Total aortic arch replacement without deep hypothermic circulatory arrest in type A aortic dissection: Left axillar artery for arterial cannulation

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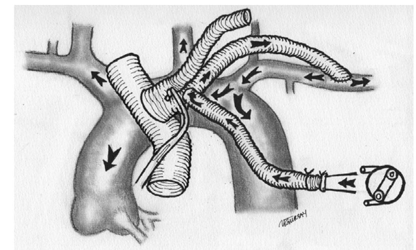
ABSTRACT

Objective: Total aortic arch replacement (TAR) necessitates hypothermic circulatory arrest (CA). The frozen elephant trunk technique (FET) additionally requires commercial hybrid grafts. Herein we describe a novel modified FET technique without CA using standard grafts thanks to left axillary artery (LAxA) cannulation in patients with acute type A aortic dissection.

Methods: LAxA anastomosis is made first using a homemade debranching graft, and cardiopulmonary bypass is initiated, followed by anastomoses of left common carotid and innominate arteries. The rest of the operation is performed with complete cerebral perfusion. Following replacement of ascending aorta/root, cardiac reperfusion is started using a root cannula which continues throughout the procedure. Distal arch anastomosis is performed clamp-on, allowing lower body perfusion via left subclavian artery. Lower body perfusion is interrupted for 5 to 8 minutes to deploy an endograft to complete a modified FET. Following cannulation of distal arch graft, perfusion of distal aorta is restarted, and all three grafts are incorporated to construct a neo-ascending aorta and arch.

Results: Between December 2018 and May 2022, 38 patients underwent TAR without operative mortality. Hospital mortality was %15.7, and spinal cord ischemia and stroke were not encountered in surviving patients. The mean lower body CA time was 7.2 ± 2.8 minutes.

Conclusions: TAR using standard endografts without CA is possible with LAxA cannulation. To perform a FET, only a short interruption of lower body circulation is sufficient to deploy an endograft, also improving hemostasis of distal anastomosis. Further studies are required with a higher number of patients to evaluate the efficiency of this novel technique. (JTCVS Techniques 2023;22:120-31)



Trifurcated debranching graft and left axillary artery cannulation before debranching.

CENTRAL MESSAGE

Use of left axillary artery as the site for arterial cannulation, along with adjunctive techniques, may allow the elimination of deep hypothermic circulatory arrest for total aortic arch replacement.

PERSPECTIVE

As a novel modification of frozen elephant trunk, using a homemade trifurcated graft with the combination of left axillary artery cannulation, branch first debranching, early cardiac reperfusion, clamp-on distal arch anastomosis, and antegrade TEVAR may eliminate the need for deep hypothermic circulatory arrest, shorten myocardial ischemia time, and improve results of total aortic arch replacement.

▶ Video clip is available online.

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In patients with acute type A aortic dissection (aTAAD), hemiarch replacement with open distal anastomosis is recommended[1]; however, in the presence of arch tears and aneurysmal dilatation, a more challenging technique, total aortic arch replacement (TAR), could be unavoidable. Current TAR techniques require circulatory arrest (CA), antegrade and/or retrograde cerebral perfusion, prolonged crossclamp (XCl) times with concomitant risks of brain and spinal cord (SC) injury, organ dysfunctions, and bleeding

Abbreviations and Acronyms

ASCP	=	antegrade selective cerebral perfusion
aTAAD	=	acute type A aortic dissection
CA	=	circulatory arrest
CPB	=	cardiopulmonary bypass
DAG	=	distal arch graft
FET	=	frozen elephant trunk
FL	=	false lumen
IA	=	innominate artery
LAxA	=	left axillary artery
LCCA	=	left common carotid artery
LSA	=	left subclavian artery
SC	=	spinal cord
SCI	=	spinal cord injury
TAR	=	total aortic arch replacement
TEVAR	=	thoracic endovascular aneurysm repair
TFG	=	trifurcated debranching graft
VA	=	vertebral artery
XCl	=	crossclamp

problems that result in high mortality, morbidity, and reintervention rates. Those features necessitate making haste and limiting its use in high-volume centers; however, there could be room for improvement to generalize its use.

We want to share our novel technique using the left axillary artery (LAxA) for arterial cannulation, which may eliminate the aforementioned disadvantages of TAR, with the hope of transforming it into a less-demanding procedure to improve both early- and long-term results and allow its wider spread use.

METHODS

Patient Selection

Patients with aTAAD whose arch replacement is indicated based on anatomic criteria (arch vessel dissections, arch re-entries, and aneurysmal dilation) were included in the study group. Although the presence of a left subclavian artery (LSA) perfused from false lumen (FL) is considered a contraindication, and due to unfavorable prognosis independent from surgical technique, patients with malperfusion causing stroke or requiring intestinal resection are excluded to reflect the results of the technique described. Patients with cardiogenic shock are also excluded due to the absence of the time needed to construct trifurcated debranching graft (TFG). This retrospective, single-center study was approved by the institutional review board of Ankara Etlik City Hospital (study ID: AEŞH-EK1-2023-068, approved on April 4, 2023). The center used an opt-out consent process, and all procedures complied with the Declaration of Helsinki.

Positioning and Monitoring

The supine position was used in all cases. In addition to cerebral near-infrared spectroscopy, bilateral upper extremities and one femoral artery were monitored to yield desired perfusion pressures.

Surgical Technique

Construction of TFG and distal arch graft (DAG) with perfusion arm. TFG is constructed from an 8/16 bifurcated Dacron graft at back-table and consisted of two 80-mm diameter limbs for LAxA (A) and left common carotid artery (LCCA) (B), respectively, in addition to a 16-mm short limb (C) for innominate artery (IA) anastomosis whereas the long tip of the body of the TFG is used for connection to neo-ascending aorta. A perfusion arm (D) is added to LAxA limb (A) for arterial cannulation (Figure 1, *A*).

The DAG is constructed from an appropriate-size Dacron tube graft. Either an 8-mm Dacron graft is anastomosed ~6 cm away from the tip of DAG at back-table to be used as the perfusion arm, or right after completion of distal arch anastomosis, an arterial cannula is inserted via a simple purse string.

Arterial cannulation. LAxA is exposed in the infraclavicular fossa and mobilized (Video 1). Following median sternotomy, innominate vein and arch vessels are dissected. A tunnel is created carefully between the infraclavicular fossa and mediastinum, and limb (A) is passed and anastomosed to LAxA end-to-side fashion following systemic heparinization. A 24-F arterial cannula is inserted into the perfusion arm (D), and cardiopulmonary bypass (CPB) is initiated following application of a clamp to isolate limb (A) from the rest of TFG. At this stage, arterial flow reaches body via limb A, LAxA, LSA, and aorta in sequence (Figure 1, *B*).

Debranching. After the commencement of CPB at 32 °C, a left ventricular vent is placed, and debranching of LCCA and IA is performed backward. At the same time, heart is empty and beating, and arterial perfusion of whole body is maintained via LAxA since LSA-arch integrity is preserved. The next is the end-to-end anastomosis of limb (B) to LCCA after its division from arch. Following deairing, the clamp at limb A is moved to the body of the bifurcated piece to perfuse both LAxA and LCCA (Figure 1, *C*). The IA is then divided from arch and anastomosed to tubular part's short end (limb C). While perfusing LCCA and LAxA from the bifurcated limbs (A and B) of TFG, perfusion also starts to IA when clamp is moved to body of TFG (Figure 1, *D*). LSA-arch integrity is maintained until the completion of distal arch anastomosis.

Cardioplegic arrest and proximal aortic replacement. XCl is applied to zone 2 while care is given to avoid recurrent laryngeal nerve and not to interfere with the flow from LSA to the distal aortic arch. Cardioplegic arrest and ascending aortic replacement are performed per surgeon's preference using Dacron grafts. In patients requiring root replacement, patient is cooled down to 28 °C.

Termination of cardiac arrest and early reperfusion of heart. Following insertion of a 14-F coronary root cannula into the ascending aortic graft and connected to the arterial line, the distal tip of ascending aortic graft was clamped to restart myocardial perfusion. Simultaneously, utmost care was given to keep heart empty via left ventricular vent. The heart was defibrillated if needed, and rest of procedure was completed with beating heart.

Construction of a Blood-Tight Distal Arch Anastomosis Without Lower-Body CA

Clamp-on anastomosis. XCl is kept in zone 2, and a clamp-on anastomosis technique is preferred for distal arch anastomosis to ensure lower body perfusion. For this purpose, a 3- to 4-cm part of Dacron tube graft is invaginated (inverted) (Figure E1), and *the folded edge* is sutured to the remnant of aortic arch at zone 1 or 0 (Figure 2, *A*). Simultaneously, brain, heart, and lower body are perfused via TFG, root cannula, and LSA, respectively.

Modified frozen elephant trunk (FET) and a short lower body CA to deploy endograft. If a single-stage FET is planned, LSA is clamped while CPB flow is decreased to keep upper-extremity blood pressure between 60 and 80 mm Hg following completion of distal

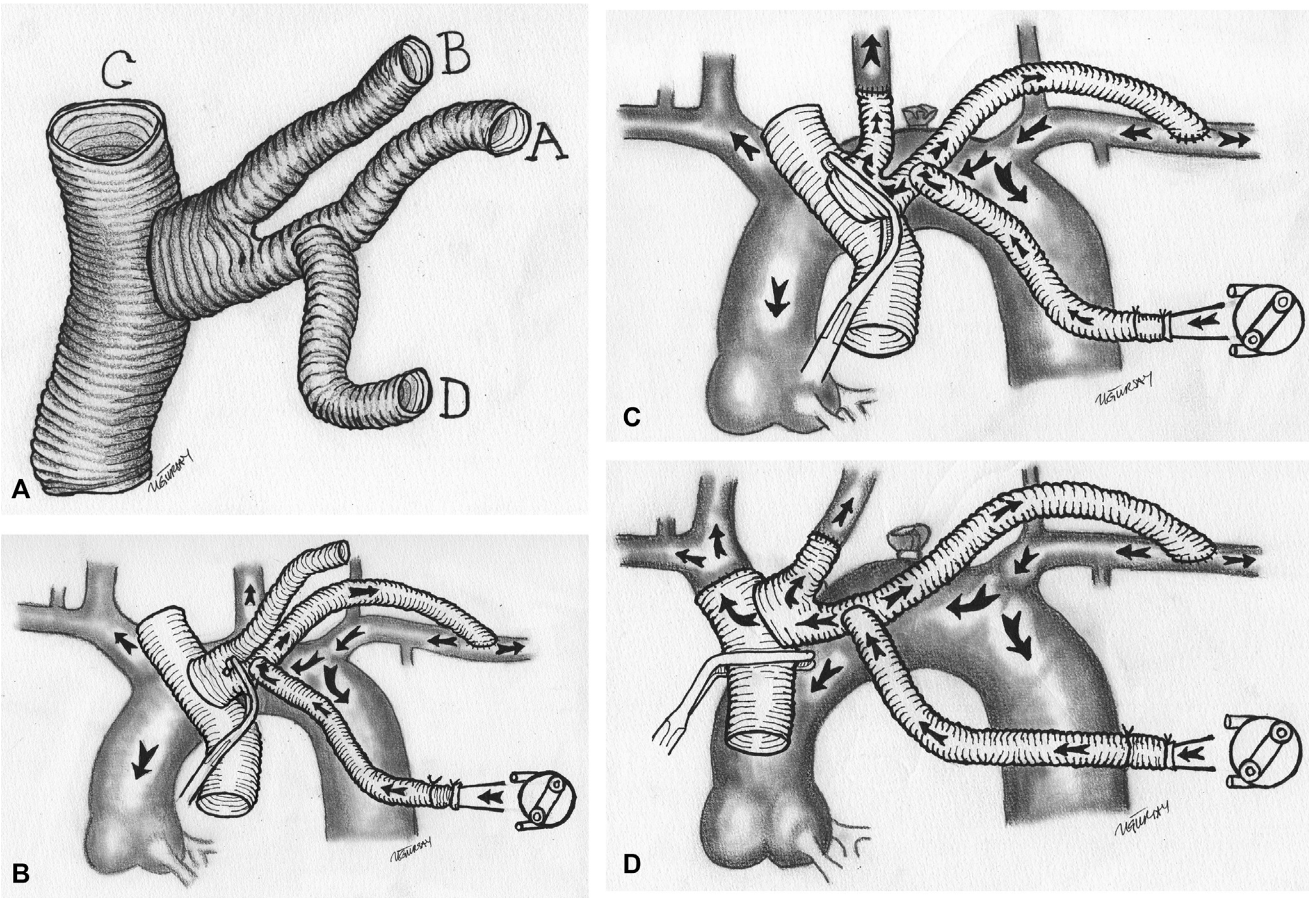
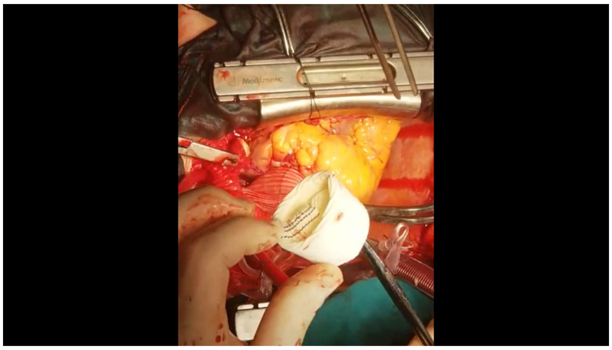


FIGURE 1. Homemade trifurcated debranching graft, its usage during the commencement of CPB and debranching procedure. A, Trifurcated graft with a perfusion arm, limb A to LSA, limb B to LCCA, limb C to IA and D perfusion arm. B, Commencement of CPB: After completion of LAxA anastomosis, a clamp is applied to limb A just proximal to the perfusion arm, and commencement of CPB, LSA is left intact for perfusion of the rest of the body. C, LCCA Debranching: following limb B anastomosis to LCCA, a clamp is applied to the body of the bifurcated part to allow perfusion of LCCA and aorta from TFG. D, IA Debranching: following limb C anastomosis to IA, a clamp is applied to the body of the TFG to allow perfusion of IA, as well as LCCA and aorta. *CPB*, Cardiopulmonary bypass; *LSA*, left subclavian artery; *LCCA*, left common carotid artery, *IA*, innominate artery; *LAxA*, left axillary artery; *TFG*, trifurcated debranching graft.

arch anastomosis. XCl on zone 2 is released, and a lower body CA is commenced. At this stage, the invaginated part of the DAG is pushed down to the distal aorta (Figure 2, *B*), and a 15-cm standard endograft is advanced down to descending aorta (Figure 2, *C*). Deployment starts in the true lumen of distal aorta and is completed in order for its most proximal 2 cm part to be landed in the DAG (docking). In this way, for intraluminal bypass purposes, double-layer inner coverage of anastomosis and a long landing zone for endograft is achieved. An angioscopy could be performed to confirm the true lumen. This procedure usually takes only 5 to 8 minutes to complete.

Cannulation on DAG and initiation of lower-body perfusion and rewarming. After endograft deployment, an arterial cannula is inserted into perfusion arm or directly into DAG using a purse suture. Reperfusion of lower body started with deairing distal aorta with reverse Trendelenburg position while the proximal end of DAG is clamped to proceed to full-flow perfusion and rewarming (Figure 3). Simultaneously LSA is ligated to prevent type II endoleak.



VIDEO 1. Operative video of a patient with aTAAD underwent TAR using LAxA cannulation. The video is recorded from the surgeon's view. Video available at: https://www.jtcvs.org/article/S2666-2507(23)00296-1/fulltext.

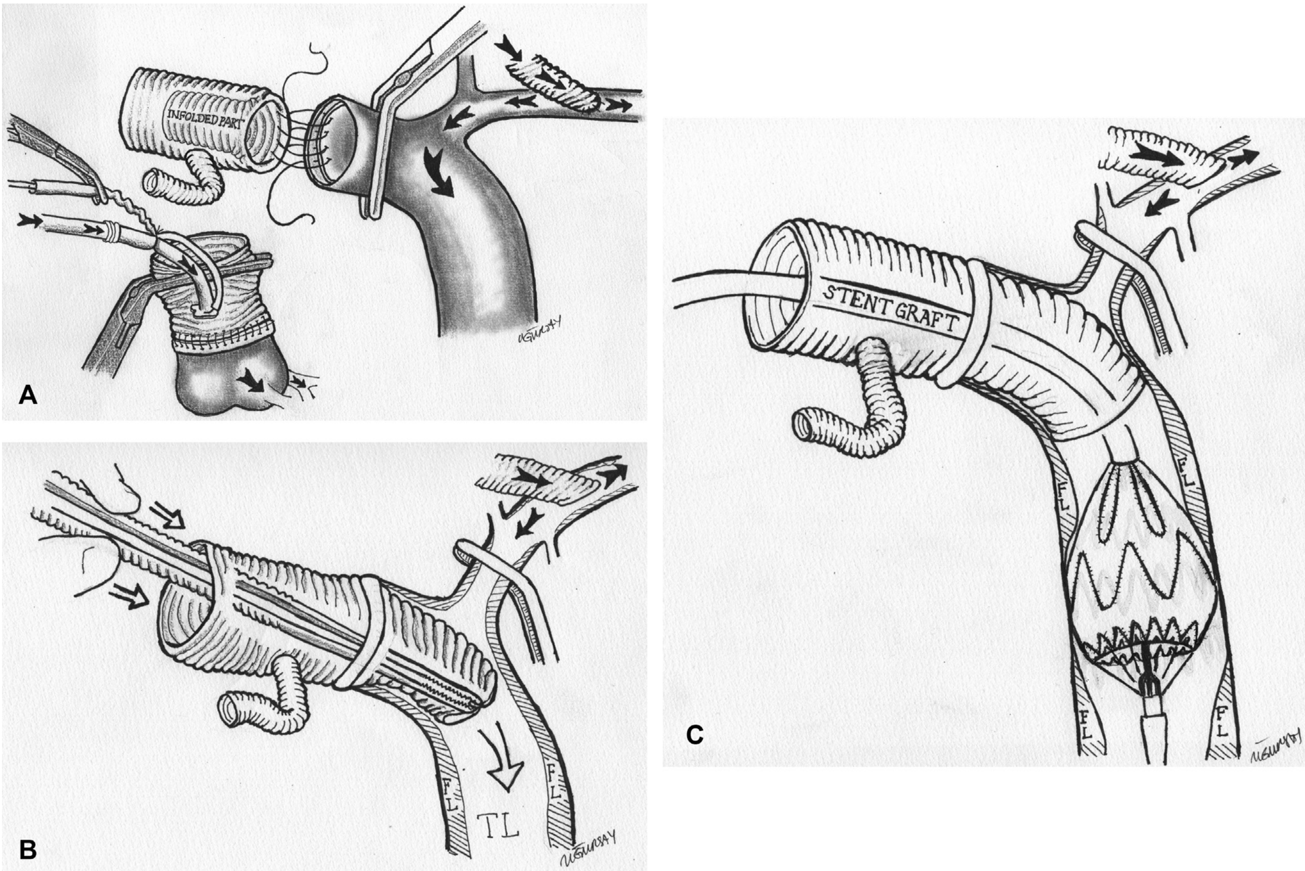


FIGURE 2. Distal arch anastomosis without interrupting distal body perfusion. A clamp-on anastomosis technique is selected to minimize visceral ischemia and the need for hypothermia. Using CET and modified FET generates a watertight anastomosis via "intraluminal bypass" concept. A, An approximately 4-cm part of Dacron graft is invaginated, and the folded edge is sutured to zone 1 while zone 2 is clamped; meanwhile, lower body, heart, and brain are perfused via LSA, root cannula, and TFG, respectively. B, A CET is created to serve as a robust landing zone for deploying a TEVAR. A brief lower-body circulatory arrest is mandatory for open interventions in distal aorta. XCl at zone 2 is removed and applied to LSA while CPB flow is reduced and titrated accordingly to right upper extremity blood pressure and NIRS levels. Invaginated part of the DAG is pushed down to the distal aorta to attain CET. C, Achieving a watertight anastomosis via a modified FET. An endograft is deployed starting 2 cm proximal to the anastomosis and is extended to the distal aorta; the suture line is covered inside to be isolated from blood flow which minimizes anastomotic bleeding. Interruption of lower body circulation usually takes 5 to 8 minutes. *FL*, False lumen; *TL*, true lumen; *CET*, classic elephant trunk; *FET*, frozen elephant trunk; *LSA*, left subclavian artery; *TFG*, trifurcated debranching graft; *TEVAR*, thoracic endovascular aneurysm repair; *XCl*, crossclamp; *NIRS*, near-infrared spectroscopy; *DAG*, distal arch graft.

Incorporation of all grafts. TFG, distal arch, and ascending aortic grafts were trimmed to achieve a neoascending aorta without kinking. Obliquely trimmed tip of TFG is anastomosed to an appropriate size hole on the right side of the DAG. Then the proximal tip of DAG is sutured to the ascending aortic graft to complete neo-ascending aorta (Figure 3).

Termination of CPB and closure. CPB is terminated after, rewarming, and achieving hemostasis of suture lines and hemodynamic stabilization (Figure 4). Different sections in the reconstructed aorta are depicted in Figure E2.

RESULTS

Between December 2018 and May 2022, 38 patients with aTAAD underwent TAR using LAxA for arterial cannulation, and the baseline characteristics of patients are summarized in Table 1. Thirty-four of those (89.5%) were operated after hours. Pericardial effusion without cardiogenic shock was present in 22 (57%). Distal aortic malperfusion existed in 4 patients (10%) before TAR, whereas arch vessel malperfusion without stroke was encountered in 8 (21%).

Operative characteristics are summarized in Table 2. The mean XCl times for standard ascending aortic and root replacement were 67.4 ± 23.4 and 163 ± 55 minutes, respectively. The mean lowest temperature during CPB was 31 ± 1.6 °C, and the mean lower body CA time was 7.2 ± 2.8 minutes. One superior mesenteric and 3 iliac arteries were stented in 4 patients admitted in early malperfusion phase. In 12 (31.5%) patients, root replacement (David/Bentall) was needed. Coronary artery bypass

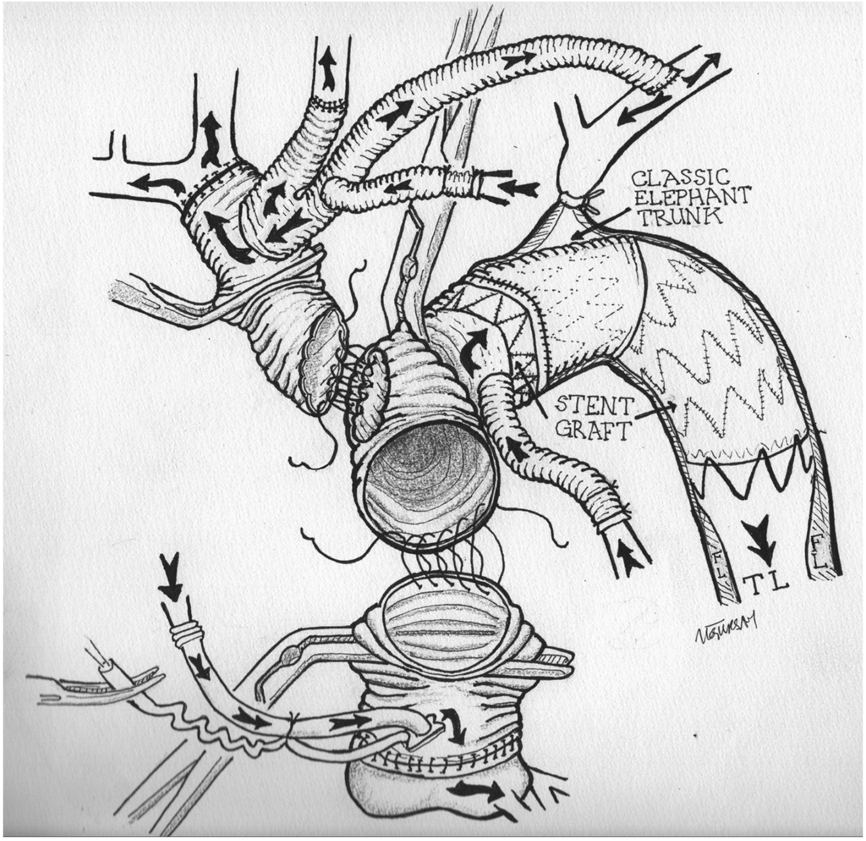


FIGURE 3. Incorporation of 3 grafts. Following ligation of LSA to prevent a type 2 endoleak, an arterial cannula is connected to the DAG and lower-body perfusion is restarted. While complete body perfusion is commenced, an appropriate-size hole is generated at the proximal part of the DAG, and the proximal tip of TFG is sutured to the DAG. TAR is completed with anastomosis of the proximal end of the DAG to ascending aortic graft. *FL*, False lumen; *TL*, true lumen; *LSA*, left subclavian artery; *DAG*, distal arch graft; *TFG*, trifurcated debranching graft; *TAR*, total aortic arch replacement.

grafting was added in 8 patients (21%) due to difficulty weaning from CPB or known history of CAD, whereas extracorporeal membrane oxygenation was required in 2 (5.2%) due to postcardiotomy failure. The lengths of deployed endografts were 20 cm in 22 (58%), 15 cm in 14, and 10 cm in 1 patient. Length selection is made according to the distance of targeted major re-entries and the availability of endografts.

Postoperative outcomes of patient population are also summarized in Table 2. Stroke or spinal cord injury (SCI) was encountered in none of patients, whereas reversible minor neurologic deficits developed in 2 (5.2%). Hospital mortality was 15.7% (6 patients). Etiology was low cardiac output in 2, pneumonia and sepsis in 2, postoperative abdominal malperfusion in 1, and late cardiac tamponade in 1 patient. Two of deaths were related to postoperative coronavirus disease 2019–related pneumonia infection. Elimination of FL without adjunct interventions was documented in 7 surviving patients (Figure 5), whereas total aortic repair was achieved in 17 (53%) patients using STABILISE (stent-assisted balloon-induced intimal disruption and relamination in aortic dissection repair) concept.

DISCUSSION

Need for a Less-Demanding Procedure

TAR in patients with aTAAD is a challenge due to the need to deal with fragile tissues and to interrupt circulation of the brain, SC, and the rest of the body. Also being predictors of mortality,[2] neurologic complications such as stroke and SCI are the most devastating complications of aortic surgery, and their frequency and size are proportionate with the length of hypothermic CA.[3] The FET technique demands high technical skills and quickness[4] and is recommended to be performed in high-volume centers.[5] In addition, difficulty in dealing with anastomotic bleedings and time pressure makes FET an unappealing procedure for low-volume surgeons. However, there is a need for a more reproducible approach with lower neurologic, visceral, and cardiac risks. We believe our technique with eliminating CA and selective antegrade selective cerebral perfusion (ASCP) and obtaining shorter XCl times with a hemostatic distal arch anastomosis has this potential. To our knowledge, this is the first report of a novel technique using LAxA for arterial cannulation with the elimination of CA.

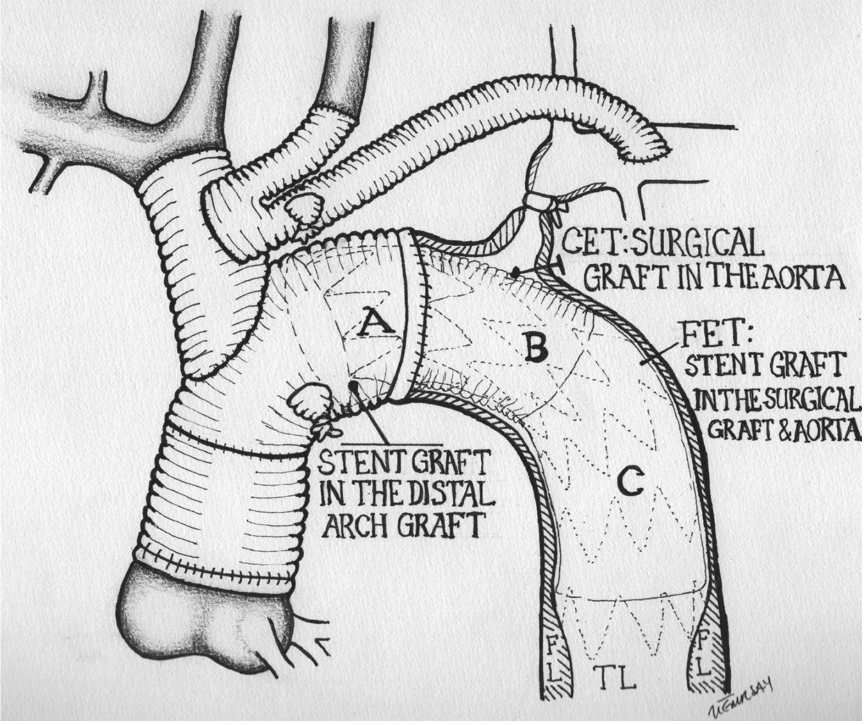


FIGURE 4. Overall appearance after completion of TAR. *CET*, Classic elephant trunk; *TAR*, total aortic arch replacement; *FET*, frozen elephant trunk; *TL*, true lumen; *FL*, false lumen.

Critical Role of VAs for Perfusion of Brain and SC, and LAxA as the Cannulation Site

We deem that the importance of LSA and left VA in current aortic surgical practice is underrated to some extent. In addition to perfusing the posterior brain, VAs are the sole source of blood supply to the SC during ASCP and lower-body CA. Bearing in mind that left VA dominance is frequent (60%),[6] only 24% of individuals have a complete circle of Willis,[7] and VA–posterior inferior cerebellar artery termination incidence can reach 6.3%[6]; varying degrees of ischemia of posterior fossa structures and SC during ASCP and lower body CA can be postulated in the absence of LSA perfusion. Even anterior brain ischemia due to the steal phenomenon can happen if an LSA with a dominant VA is not clamped during ASCP, which is not infrequent. All the aforementioned postulations could explain varying degrees of neurologic impairments if not a major stroke. In line with these assumptions, Pacini and colleagues[8] demonstrated that even bilateral ACSP develops ischemic injury of the posterior brain, correlated with the length of ACSP, and attributed to the lack of LSA perfusion. We share their concerns and believe one of the major disadvantages of ASCP/lower-body CA is the requirement of deeper hypothermia to protect the SC and abdominal viscera. However, in addition to difficulty in titrating ASCP flow to maintain supply/demand balance of brain, hypothermia-induced loss of cerebral autoregulation, and variations of cerebrovascular anatomy may cause under or overperfused areas, both are related to postoperative neurologic dysfunctions. However, at least hypothetically, the debranching graft, carrying unlimited flow through all arch vessels with adequate pump pressures, would generate more physiological perfusion thanks to intact cerebral autoregulation with mild/moderate

TABLE 1. Baseline characteristics of patients

Patient variable	N = 38	%
Age, y ± SD (range)	52 ± 12.6 (29-81)	NA
Female	9	23.6
Hypertension	38	100
Diabetes mellitus	18	47.3
COPD	16	42
Re-do sternotomy	5	13
Cardiac tamponade	22	57
Distal malperfusion	4	10
Dissected arch vessels	21	55
Arch vessel malperfusion	8	21
Preoperative acute renal failure	5	8
Preoperative endovascular intervention	4	10
Marfan syndrome	2	5.2

Values are presented as n and (%). *NA*, Not available; *COPD*, chronic obstructive pulmonary disease.

TABLE 2. Operative and postoperative characteristics of the study group

Patient variable	N = 38	%/range
Mean XCl time, min	89.1 ± 51.7	33-235
Ascending aortic replacement	67.4 ± 23.4	33-107
Root replacement (David/ Bentall)	163 ± 55	80-235
CPB time, min	292 ± 52.6	220-400
Lowest temperature, °C	31 ± 1.6	24-32
Lower body circulatory arrest, min	7.2 ± 2.8	5-14
Aortic valve repair	15	40
Root replacement (David/ Bentall)	12	31.5
CABG	8	21
FET length		
20 cm	22	58
15 cm	15	39.4
10 cm	1	2.6
Intraoperative mortality	0	0
Perioperative ECMO	2	5.2
30-d mortality	6	15.7
Late mortality	2	
Major neurologic deficit	0	0
Reversible neurologic deficit	2	5.2
Spinal cord injury	0	0
Re-exploration	9	23
New-onset renal failure	3	7.9
Bleeding requiring surgery	8	21
Respiratory insufficiency	16	42
Perioperative COVID-19	3	7.9
Total aortic repair with STABILISE concept	17	53

XCl, Crossclamp; *CPB*, cardiopulmonary bypass; *CABG*, coronary artery bypass grafting; *FET*, frozen elephant trunk; *ECMO*, extracorporeal membrane oxygenation; *COVID-19*, coronavirus disease 2019–related pneumonia; *STABILISE*, stent-assisted balloon-induced intimal disruption and relamination in aortic dissection repair.

hypothermia. Although postoperative awakenings of our patients were quite similar to patients who underwent standard open-heart surgery, at best, these inferences are hypothesis-generating and require further studies comparing cerebral perfusion strategies. We believe the aforementioned circumstances should be blamed in the pathogenesis of stroke and SCI in FET, as well as long endografts.

Compared with right axillary artery, routine cannulation of LAxA as the main arterial inflow is unusual. Aside from a few case reports,[9,10] to our knowledge, we found only one study in the literature using LAxA for arterial cannulation, yet the location of cannulation was not the main subject.[11] However, LAxA cannulation provides uninterrupted flow to LSA, consequently to the left VA and lower body, together with debranched arch vessels during distal arch anastomosis. We presume that complete circulation could prevent the aforementioned ischemic risks, as supported by the absence of SCI and stroke in our study group.

We consider there are some merits in preferring extrathoracic/infraclavicular anastomosis instead of intrathoracic LSA anastomosis. Although LSA anastomosis is attractive for avoidance of one more incision, it is the deepest and probably most challenging anastomosis and dangerous since proximal LSA is very fragile in patients with aTAAD. We consider this extra incision means one less major intrathoracic bleeding source with a serious cardiac tamponade potential. Furthermore, in FET technique, intrathoracic anastomosis hampers left VA perfusion unless a separate LAxA cannulation is made.

Modification of Branch-First Technique

We are inspired by the branch-first TAR described by Matalanis and Ip,[12] based on the debranching of arch vessels before the cardioplegic arrest, which may improve neurologic protection[13] and shorten the cardiac ischemia times. We believe their description of branch-first TAR has disadvantages compared with our technique, such as retrograde perfusion related to the obliged femoral cannulation due to initial debranching of IA and need for lower body CA, whereas in LAxA cannulation, almost all flow is antegrade, negligibly there is a retrograde flow momentarily and only in zones 2 and 1 until debranching is completed, which is performed immediately after the commencement of CPB.

Early Reperfusion of the Heart

Others also prefer to complete the rest of the FET procedure in beating heart[4]; however, in our experience, its combination with a modified branch-first approach significantly shortened our XCl times (89.1 ± 51.7 minutes) compared with the results of high-volume centers[14] and large registries[5] (141.7 ± 54 minutes and 133 minutes, respectively).

Comparison with FET

There has been increasing adoption of the FET technique due to its early- and long-term advantages. While it simplifies treatment of complex arch disease, lowers mortality,[15] and mitigates malperfusion in variable degrees. Despite reflecting the results of the initial learning curve of a novel technique in a high-risk population affected by coronavirus disease 2019–related pneumonia, our outcomes are comparable, if not better, with the results of high-volume centers and registries. Although our 15.7% mortality rate is similar to 17.5% combined mortality rate of 2 major European high-volume centers,[14] our mortality is much

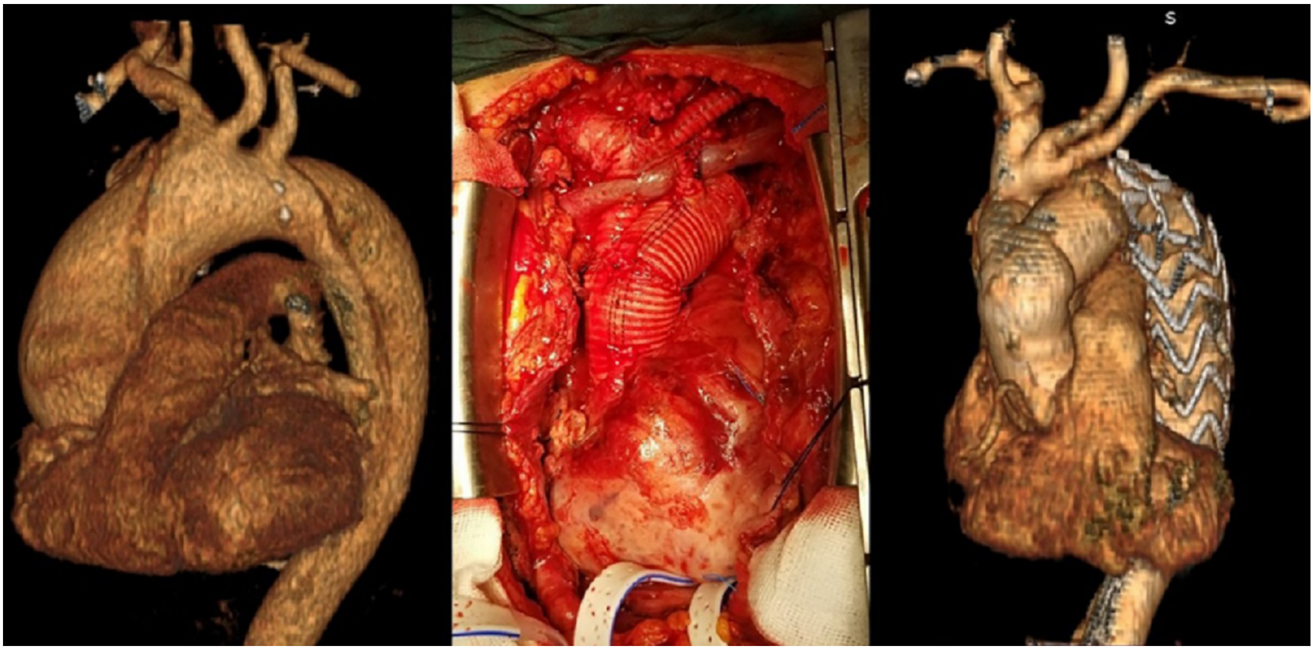


FIGURE 5. Pre- and postoperative 3-day reconstructions of CTAs and intraoperative view after completion of TAR. *CTA*, Computed tomography angiography; *TAR*, total aortic arch replacement.

lower than in the ARCH registry (24%).[5] When considering that length of myocardial ischemia and ASCP/CA times correlate with operative mortality,[8] and stroke and SCI are its predictors,[2] the absence of major neurologic complications, shorter myocardial ischemia times, and the avoidance/minimization of CA probably contribute to the reasonable mortality rate in our study.

FET also is opted for its long-term benefits related to eliminating FL patency, paving the way to positive aortic remodeling, and improved reoperation and survival rates. In line with these advantages, our results, despite the small sample size, demonstrate long-term benefits such as total aortic repair and survival. Our surviving patients with patent FL underwent a combination of planned interventions such as second thoracic endovascular aneurysm (TEVAR) extensions down to supra celiac aorta, modified PETTICOAT (provisional extension to induce complete attachment), and the STABILISE concept, which ensured total aortic repair in 53% of surviving patients.

Advantages of Clamp-On Technique: A Distal Arch Anastomosis Without Visceral Ischemia

Neurologic complications drive dismal outcomes following aortic surgery despite various cerebral-protection strategies, and stroke incidence ranges from 2.5% to 20% for the FET technique[16] and is reported at 10.1% in the ARCH registry.[5] SC malperfusion and loss of collateral networks are accepted as limiting factors for the FET,[17] and its risk is reported 8% in E-vita Open Registry.[18] In FET, distal anastomosis is performed using an open-distal technique, causing lower-body CA (visceral ischemia) and ASCP times reaching 51.2 ± 16 minutes and 90.8 ± 38 minutes, respectively, even in high-volume aortic centers.[14] Although prolonged ASCP and CA have been shown as predictors of increased mortality and neurologic complications,[8,19] we believe the combination of LAxA cannulation, modified branch-first, and clamp-on anastomosis techniques means complete body perfusion, which reduces the risk of visceral and neural injury and allows the execution of anastomosis without haste. In line with this assumption, there was no stroke and SCI in our study group despite avoiding excessive hypothermia and deploying long endografts in most patients (200 mm endografts in 22 patients, 58%). Furthermore, by clamping zone 2, suturing surgical graft to less deep and more proximal zone 1 is not only easier but also safer owing to avoiding recurrent laryngeal nerve. In contrast to the absence of its injury in our series, it reaches 12.8% in the literature.[16]

Modified FET: A Secure and Watertight Distal Arch Anastomosis

Repairing anastomotic bleeding in patients who underwent aTAAD surgery could be troublesome due to fragile aorta. However, most anastomotic bleedings are related to patent and pressurized FL. Fixing them following CPB termination is one of TAR's most worrying challenges for low-volume surgeons. They are typically located at zone 3 or 2, deep down in the chest; therefore, placing reinforcing sutures could be troublesome, especially at the posterior suture line, and may require hazardous manipulations, which could cause dangerous tears or significant hemodynamic impairments. However, FET improves hemostasis at distal arch anastomosis, particularly when there is a long length of endograft opposition.[20] In the absence of industrial FET grafts, to attain a more hemostatic anastomosis via modified FET, we contemplated that the *intraluminal bypass* concept, as proposed years ago,[21] could increase the imperviousness of distal arch anastomosis by isolating the suture line from blood flow. We believe our distal anastomosis technique is more hemostatic than FET since endograft traversing anastomosis. Unlike FET, it prevents contact of blood to suture line, compresses the anastomosis internally by its radial force, diverts blood flow to true lumen, and obstructs FL effectively. Accordingly, we never needed to place a reinforcement suture for distal arch anastomotic bleeding following off-bypass in our series.

Modified FET: Antegrade Endograft Deployment With a Short Lower-Body CA and Need for Classic Elephant Trunk

Inspired by the antegrade endograft deployment technique pioneered by Pochettino and colleagues,[22] for FET purposes, an endograft is deployed to descending aorta anterogradely in our approach, while its proximal end is docked to DAG. However, in line with our previous experience in zone 0 TEVAR, some evidence suggests the need for at least a 4- to 6-cm long landing zone in surgical grafts to prevent type Ia endoleaks.[23] For this purpose, we preferred creating a short classic elephant trunk with suturing an invaginated graft to arch remnant to extend the landing zone distal instead of proximal, which would interfere with anastomosis of TFG or elongate the neoascending aorta inconveniently.

Total Elimination of CA

If desired, short lower-body CA could also be avoided by abandoning FET. In that case, a standard Dacron graft is sutured to zone 1 while the clamp is on at zone 2, allowing uninterrupted flow to the lower body, which may be followed by cannulation of DAG to expedite rewarming. Therefore, endograft deployment could be postponed, like type II hybrid repair.[24] However, the hemostatic effect of "intraluminal bypass concept" will not be effective immediately.

Limitations of the Technique

Despite numerous advantages stated previously, our technique has several disadvantages worth mentioning. Since TFG has yet to be commercially available, its construction prolongs operation. However, a second surgeon can construct during the preparation of target vessels or anesthesia induction. Although the presence of several anastomoses makes hemostasis an issue, all are within reach, and a meticulous technique helps. Another inevitable problem is the prolonged CPB time. However, TAR is a big operation, and the same drawbacks are the case for standard FET technique.

CONCLUSIONS

TAR is a demanding surgery, necessitating the use of high-volume centers and expert surgeons, which may not always be available and everywhere. Our novel technique doesn't need deep hypothermia and prolonged visceral ischemia owing to the uninterrupted perfusion through LSA and provides a safer and easier operation using widely available and less costly endografts, ensuring the advantages of FET. It also allows total elimination of CA if TEVAR is delayed. This technique is also suitable for reoperative arch replacements following hemiarch repair and aneurysms. Despite our promising results, our sample size is small, and further studies evaluating adequacy of LAxA cannulation and comparing cerebral perfusion dynamics of ASCP and modified branch-first techniques are warranted. We believe that once thoroughly understood, TAR with LAxA cannulation could be more reproducible, and it can be performed in low-volume centers, even by less-experienced surgeons who are not yet experts in aortic surgery.

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 or reviewing 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: total arch replacement, frozen elephant trunk, type A aortic dissection, circulatory arrest, deep hypothermia, left axillary artery cannulation

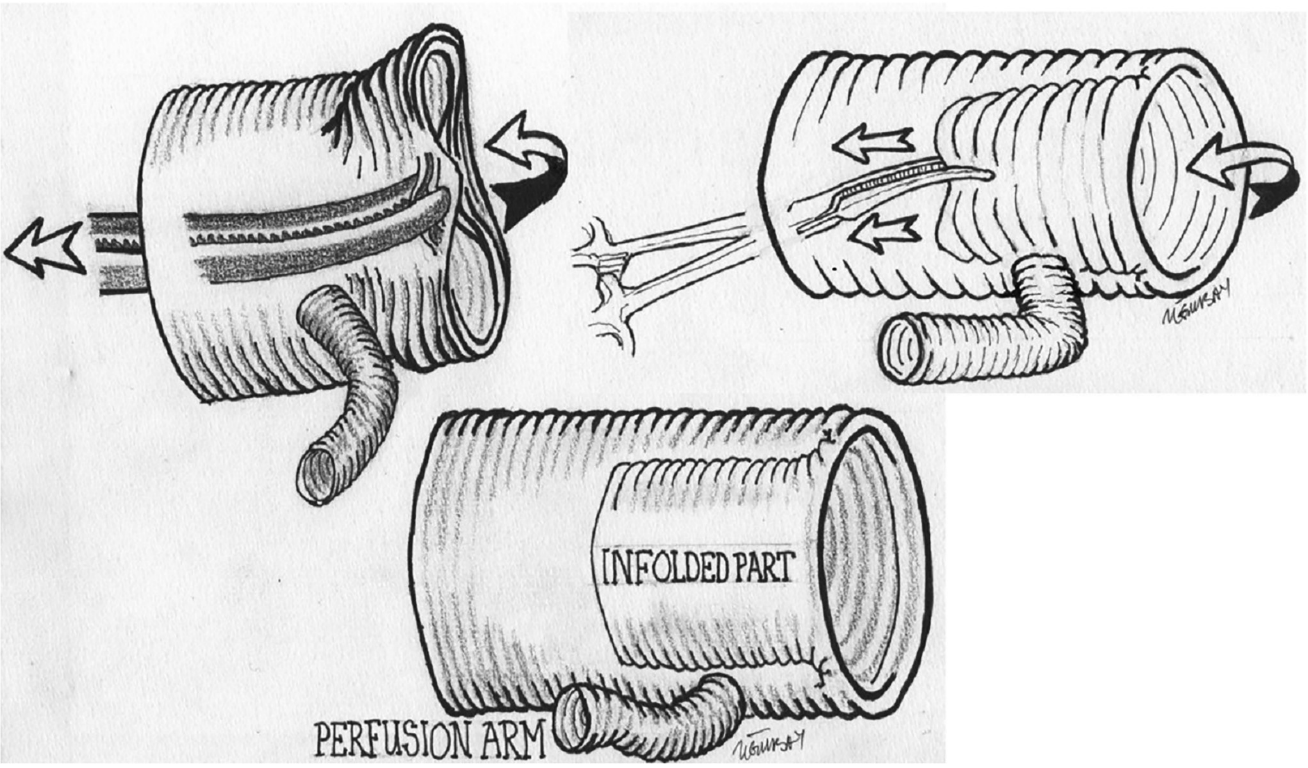

FIGURE E1. A forceps is used for invaginating a 3-4 cm long segment of the Dacron graft. A side arm for arterial cannulation could be sutured beforehand to shorten lower body circulatory arrest time, or arterial cannulation can be done following the placement of a purse suture (Video 1).

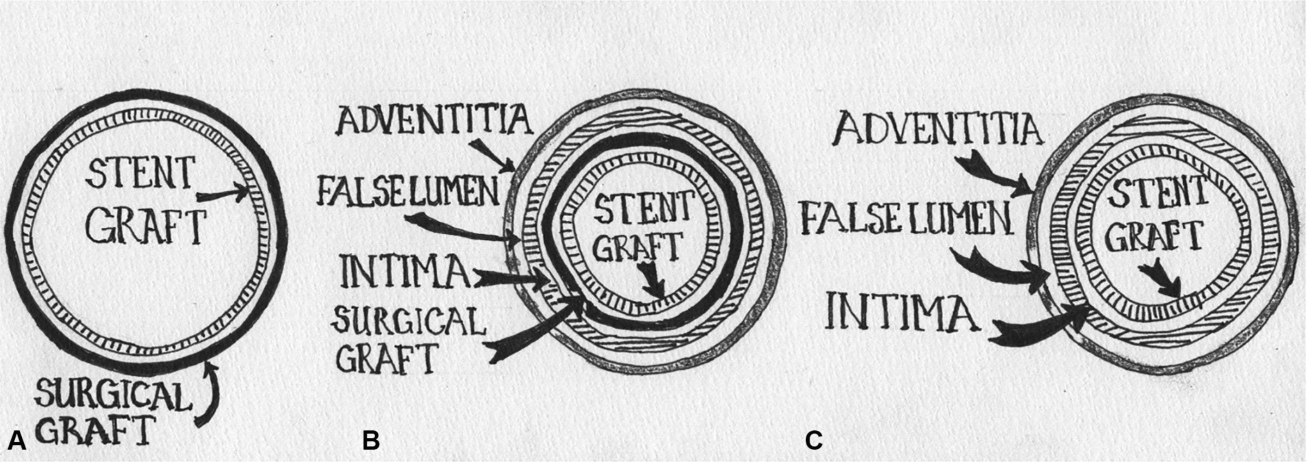

FIGURE E2. Cross sections after completion of TAR. A, Proximal landing zone located in the DAG. B, Proximal landing zone located in CET. C, Endograft inside the distal thoracic aorta, which expands true lumen and covers distally located re-entries. *TAR*, Total aortic arch replacement; *DAG*, distal arch graft; *CET*, classic elephant trunk.