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Tips and Tricks of the Trade

Total Arch Replacement Operative Techniques

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Open total arch replacement (TAR) surgery is performed most commonly following a previously repaired acute type A aortic dissection (ATAAD) that results in an arch aneurysm.[1] More infrequently, TAR is performed for a chronic type B aortic dissection involving the arch, or for an isolated arch aneurysm. Detailed preoperative planning and intraoperative techniques of TAR, along with practical tips and tricks, are discussed in this paper.

Preoperative Planning

For elective TAR surgery, the surveillance of the arch aneurysm is done via computed tomography (CT) angiography of the chest, individualized per patient. The CT is performed most commonly annually, and every 6 months closer to the time of the operation. Patient selection is made following the latest American College of Cardiology/American Heart Association and Canadian Cardiovascular Society aortic guidelines.[1,2] Symptomatic arch aneurysm with low to moderate operative risk, and asymptomatic arch aneurysm $\geq$ 5.5 cm are indications for TAR.

Case planning is performed with a comprehensive history and physical, review of investigations, and imaging. A coronary angiogram is evaluated for coronary artery disease. A transthoracic echocardiogram is evaluated for heart function and valve competency. CT angiography (CTA) of the head and neck should be performed preoperatively. Carotid ultrasound is not routinely performed.

CTA of the chest/abdomen/pelvis typically is performed, with electrocardiogram gating. Safety of re-entry of the chest is reviewed. The aorta is evaluated from the aortic valve and distally, assessing for the coronary anatomy, state of the previous surgery, size. and extent of the aneurysm or dissection, great vessel anatomy and involvement, and vertebral artery anatomy and dominance. Access vessels (axillary and femoral arteries) are evaluated for calibre, tortuosity, calcification, dissection, and aneurysm. Postimaging processing software, such as TeraRecon (TeraRecon Inc, Fremont, CA), 3mensio (3Mensio Medical Imaging BV, Utrecht, Netherlands) or OsiriX (Pixmeo, Geneva, Switzerland), is useful for detailed evaluation of the aorta and graft sizing.

Maintaining flexibility on where the distal anastomosis is during TAR procedures is important. Oversewing the base of the debranched great vessels increases the options for this anastomosis. Considerations should include the presence of significant calcification and/or atheroma, and major entry tears. Views differ regarding the optimal site of distal anastomosis. A zone-2 anastomosis site is preferred by some, due to its having a more robust aortic tissue and a better aorta-to-graft size match,[3,4] whereas zone 0 or 1 is advocated for improved exposure and feasibility of the surgery.[5] Zone 0-1 anastomosis is highlighted in the current article (Fig. 1). Due to potential difficulty with exposure, the left subclavian artery (LSCA) may be revascularized in an extrathoracic manner. The LSCA can be occluded postoperatively with an Amplatzer vascular plug (Abbott Laboratories, Chicago, IL) to prevent an endoleak in the setting of a frozen elephant trunk (FET) or a conventional elephant trunk (ET). Currently, the general trend in TAR is to move the distal anastomosis so it is more proximal, and to perform an extrathoracic bypass of the LSCA.

Proximal anastomosis should be made as proximal as possible, as the distance between the proximal and distal anastomoses progressively decreases as the distal anastomosis is moved into zones 2, 1, and 0. The predicted length between the proximal and the distal anastomoses should be anticipated on CTA, to determine if a 3-branch graft, a trifurcated graft, or a custom-made graft is required.

Either a 2-stage conventional ET or a single-stage FET is an option if the disease extends into the proximal descending thoracic aorta. Whether FET or ET is used depends on several factors, including patient risk profile, surgeon experience, technique profiles, cost, anatomy, and extent of disease.[6] Conventional ET typically is used in higher-risk patients who cannot tolerate a longer single-stage procedure, and have extensive distal aortic disease—be that either a dissection or an aneurysm. From the cost perspective, if the descending aortic pathology extends beyond the length of the FET graft, necessitating a second thoracic endovascular aortic repair (TEVAR) procedure postoperatively anyway, then a 2-stage conventional ET may be considered. Anatomically, small true lumen size in

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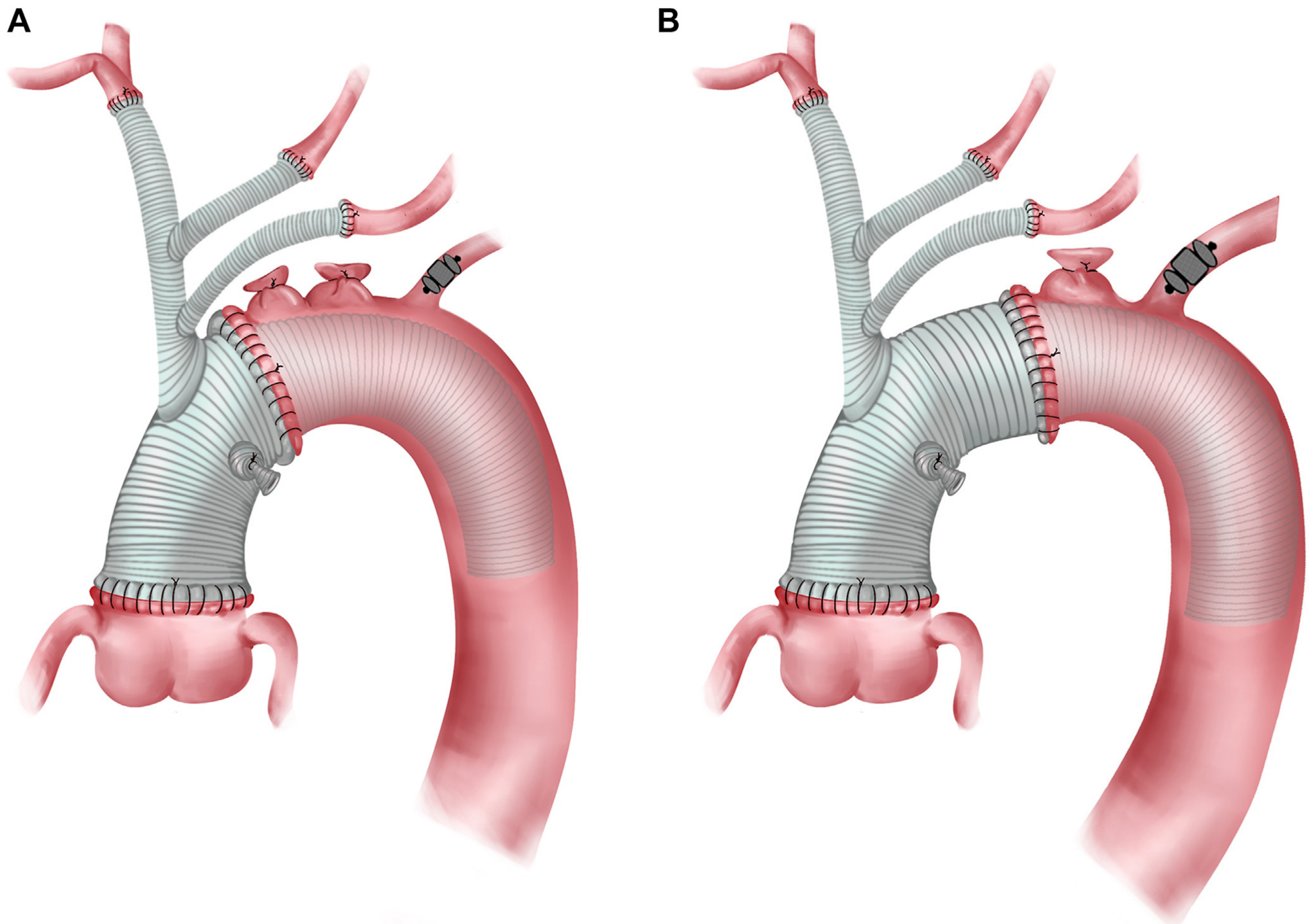

Figure 1. The distal anastomosis is moved proximally from (**B**) to (**A**) by oversewing the base of the debranched great vessels. With this principle, the majority of the total arch replacement (TAR) distal anastomosis can be performed in either zone 0 or zone 1 with improved exposure. The left subclavian depicted can be plugged with an Amplatzer device (Abbott Laboratories, Chicago, IL) and revascularized in an extrathoracic manner.

the descending aorta also favours FET, as introducing a conventional ET graft into a small true lumen can be challenging and is associated with incomplete expansion of the conventional ET. Although the comparison of outcomes between a conventional ET and an FET may be challenged, as they have different surgical indications and extent of repair, a systematic review and meta-analysis demonstrated a lower mortality rate and a higher risk of spinal cord ischemia in patients who underwent FET vs conventional ET.[7]

Available FET grafts include the Thoraflex Hybrid FET (Terumo Aortic, Sunrise, FL), which is approved by Health Canada, and the EVITA Open Neo (Artivion Inc, Atlanta, GA) and the Cook Hybrid FET (Cook Medical, Bloomington, IN), which are not approved by Health Canada and in 2023 required a special access program. Dacron ET grafts with cuffs and premade branches in various configurations can facilitate the mismatch between the aorta and the Dacron.

Either of 2 techniques can be used—an arch-first technique, which prioritizes head vessel anastomosis, or a conventional technique, which prioritizes the distal anastomosis. The advantage of the arch-first technique is that it provides easier access to the LSCA anastomosis in the chest, without the distal anastomosis pressurizing the aorta and the graft limiting the exposure of LSCA. However, this procedure requires deeper hypothermia and a longer systemic circulatory arrest time to protect the ischemic lower body. The conventional technique allows less time for systemic flow restoration and improves the flow of the operation. The conventional technique is described herein in conjunction with the Siena Plexus graft (Terumo Aortic), which is preferred for the utility of the cuff and the presence of radio-opaque markers. The distal anastomosis is first completed, and systemic flow is restored via the side limb of the graft. This step is followed by an left common carotid (LCC) anastomosis, after which bilateral antegrade cerebral perfusion (ACP) can start and the patient can be re-warmed. This step is followed by the proximal, innominate, and extrathoracic LSCA anastomosis. The approximate time for each anastomosis can be estimated, to indicate how much time the patient will be under systemic circulatory arrest, and under left hemispheric circulatory arrest, and predict x-clamp time (Fig. 2).

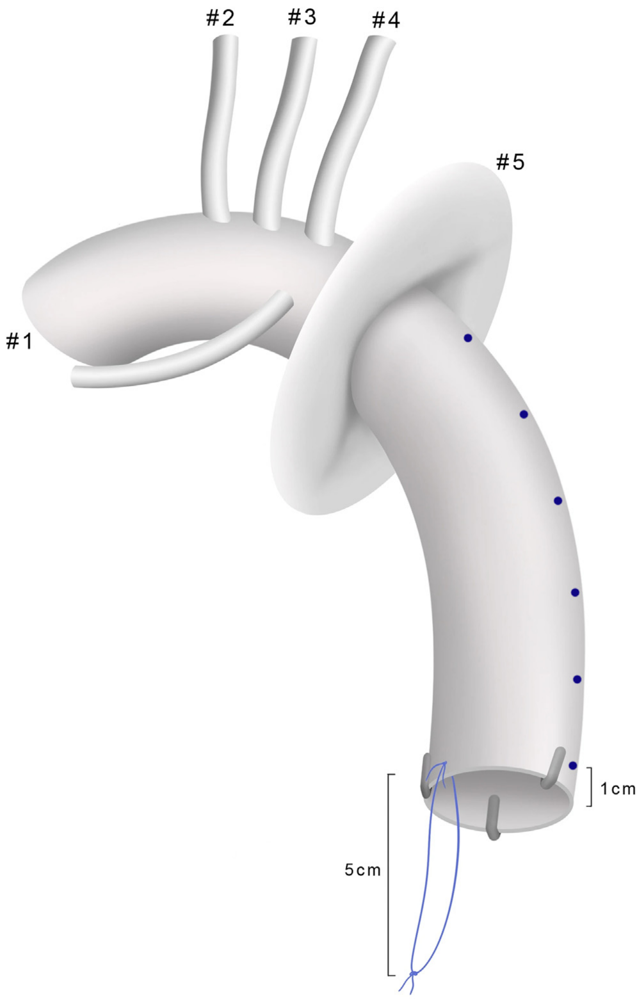

Figure 2. The placement of the Ligaclips and the pacing wire is depicted. The graft is trimmed 1 cm beyond the last radio-opaque marker. Using the conventional technique, the sequence of anastomosis is 5 → 3 → 1 → 2 → 4. Cross-clamp time can be predicted as #5 + #3 + #1 anastomosis time. Similarly, the predicted left hemispheric circulatory arrest time is #5 + #3 anastomosis time, and the predicted systemic circulatory arrest time is #5 anastomosis time.

Operative Techniques

Access

The right axillary artery is accessed via the deltopectoral groove with the pectoralis minor divided. The left axillary artery cut-down is simultaneously performed, in preparation for the LSCA externalization. The left femoral artery is accessed percutaneously with a J wire that is advanced under echo guidance in the true lumen. A redo median sternotomy would be performed for a previous ATAAD repair.

Cannulation

An 8-mm Gelweave graft (Terumo Aortic) is anastomosed to the right axillary artery to a preconfigured Y tubing, to allow simultaneous ACP and distal body perfusion via the side limb once the distal anastomosis is complete. A 2-stage venous cannula is placed in the right atrium. The patient is heparinized and cooled subsequently. Femoral venous cannulation is used if concerns for re-entry are present.

Preparation

While the patient is cooling, the innominate vein can be mobilized and ligated. The mid aortic arch is mobilized, and vessel loops are placed around the innominate artery and the LCC artery. The graft of choice is prepared. If a conventional ET is used, 3 LT400 Ligaclips (Ethicon Inc, Somerville, NJ) are placed at 120 degrees from each other, and a pacing wire is sutured on the lesser curve of the graft (Fig. 2).

Myocardial protection

Antegrade and retrograde cardioplegia options exist, and retrograde is preferred in cases in which the scar tissue associated with previous ATAAD repair makes antegrade cardioplegia cannulation difficult, or in cases in which aortic valve insufficiency coexists. Retrograde cardioplegia is started once the ACP begins. Once the heart fibrillates, the left ventricle vent is placed via the right superior pulmonary vein.

Brain protection

A moderate hypothermic circulatory arrest is achieved with a target temperature of 26°C to 28°C. Once the target temperature is reached, ACP flow is temporarily decreased to 500 mL/min, and Serafin and Cosgrove clamps (Edwards Lifesciences, Irvine, CA) are applied to the LCC artery and the innominate artery, respectively. ACP flow is then started at 10 mL/kg/min and is increased to 15 mL/kg/min if necessary. Cerebral regional oxygen saturation is monitored with near-infrared spectroscopy (NIRS). If the left-sided cerebral oxygen saturations remain decreased, with ACP provided by right axillary ACP only, then a bilateral ACP should be instituted via cannulation of the LCC.

Graft anastomosis

The great vessels are debranched, and their bases are oversewn. The FET is advanced over the pre-placed guidewire and deployed per the instructor's manual; in the case of a conventional ET, the ET is placed so as to ensure that the pacer wire is accessible for future access. The distal anastomosis is then completed. Inflow graft cannulation with a 22-F aortic cannula is made via the side limb, and systemic flows are restored. The graft is then de-aired, clamped, and pressurized, and the distal anastomosis is checked and reinforced with sutures. LCC anastomosis is completed next. It is then de-aired, and bilateral ACP is started. The patient is re-warmed to normothermia. Proximal anastomosis is made at the level of the sinotubular junction after trimming the in-situ proximal graft. The cross-clamp is subsequently removed. After measuring the distal limb of the graft, the aorta-innominate artery anastomosis is completed. The graft is de-aired, and the right axillary artery inflow is stopped. Total cardiac, cerebral, and systemic flows are maintained with the arterial flow into the side limb. LSCA anastomosis is completed last. An 8-mm Dacron graft is externalized into the left deltopectoral grove via the second intercostal space.

Postoperative Management

Neurovitals checks in the intensive care unit are important, to check for signs and symptoms of spinal cord ischemia, including lower-extremity weakness or paralysis. To minimize the spinal cord ischemia risk, the shortest length of the FET is always used, unless the goal is to complete the pathology in 1 stage, in which case, a longer graft needs to be used. Cerebrospinal fluid drain is not used routinely unless the second stage procedure with the TEVAR extends beyond the level of T6. Before discharge, a CTA scan is completed to assess for the reconstruction and any endoleaks. After discharge, patients are followed with routine serial CT imaging for graft integrity and patient progress.

Tips and Pitfalls

- As previously described, the pacing wire on the ET is placed on the lesser curve, to stabilize the graft distally, allowing for easier cannulation. The pacing wire acts as a counter source of traction to help position the graft during a subsequent TEVAR. The wire should be sutured 3 rings from the distal end of the graft, and it can be secured with 1 knot. The wires should be 5 cm, and another knot can be placed at the end. The pacing wires can stay in situ (Fig. 2).
- The Siena Plexus graft is trimmed to just beyond the last radio-opaque marker (Fig. 2).
- The sequence for de-airing follows release of the proximal clamp, followed by a distal clamp with the proximal clamp in situ, followed by the release of all clamps. For LCC anastomosis, for example, the steps proceed as follows: the Serafin is released first; the graft is poked; the Serafin is put back on; the distal Kelly clamp is released; the graft is poked; and then the Serafin is removed. The same is done for innominate anastomosis de-airing.

Ethics Statement

Research reported has adhered to the relevant ethical guidelines.

Patient Consent

The authors confirm that patient consent is not applicable to this article, as no patient information was included.

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Disclosures

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