Total Aortic Arch Replacement Without Deep Hypothermic Circulatory Arrest In Type A Aortic Dissection: Left Axillary Artery For Arterial Cannulation

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Glossary of Abbreviations

ASCP: Antegrade selective cerebral perfusion

aTAAD: Acute type A aortic dissection

CA: Circulatory arrest

CABG: Coronary artery bypass grafting

CET: Classic elephant trunk

COPD: Chronic obstructive pulmonary disease

COVID-19: Coronavirus disease 19 related pneumonia

CPB: Cardiopulmonary bypass

DAG: Distal arch graft

DHCA: Deep hypothermic circulatory arrest

ECMO: Extra-corporeal membrane oxygenation

FET: Frozen elephant trunk

FL: False Lumen

IA: Innominate artery

LAXA: Left axillary artery

LCCA: Left common carotid artery

LSA: Left subclavian artery
NIRS: Near-infrared spectroscopy

SC: Spinal Cord

SCI: Spinal cord injury

TAR: Total aortic arch replacement

TEVAR: Thoracic endovascular aneurysm repair

TFG: Trifurcated debranching graft

VA: Vertebral Artery

XCI: Cross-clamp
Central Picture Legend: Trifurcated debranching graft and left axillary artery cannulation before debranching
Central Message:

Usage 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 Statement:

As a novel modification of frozen elephant trunk, using a home-made 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.
**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 CPB 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 5-8 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 mins.

**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.

Keywords: Total arch replacement, frozen elephant trunk, type A aortic dissection, circulatory
arrest, deep hypothermia, left axillary artery cannulation
INTRODUCTION

In patients with aTAAD, hemiarch replacement with open distal anastomosis is recommended [1]; however, in the presence of arch tears and aneurysmal dilatation, a more challenging technique, TAR, could be unavoidable. Current TAR techniques require CA, antegrade and/or retrograde cerebral perfusion, prolonged XCI times with concomitant risks of brain and SC injury, organ dysfunctions, and bleeding problems that result in high mortality, morbidity, and re-intervention 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 LAXA for arterial cannulation, which may eliminate the disadvantages mentioned above 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.
MATERIAL AND 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. While the presence of an LSA perfused from 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 TFG. This retrospective, single-center study was approved by the institutional review board of Ankara Etlik City Hospital (Study ID: AESH-EK1-2023-068, approved on April 04, 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 NIRS, bilateral upper extremities and one femoral artery are monitored to yield desired perfusion pressures.

Surgical Technique:

Construction of TFG and DAG with Perfusion Arm:

TFG is constructed from an 8/16 bifurcated dacron graft at back-table and consists of two 8 mm diameter limbs for LAxA (A) and LCCA (B), respectively, and a 16 mm short limb (C) for IA anastomosis while 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 1a).
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). Following median sternotomy, innominate vein, and arch vessels are dissected out. A tunnel is created carefully between infraclavicular fossa and mediastinum, and limb (A) is passed and anastomosed to LAXA end-to-side fashion following systemic heparinization. A 24F arterial cannula is inserted into the perfusion arm (D), and 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 1b).

*Debranching:*

After the commencement of CPB at 32º 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 de-airing, the clamp at limb A is moved to the body of the bifurcated piece to perfuse both LAXA and LCCA (Figure 1c). 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 1d). LSA-arch integrity is maintained until the completion of distal arch anastomosis.
Cardioplectic 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. Cardioplectic arrest and ascending aortic replacement are performed per surgeon’s preference using dacron grafts. In patients requiring root replacement, patient is cooled down to 28º C.

Termination of Cardiac Arrest and Early Reperfusion of Heart:

Following insertion of a 14F 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. Heart is defibrillated if needed, and rest of procedure is 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 3-4 cm part of dacron tube graft is invaginated (inverted) (Supplemental Figure 1), and the folded edge is sutured to the remnant of aortic arch at zone 1 or 0 (Figure 2a). Simultaneously, brain, heart, and lower body are perfused via TFG, root cannula, and LSA, respectively.

Modified 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 to 80 mmHg following completion of distal 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 2b), and a 15 cm standard endograft is advanced down to descending aorta (Figure 2c). Deployment starts in the TL 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 5-8 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 de-airing distal aorta with reverse Trandelenburg 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.

Incorporation of All Grafts:

TFG, distal arch, and ascending aortic grafts were trimmed to achieve a neo-ascending 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 Supplemental Figure 2.
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 mins, respectively. The mean lowest temperature during CPB was 31±1.6 °C, and the mean lower body CA time was 7.2±2.8 mins. One superior mesenteric and three iliac arteries were stented in four patients admitted in early malperfusion phase. In 12 (31.5%) patients, root replacement (David/Bentall) is needed. CABG is added in 8 patients (21%) due to difficulty weaning from CPB or known history of CAD, while ECMO is 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 SCI is encountered in none of patients, while 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, postnate abdominal malperfusion in 1, and late cardiac tamponade in 1 patient. Two of deaths were related to postoperative COVID-19 infection. Elimination of FL without adjunct interventions is documented in 7 surviving patients (Figure 5), while total aortic repair is achieved in 17 (53%) patients using STABILISE 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 brain, SC, and rest of 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]. FET technique demands high technical skills and quickness [4] and is recommended to be performed in high-volume centers [5]. Additionally, 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 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.

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 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 above postulations could explain varying degrees of neurologic impairments if not a major stroke. In line with these assumptions, Pacini et al. 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 [8]. 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 over-perfused areas, both are related to postoperative neurological 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 hypothermia. Although postoperative awakenings of our patients were quite similar with the standard open heart surgery patients, at best, these inferences are hypothesis-generating and require further studies comparing cerebral perfusion strategies. We believe, the above-mentioned circumstances should be blamed in the pathogenesis of stroke and SCI in FET, as well as long endografts.

Compared to 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 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 above mentioned 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 aTAAD patients. 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 et al. [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 to our technique, such as retrograde perfusion related to the obliged femoral cannulation due to initial debranching of IA and need for lower body CA. Whenas, 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 Heart

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

Comparison With FET
There has been increasing adoption of FET technique due to early and long-term advantages. While it simplifies treatment of complex arch disease, lowers mortality [15], and mitigates malperfusion to some extent. Despite reflecting the results of the initial learning curve of a novel technique in a high-risk population being affected by covid-19, our outcomes are comparable, if not better, to results of high-volume centers and registries. Although our 15.7% mortality rate is similar to 17.5% combined mortality rate of two major European high-volume centers [14], our mortality is much lower than in the ARCH registry (24%) [5]. When considering 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 avoidance/minimization of CA probably contribute to the reasonable mortality rate in our study.

FET also 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 like total aortic repair and survival. Our surviving patients with patent FL underwent a combination of planned interventions like second TEVAR extensions down to supra celiac aorta, modified PETTICOAT, and 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 2.5–20% for FET technique [16] and is reported at 10.1% in ARCH registry [5]. SC malperfusion and loss of collateral networks are accepted as the limiting factor for the FET [17], and its risk is reported 8% in E-vita Open
In FET, distal anastomosis is performed using an open-distal technique, causing lower body CA (visceral ischemia) and ASCP times reaching 51.2±16 mins and 90.8±38 mins, respectively, even in high-volume aortic centers [14]. While prolonged ASCP and CA have been shown as predictors of increased mortality and neurological complications [8, 19], we believe the combination of LxA 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 CET*

Inspired by the antegrade endograft deployment technique pioneered by Bavaria et al. [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 4-6 cm long landing zone in surgical grafts to prevent type Ia endoleaks [23]. For this purpose, we preferred creating a short CET 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 neo-ascending aorta inconveniently.

*Total Elimination of Circulatory Arrest:*

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 Technique

Despite numerous advantages stated before, 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. While presence of several anastomoses makes hemostasis an issue, however, all are near 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.

Conclusion

TAR is a demanding surgery, necessitating high-volume centers, and expert surgeons that 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 circulatory arrest if TEVAR is delayed. This technique is also suitable for re-operative 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, yet not the experts in aortic surgery.
ACKNOWLEDGEMENTS:

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REFERENCES


Table 1: Baseline characteristics of patients (n = 38), values are presented as n and (%)

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Table 2: Operative and postoperative characteristics of the study group

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<td>Total Aortic Repair with STABILISE concept</td>
<td>17</td>
<td>53</td>
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Figure 1: Home-made 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.

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 water-tight 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.
a. Achieving a water-tight 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 5-8 minutes.

Figure 3: Incorporation of three 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.

Figure 4: Overall appearance after completion of TAR.

Figure 5: Pre- and post-operative 3d reconstructions of CTAs and intraoperative view after completion of TAR.

Supplemental Figure 1: 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).

Supplemental Figure 2: 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.
Table 1: Baseline characteristics of patients. Values are presented as n and (%).

Table 2: Operative and postoperative characteristics of the study group. Values are presented as n and (%).
Video Legend: Operative video of a patient with aTAAD underwent TAR using LAxA cannulation. The video is recorded from the surgeon`s view.