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Selective cerebral extracorporeal circulation-enhanced total endovascular arch replacement using *in situ* fenestration

In situ fenestrasyon kullanılarak selektif serebral ekstrakorporeal dolaşım desteğinde total endovasküler arkus replasmanı

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ABSTRACT

In this article, we present a newly designed cerebral perfusion technique during the *in situ* fenestration procedure with three covered stent placement in an endovascular total aortic arch repair of a 68-year-old male patient. This technique enables the endovascular repair of the ascending aorta and aortic arch pathologies with commonly available thoracic aorta stent grafts in a safer and more effective manner.

Keywords: Aortic arch repair, cardiopulmonary baypas, cerebral perfusion, endovascular repair, in situ needle fenestration.

ÖZ

Bu çalışmada, 68 yaşında bir erkek hastanın total endovasküler aortik ark onarımında *in situ* fenestrasyon işlemi ile üçlü kaplı stent yerleştirilmesi sırasında yeni tasarlanmış serebral perfüzyon tekniği sunuldu. Bu teknik, aortik ark ve çıkan aort patolojilerinin yaygın olarak elde edilebilen torasik aorta stent greftleri ile güvenli ve etkin bir şekilde endovasküler onarımını mümkün kılmaktadır.

Anahtar sözcükler: Arkus aort onarımı, kardiyopulmoner baypas, serebral perfüzyon, endovasküler onarım, *in situ* iğne ile fenestrasyon.

Total arch surgery is the gold standard procedure for the repair of entry tear and false lumen-related complications in patients previously operated for acute type A aortic dissections.[1-3] Although satisfactory outcomes have been described with acceptable survival rates for this complex surgery, it may be difficult to perform in frail patients due to the extremely invasive nature of the arch surgery and the considerable adverse event rates.[4,5] This kind of aortic pathologies in an endovascular manner poses another complex challenge, and also commercially unavailable devices in our region further complicate the issue.

In recent years, stent graft replacement techniques for arch pathologies have evolved, and debranching thoracic endovascular aortic repair interventions, additional modifications with chimney technique, and fenestrated stent grafts may be potentially used in the aortic arch region pathologies.[6]

In this study, we suggested a newly designed selective cerebral perfusion enhanced total endovascular arch replacement technique with the use of *in situ* fenestration for the repair of residual aortic pathology after the repair of type A aortic dissection.

SURGICAL TECHNIQUE

A 68-year-old male was operated on for type A dissection. The patient had a prior operation with the Bentall procedure with a biologic aortic valve. At the 12-month follow-up, computed tomography (CT) revealed residual dissection of the aortic arch and proximal descending aorta after the replacement of the ascending aorta for the type A acute aortic dissection. The false lumen was patent along the aortic arch and descending artery, and the false lumen diameter had increased.

After explaining the advantages and disadvantages of an open frozen elephant trunk operation or a total debranching procedure as an option to the patient, the patient strongly preferred endovascular therapy. After the sessions between the cardiovascular surgery

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clinic, perfusion team, and anesthesiology department, selective cerebral extracorporeal circulation-enhanced total endovascular arch replacement using *in situ* fenestration technique was planned.

The patient's history and medical examination reports were thoroughly reviewed along with cardiac and pulmonary function from a multistep preoperative assessment. All informative intraoperative decisions concerning surgical technique and patient management were assessed.[7,8] The patient's CT angiography scans were reviewed to define the extensive pathology, size, and the branches of the aortic arch (Figures 1a, b).

The patient was placed in a supine position, and under general anesthesia, a 14-gauge (G) needle was inserted into the lumbar interspaces L3-L4 or L4-L5, and a cerebrospinal fluid catheter was advanced until the cerebrospinal fluid was obtained. The cerebrospinal fluid pressure was monitored during the operation to achieve the target pressure <15 mmHg. A rapid pacing diode was inserted into the right ventricle via the right internal jugular vein for the quick maneuver of the thoracic graft movements. Transesophageal echocardiography was placed to ensure the precise deployment of the stent graft and examine the interaction between the aortic valve bioprosthesis and the guidewire (Figures 2a, b). To the patient's forehead position, diodes for near-infrared spectroscopy INVOS 5100C (Somanetics, Troy, MI, USA) were attached bilaterally for screening the regional oxygen saturation.

Perfusion strategy

Bilateral femoral arteries, right axillary artery, left brachial artery, and bilateral carotid arteries were exposed via cutdown. Between the left carotid artery and left subclavian artery, using an 8-mm Dacron graft, caroticosubclavian bypass was established, and an additional 8-mm tubular graft was interpositioned into the former graft for antegrade perfusion of the left subclavian and left common carotid artery during the endovascular procedure. The aim of the caroticosubclavian bypass was to achieve the perfusion of the two arteries and preserve the flow in case of a worse scenario that might occur during the fenestration procedure. A 20-French (Fr) venous cannula was inserted from the right femoral vein to the right atrium. A 16-Fr arterial cannula was implanted into the right axilary artery, and an additional 16-Fr arterial cannula was placed into the 8-mm additional Dacron graft for the left carotid artery and left subclavian artery perfusion. The target activated clotting time was >350 sec. The flow rate was set at 10 mL/kg/min with the use of an independent roller pump, and the flow ratio for the innominate artery and the implanted graft divided into the left common carotid artery and the left subclavian artery was 3:2. The circuit pressure was established at 100 to 150 mmHg, and the perfusion blood temperature was maintained at 34°C. The detailed scheme of the perfusion technique is demonstrated in Figure 3 and 4.

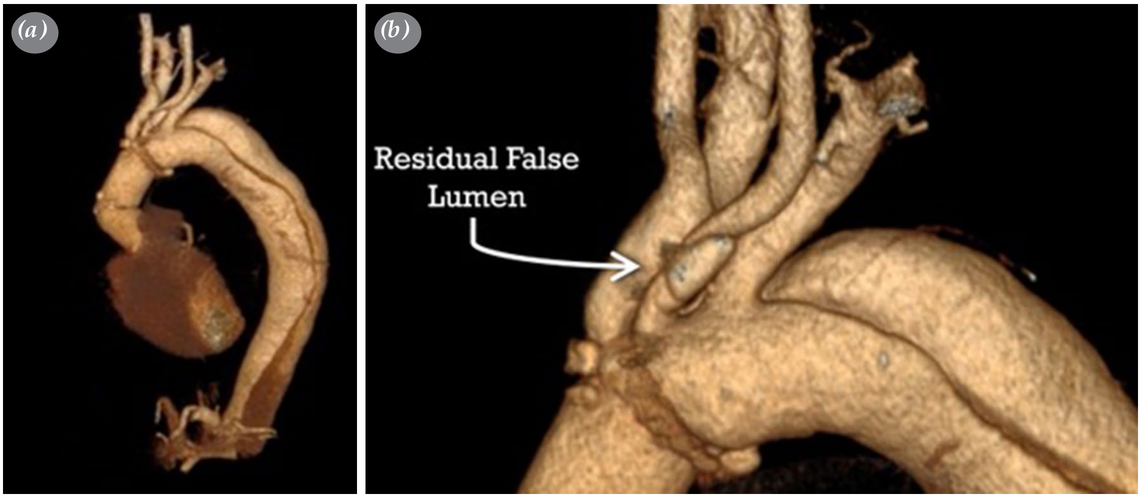

Figure 1. Preoperative computed tomographic images of the patient. **(a)** Three dimensional rendered images of the dissected aortic arch, and **(b)** three-dimensional sequence demonstrating a residual patent false lumen in the aortic arch with branch vessels.

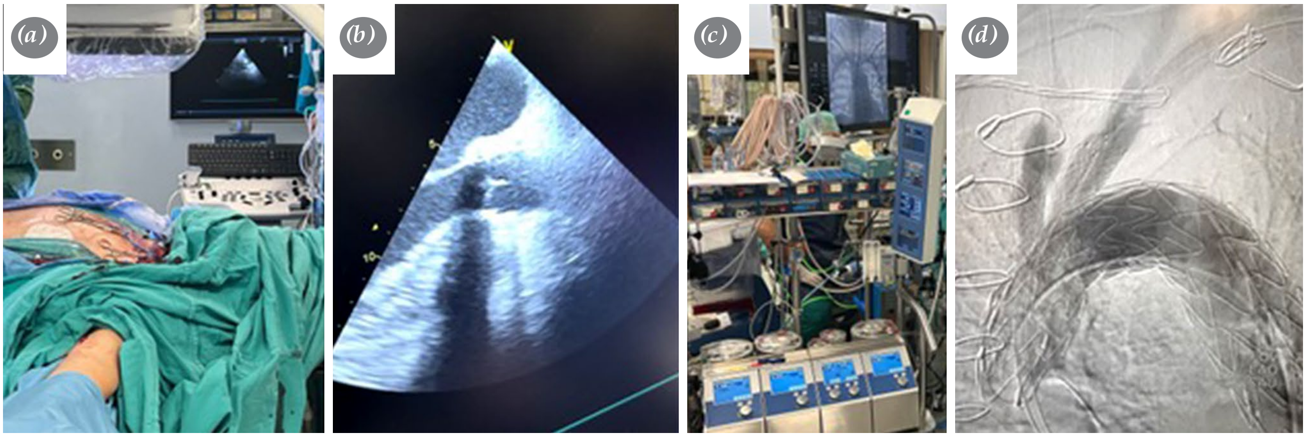

Figure 2. Operative details. **(a, b)** Transesophageal echocardiography was placed preoperatively and helped physicians the precise deployment period; the tip of the stent graft delivery kit was advanced through the aortic valve into the left ventricle. **(c)** Extracorporeal circulation for selective cerebral bypass machines. **(d)** Angiogram during the procedure is demonstrated.

Total endovascular aortic arch *in situ* fenestration technique

For the deployment of the stent graft into the prior attached anastomosed graft, a guidewire was placed in the left ventricle as in a standard transfemoral aortic valve replacement (Figure 2a). In the case of a mechanical aortic valve prosthesis, the use of the aortic arch endovascular stent grafts is not recommended since the guidewire and the nose cone of the delivery system could interfere with and potentially cause harm to metallic valve leaflets (Figure 2b). Device selection was made according to the aortic arch anatomy and the clinical profile of the patient. Due to the lack of regional supply for this kind of device, we used a 32×32×200-mm thoracic stent graft to seal the ascending aorta (Ankura; Lifetech Scientific, Shenzhen, China). The delivery system of the device was tracked into place by advancing the tip of the graft through the aortic valve into the left ventricle. Once the device was in position, rapid pacing was initiated, and selective cerebral extracorporeal circulation was started at a flow rate of 1 L/min. The stent graft was deployed, and the rapid pacing was stopped.

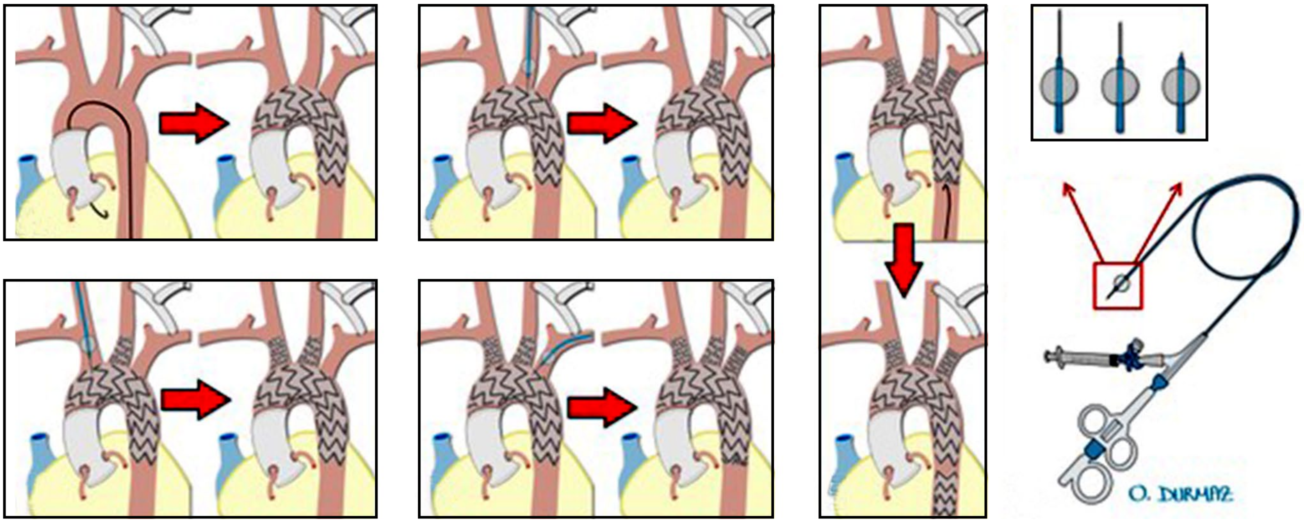

Figure 3. Operative details of the *in situ* fenestration. **(a)** Stent graft was positioned into the tubular graft. **(b)** Left common carotid artery fenestration under selective cerebral perfusion. **(c)** Right brachiocephalic artery fenestration technique via right common carotid artery. **(d)** Left subclavian artery *in situ* fenestration. **(e)** Additional thoracic aortic graft deployment. **(f)** *In situ* fenestration puncture tool kit.

Immediately after, the nose cone of the delivery system was retrieved and positioned at the distal end of the endograft. For the aim of creating *in situ* fenestration under the assistance of bilateral cerebral perfusion, the branches were cannulated from above (Figure 3). First, the left common carotid artery was punctured by Seldinger's method using an 8-Fr vascular introducer, followed by the insertion of a puncture needle system (FuThrough; Lifetech Scientific, Shenzhen, China) consisting of a self-centering balloon catheter equipped with a 20-G needle that is adjustable in length through the sheath of the left carotid artery (Figure 3a). After pushing the trigger of the puncture needle, *in situ* fenestration was created. The V-18 Guidewire (ControlWire® Guidewire, Boston Scientific, NJ, USA) was progressively, advanced into the fenestration and gently dilated using 4- to 8-mm noncompliant balloons. For finalizing this step, the dilated hole was bridged with an expandable 7×37-mm chrome-cobalt-ePTFE (expanded polytetrafluoroethylene) balloon stent graft (BeGraft; Bentley, Hechingen, Germany) possibly deployed antegrade up to 5 mm inside the fenestration (Figure 3b). Afterward, the right carotid artery was punctured via a 9-Fr sheath. The Futhrough puncture system (FuThrough™; Lifetech Scientific, Shenzen, China) was placed after the succesful puncture of the main body stent graft. After the stepwise dilatation of the puncture hole, a 12×39-mm chrome-cobalt-ePTFE stent graft (BeGraft-Bentley; Hechingen, Germany) was implanted (Figure 3c). The sealing zone in the innominate artery should be >20 mm in length and >20 mm in diameter for precise sealing. For the third fenestration of the thoracic stent graft at the left subclavian artery, an 8-Fr steerable sheath (Fustar;

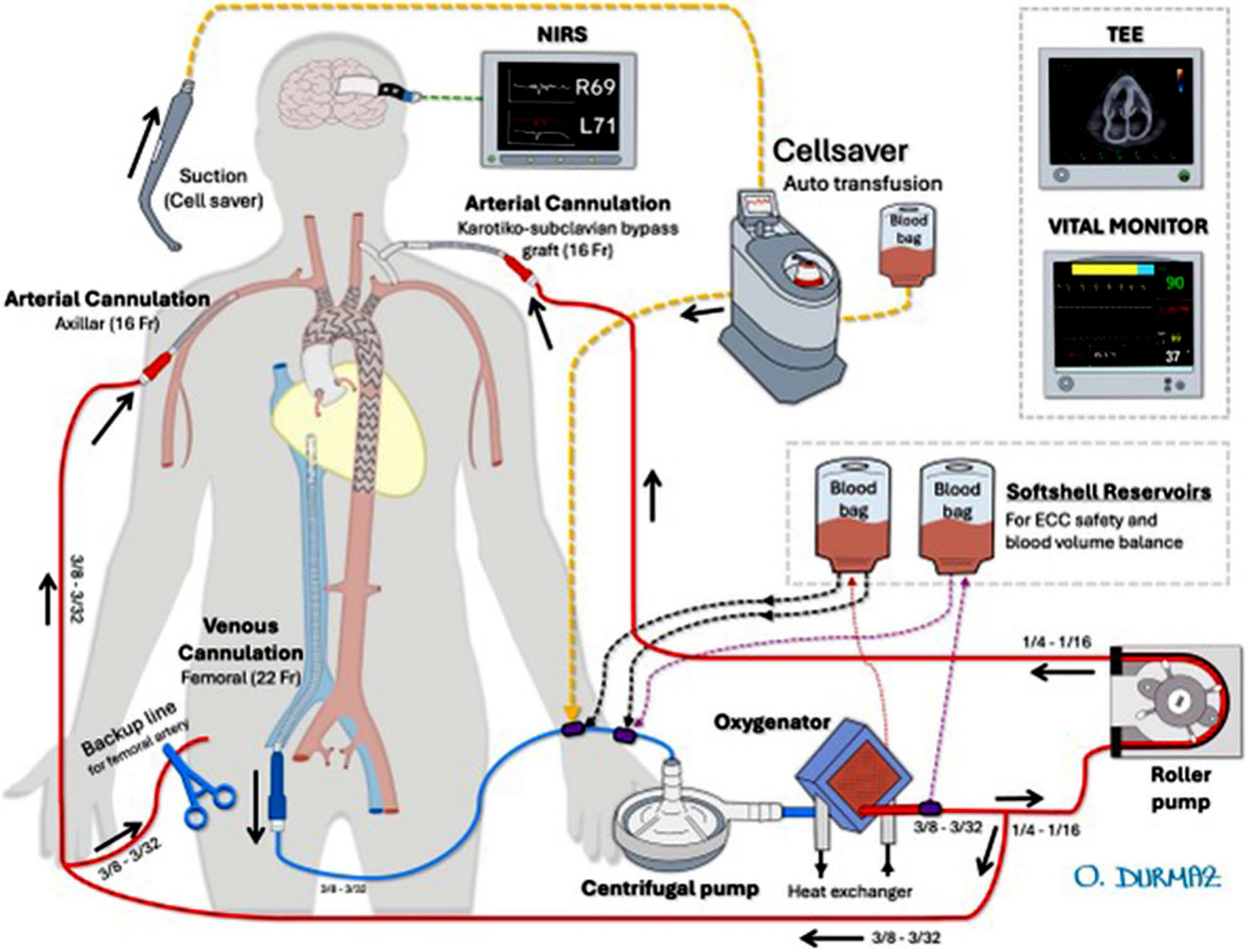

Figure 4. Details of selective cerebral bypass circuit configuration.

Lifetech Scientific, Shenzhen, China) was inserted through the left brachial artery surgical cutdown to be placed as perpendicular as possible to the greater curvature of the aortic arch, considerable in direct contact with the outer curvature of the endograft (Figure 3d). After the creation of the fenestration, a 0.018 guidewire was then advanced into the ascending aorta, and the hole was dilated using noncompliant balloons 4 to 10 mm in diameter. A 10×37-mm chrome-cobalt-ePTFE stent graft (BeGraft; Bentley, Hechingen, Germany) was implanted. Stable branch reconstructions were confirmed with digital substraction angiography (Figures 3e, f), (Figure 5). After smooth bilateral carotid and vertebral blood flow were achieved, selective cerebral extracorporeal circulation was slowly downregulated, and the whole procedure ensured that the near-infrared levels were satisfactory. Selective cerebral extracorporeal circulation was stopped. Aortography was performed, and an additional stent graft was considered for the reentry flow at the level of mid-thoracic aorta level above the visceral arteries. An

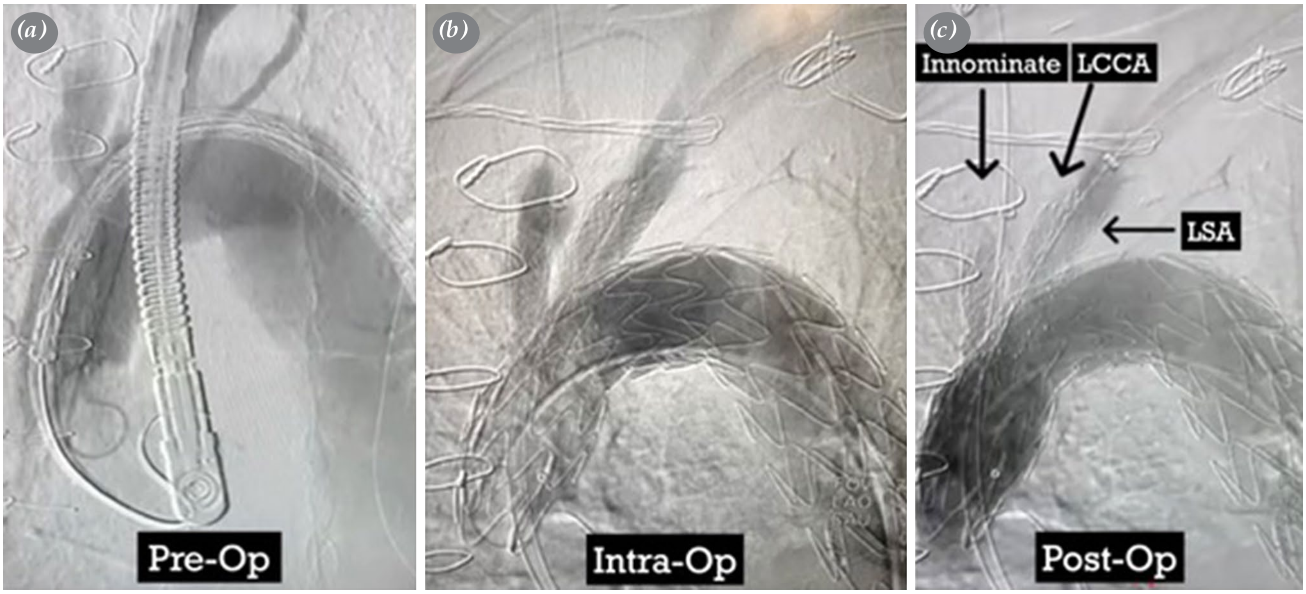

Figure 5. Final angiogram presenting the thoracic stent positioned in the previously placed tubular graft, with triple *in situ* fenestration by covered stents to the brachiocephalic trunk, left carotid artery, and left subclavian artery.

Figure 6. Computed tomography images one week after the procedure. **(a)** A three-dimensional reconstruction of the aortic arch with triple stents in the brachiocephalic trunk, left carotid artery, and left subclavian artery. **(b)** Rendered image sequences clearly demonstrate the configuration of the three covered stents, **(c)** The patient’s incision lines after the operation.

additional 34×34×160-mm tapered thoracic graft (Ankura; Lifetech Scientific, Shenzhen, China) was deployed. The control angiography following endovascular total arch repair with the use of *in situ* fenestration demonstrated a satisfactory visualization of all the arch branches without any endoleaks (Figure 5). The dissection was entirely isolated, and the contrast media could be observed in the arch branch vessels. Following the termination of extracorporeal circulation, caroticosubclavian bypass graft was removed, and the incisions were closed. The operative time was 302 min, and the extracorporeal circulation time was 42 min. The patient was returned to the intensive care unit and awoke after 1 h. The patient was extubated 2 h later, and the intensive care unit stay was 34 h. Six days later, the patient was discharged, and the CT scan before discharge demonstrated that the blood vessels were in good condition (Figure 6).

DISCUSSION

The primary objective of the operative strategy in acute Stanford type A aortic dissection is to repair the aorta to avoid a life-threatening rupture and establish the blood flow into the true aortic lumen.[9] In approximately 70% of patients, dissection involves the aortic arch.[1,10] Due to the presence of an entry tear within the aortic arch, total aortic arch replacement is indicated.[1,2,9] The early results verified that endovascular stent grafting of the aortic arch in precisely selected patients with residual dissection after acute type A aortic dissection repair may be feasible and safe.[11,12] Although it should always be assumed that open surgery is still the first recommended therapy, endovascular interventions could be considered due to the clinical and technical properties of high-risk patients.[13]

The first report of *in situ* fenestration thoracic stent graft repair by the support of temporary bypass (aim of cerebral protection from the left femoral artery to the bilateral carotid arteries) was made by Sonesson et al.[14] In their technical note, they used a shunt system including a Medtronic Biomedicus centrifugal pump. They used 6-Fr introducers for carotid artery perfusion. Their particular case promised a potential for arch vessel repair. Furthermore, Katada et al.[5] presented a case series including arch aneurysms and chronic type A dissection in nine patients. They planned an endovascular total aortic arch repair procedure design with *in situ* fenestration via cardiopulmonary bypass. In their cardiopulmonary system, a 14-Fr axillary artery route and a 6-Fr brachial artery route were used for perfusion support. Katada et al.[5] did not prefer selective cerebral perfusion; however, they suggested left subclavian artery transposition into the common carotid artery during the perfusion support via bilateral axillary and brachial artery support. They presented two stroke events, and *in situ* fenestration was successful in six of seven patients. They used a percutaneous transhepatic cholangiography needle. In our suggested method, open surgical intervention for all cannulation and *in situ* fenestration sites may have an advantage for this kind of anatomical difficulties. Preferred cerebral perfusion modification is an important issue as most of these patients with aortic pathologies also have diseased cerebrovascular vessels. Computed tomography scans reveal that two-side approaches, such as brachial-axillary or bilateral carotid, may not establish sufficient perfusion of the brain.[15] Moreover, the integrity of the Willis circuit does not frequently have sufficient capacity for perfusing the contralateral hemisphere. We preferred to modify the cerebral perfusion modality for all cerebrovascular vessels including vertebral arteries. We believe this modification also enforces the perfusion of the whole brain during the *in situ* fenestration intervention period. There is a lack of consensus on whether uni- or bilateral cerebral perfusion techniques provide superior hemispheric flow for aortic arch operations.[15] Minimized extracorporeal circulation could be an alternative with the advantageous effect of reduced hemodilution and shortening of tubing length. On the other hand, embolic load might be higher. This issue led us to use a modified conventional circulation modality. Nevertheless, cardiopulmonary extracorporeal circuit establishes a viable support for arch surgery; minimal invasive approaches may cause us to forget our baseline strategies in the endovascular era.

In conclusion, the background knowledge of open surgery for the aortic arch and the aim to apply it in a high-risk condition for an endovascular approach were combined in this study. Using venoarterial extracorporeal circulation with separated circuits via roller heads for selective cerebral perfusion supported us in facilitating the endovascular total arch replacement during the whole fenestration period of the operation. In this modified method, *in situ* fenestration period was well tolerated, and the physicians felt comfortable without concern of bihemispheric flow continuity.

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Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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