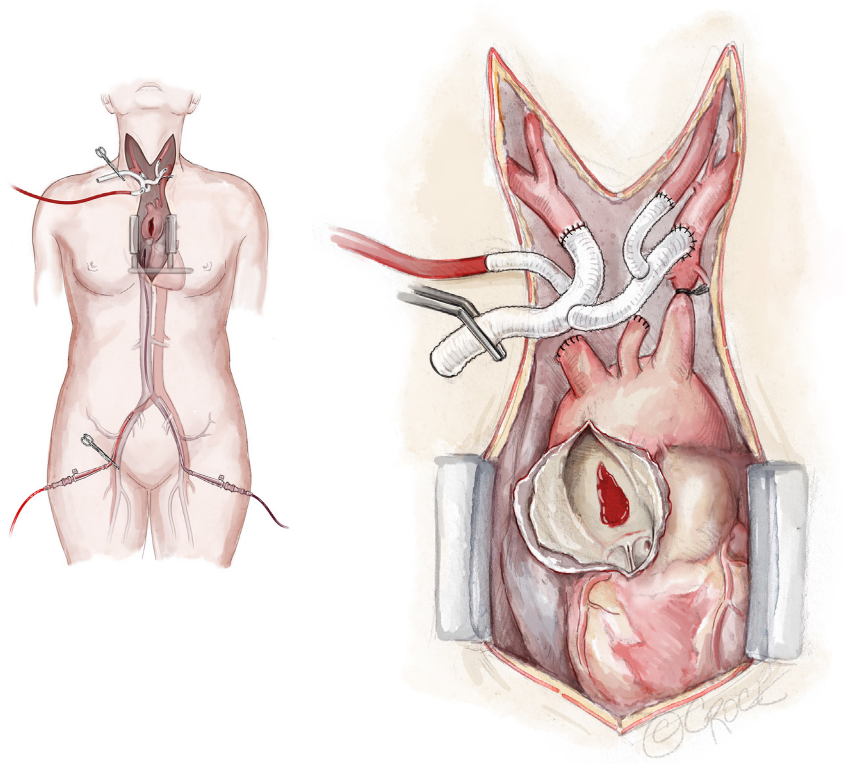

FIGURE 6. Continuous antegrade cerebral perfusion via the head circuit is established at the level of the neck before resternotomy is performed.

Takotsubo cardiomyopathy associated with mild left ventricular systolic dysfunction and previous thromboembolic cerebellar stroke without permanent neurological sequelae. A preoperative computed tomography scan demonstrated the anterior ascending aortic pseudoaneurysm eroding into the posterior sternal table. Following a period of medical optimization with prehabilitation and antifungal therapy, she underwent an elective reoperative aortic root and arch replacement. Repeat debranching of the supra-aortic vessels occurred at supra-sternal segments of the native IA, left CCA, and left SCA utilizing the cervical branch-first technique as described. The mediastinum was reentered without aortic breach, albeit with minor 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 hemodialysis. Apart from delirium, she experienced no permanent neurological dysfunction. She was discharged to rehabilitation following a 2-month hospital admission.

Case 2

A 60-year-old man 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 tract. 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 reentered safely, although an extended period on CPB was required for a technically challenging operation. He was transitioned onto ECMO, and his mediastinum was packed to manage severe coagulopathy before successful closure the following day. He was subsequently weaned off ECMO after 1 week. His postoperative care was further complicated by severe acute respiratory and renal failures requiring a prolonged ventilatory wean via a tracheostomy and hemodialysis, new biventricular failure requiring chemical inotropy, and complete heart block requiring insertion of a permanent pacemaker. He experienced 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 edema in the setting of acutely decompensated biventricular failure and did not survive the event.

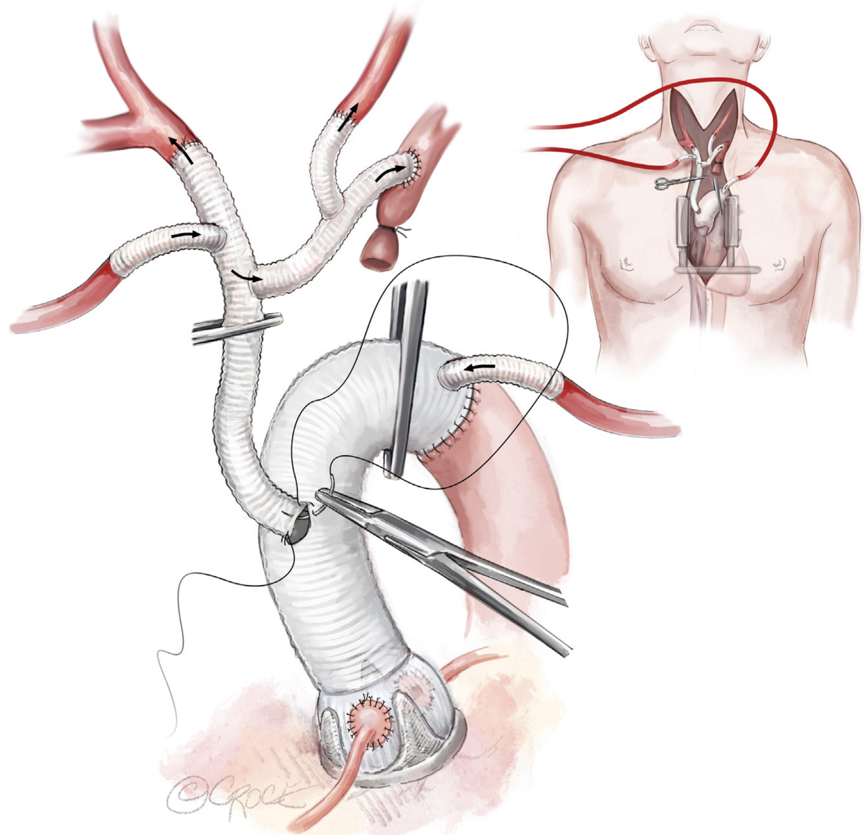

FIGURE 7. Reconstruction of the aorta is performed as necessary. The common limb of the trifurcation graft is anastomosed end-to-side to the ascending aorta graft as the final step of the aortic repair.

Case 3

A 66-year-old man with prior mechanical Bentall procedure and hemiarch 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 thoracic endovascular aortic repair 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 computed tomography 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 reentered safely. The prior proximal anastomosis on the sewing ring at the level of the valve conduit was found to be completely dehisced, with the polyethylene terephthalate 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 postoperative day 1 with no postoperative neurologic dysfunction. He was discharged home 3 weeks later after a period of medical management for postoperative tachybradyarrhythmia.

Case 4

A 64-year-old man 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

TABLE 1. Summary of patient characteristics and operative details

Age* (y)	Sex	Indication for reoperation	Previous aortic surgery (indication)	Operation	Total bypass (min)	Lower body CA (min)	Postoperative complications†
48	F	Recurrent aortic root polyethylene terephthalate graft and AV homograft mycotic pseudoaneurysm with sternal erosion	• Mechanical Bentall procedure • Aortic root replacement (polyethylene terephthalate graft tear) • Reoperative aortic root replacement (*Candida* endocarditis) • Reoperative aortic arch replacement, debranching of IA, LCCA, LSCA, FET graft • Reoperative ascending aortic + aortic root replacement with homograft (*Bordatella* endocarditis/root abscess)	Reoperative aortic root and arch replacements	386	86	ECMO Tracheostomy Hemodialysis
60	M	Prosthetic AV infective endocarditis, AV dehiscence, aortic root abscess with extension into RVOT and PV	• Mechanical Bentall procedure (acute type A dissection) • 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; CABG‡	734	0	ECMO Reoperation for bleeding POD 0 Tracheostomy Hemodialysis PPM
66	M	Complete endocarditic Bentall graft dehiscence with contained ascending aortic rupture	• Mechanical Bentall procedure, debranching of IA and LCCA, aortic arch replacement (acute type A dissection) • LCCA-LSCA extra-anatomical bypass + TEVAR	Reoperative mechanical Bentall procedure; Mechanical MVR; TV repair with annuloplasty‡	436	3	None
64	M	Severe AR, residual chronic type A dissection	• CABG • Ascending aorta replacement (acute type A dissection)	Reoperative tissue aortic root replacement, debranching of aortic arch, FET graft	448	60	None

CA, Circulatory arrest; *F*, female; *AV*, aortic valve; *IA*, innominate artery; *LCCA*, left common carotid artery; *LSCA*, left subclavian artery; *FET*, frozen elephant trunk; *ECMO*, extracorporeal membrane oxygenation; *M*, male; *RVOT*, right ventricular outflow tract; *AVR*, aortic valve replacement; *PV*, pulmonary valve; *LVOT*, left ventricular outflow tract; *CABG*, coronary artery bypass grafting; *POD*, postoperative day; *PPM*, permanent pacemaker; *TEVAR*, thoracic endovascular aortic repair; *MVR*, mitral valve replacement; *TV*, tricuspid valve; *AR*, aortic regurgitation; *FET*, frozen elephant trunk. *Age at time of operation. †Defined by the need for postoperative nonpharmacological management during the same admission. ‡Emergency surgery.

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 an FET. The mediastinum was reentered 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 separated from CPB with minimal chemical inotropic support. His postoperative course was unremarkable except for mild acute kidney injury, managed conservatively. He did not experience postoperative neurological dysfunction and was discharged home on postoperative day 11.

DISCUSSION

Reoperative aortic surgery is associated with a 2-fold increased risk of morbidity and mortality compared with 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 reentry, total circulatory arrest can be instituted while antegrade cerebral perfusion cannulas can be inserted to maintain cerebral perfusion, especially because 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 subendocardial ischemia because 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] although it is rarely totally effective and presents with its own significant risks. Large volume suction in the setting of significant aortic regurgitation can also lead to critical systemic hypoperfusion. Secondly, 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 embolize 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 reentry into a hostile mediastinum.[6-8] To date, this is the only technique that describes the establishment of an independent, continuous, and complete antegrade cerebral circulation commenced before sternal reentry. 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 minimized by delaying core cooling until bilateral arch branch reconstruction to the head circuit is secured, so if ventricular fibrillation occurs, direct sternal reentry and rapid decompression can be performed without waiting for complete cooling. There are no periods of cerebral circulatory arrest, and myocardial and distal organ ischemic 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 due to the unobstructed access to the full extent of the aorta and with no time pressure, ensuring a 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 arteritis with severe intraluminal obstruction of the proximal arch branches and dense

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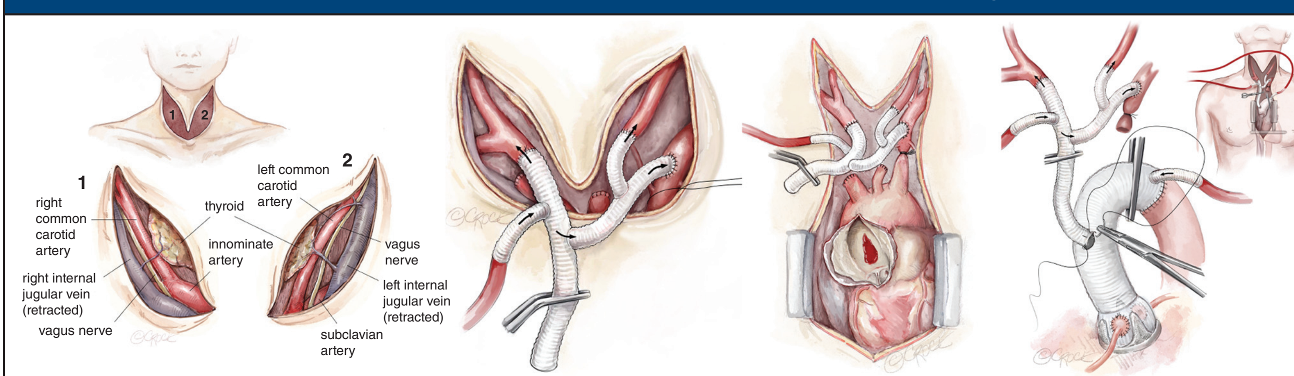

Case series (n = 4)	Post-op ECMO	Post-op neurological, visceral, peripheral arterial complications	In-hospital mortality
6th redo: recurrent mycotic pseudoaneurysm	Yes	No	No
3rd redo: aortic root abscess, extension into RVOT	Yes	No	No
1st redo: proximal dehiscence of infected Bentall graft	No	No	No
3rd redo: residual Stanford Type A aortic dissection	No	No	No

The cervical branch-first technique offers unparallel advantage in neuroprotection from an early stage of complex reoperative aortic surgery

FIGURE 8. Illustrated operative technique and operative outcomes for the cervical branch-first technique in complex redo sternotomies. *ECMO*, Extracorporeal membrane oxygenation; *RVOT*, right ventricular outflow tract.

para-aortic adhesions. The cervical approach allowed anastomoses to healthy distal arch vessels of normal caliber, 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, although very preliminary, already suggest a very useful tool. No in-hospital mortality and no significant cerebral morbidity in a high-risk cohort such as described above, is certainly worthy of further investigation.

CONCLUSIONS

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 4 extremely high-risk patients merit further investigation and validation by other groups (Figure 8).

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: branch-first total arch repair, complex redo sternotomy, redo open aortic surgery

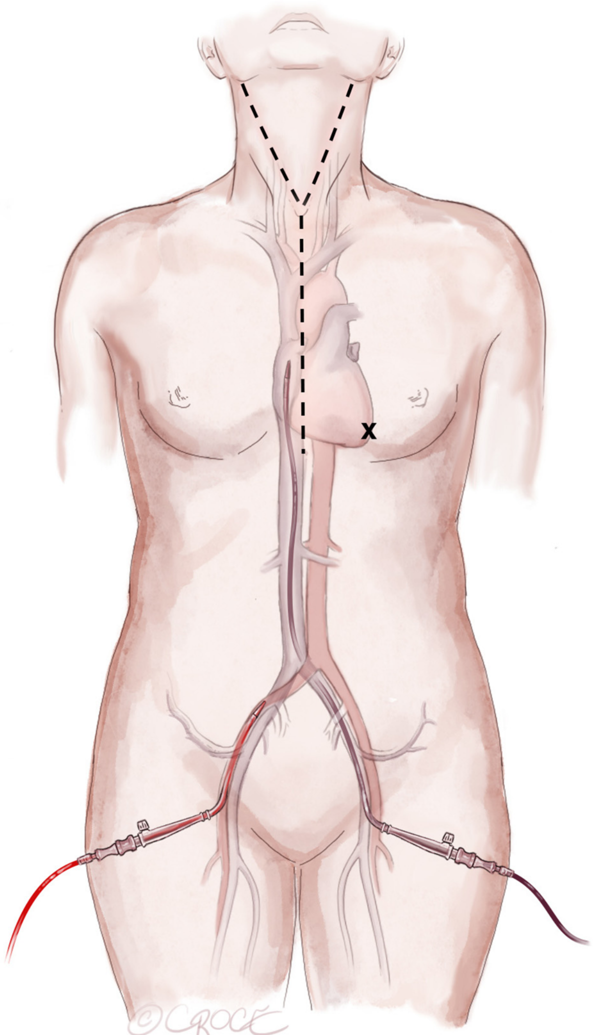

FIGURE E1. A *V*-shaped incision is made along the medial borders of sternocleidomastoid muscles bilaterally, adjoining the midline sternotomy skin incision.

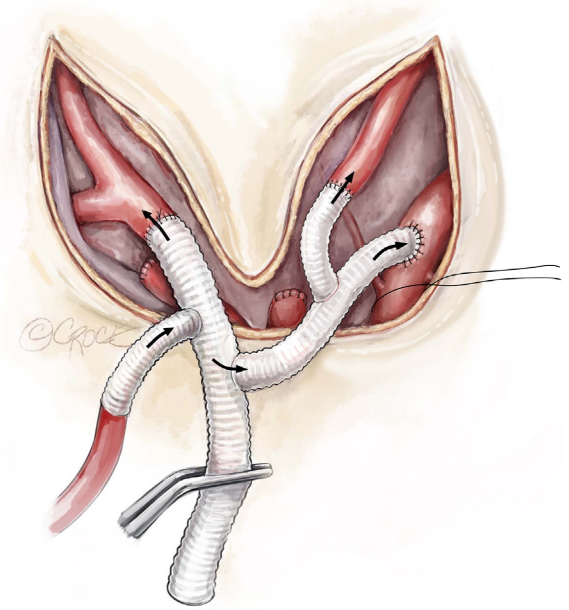

FIGURE E2. A heavy silk tie is used to occlude the left subclavian artery below the level of the left vertebral artery and left internal thoracic artery.

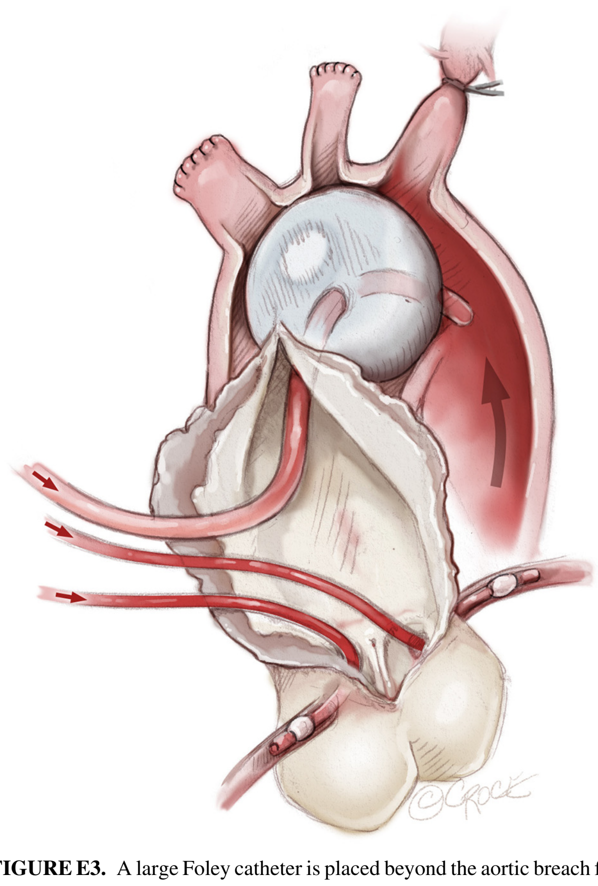

FIGURE E3. A large Foley catheter is placed beyond the aortic breach for balloon occlusion of the aortic lumen. Direct ostial cannulation is inserted for antegrade cardioplegia.