ELSEVIER

Case Report

In-Situ Fenestration of a PTFE Thoracic Aortic Stent Graft for Delayed Left Subclavian Artery Revascularization Following Frozen Elephant Trunk Repair of Type A Aortic Dissection

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Left subclavian artery revascularization during endovascular repair of aortic dissection is often accomplished by left carotid-subclavian artery bypass or transposition. In situ fenestration of thoracic stent grafts provides an alternative method of revascularization without manipulation of the left carotid artery. We describe a case whereby in situ laser fenestration, combined with catheter-directed thrombectomy, was utilized to revascularize a thrombosed left subclavian artery following a frozen elephant trunk repair of type A aortic dissection. A 75-year-old male presented with pericardial tamponade and aortic insufficiency, secondary to type A aortic dissection. Patient underwent an emergent replacement of the aortic root, valve, arch, and ascending aorta in the frozen elephant trunk configuration. The innominate and left carotid arteries were revascularized with a bifurcated bypass graft from the ascending aortic graft. The left subclavian artery (LSCA) was covered with an antegrade deployment of a cTAG stent graft. During the immediate postoperative period, the patient was found to have a dissection of the left common carotid artery (LCCA) and pseudoaneurysm of the bypass graft anastomosis. The left carotid artery was replaced up to the proximal internal carotid. During rehabilitation, the patient developed left subclavian steal syndrome, with a CT angiography demonstrating thrombosis of the subclavian origin, and duplex ultrasound showing a reversal of the left vertebral flow. In order to revascularize the left subclavian artery without using the left carotid as the inflow, the in situ laser fenestration technique was planned. The vertebral artery origin was protected with a neuroclip through a supraclavicular incision. Through a brachial artery cutdown, a 9Fr flex sheath was positioned at the origin of the subclavian artery. A suction thrombectomy catheter was used to create a central channel in the thrombus. A 0.035″ 3.2 mm over-the-wire laser atherectomy catheter was used to create a fenestration through the cTAG stent graft. The subclavian branch stent was stented with an iCast balloon-expandable covered stent, excluding the mural thrombus. The patient recovered well with resolution of symptoms and was discharged home. Postoperative CT scan showed patent left subclavian branch stent and no endoleak across the fenestration of the aortic stent graft. Delayed laser in situ fenestration of a PTFE stent graft can be performed safely. The vertebral artery protection and catheter-directed thrombectomy are important adjuncts to reduce the risk of posterior stroke.

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Threshold for left subclavian artery (LSCA) revascularization during endovascular or open thoracic aortic repair remains heterogeneous among practices, varying from aggressive prophylactic staged or concomitant revascularization, to selective revascularization determined by clinical sequelae of LSCA coverage. While LSCA supplies the cerebral and spinal cord circulation via the vertebrobasilar pathway, the dual nature of vertebrobasilar system combined with lack of level 1 data supporting obligatory revascularization, has led many to adopt the approach of selective revascularization of LSCA following emergent thoracic endovascular aortic repair (TEVAR) requiring LSCA coverage.[1–4] In open arch reconstructions in the frozen elephant trunk procedure, the patient anatomy often makes the strategy of initial coverage of the left subclavian artery origin safer, as the left subclavian origin can be more challenging to expose from median sternotomy.[5–7]

When LSCA coverage results in a clinically significant left arm or vertebral insufficiency, LCSA revascularization is required. Traditional LCSA revascularization techniques involve using left common carotid as the inflow artery to perform a left subclavian transposition onto the left common carotid, or left common carotid to subclavian artery bypass grafting.[8]

More recently, in situ fenestration techniques have been described using a needle puncture or energy mediated systems, such as laser or radiofrequency ablation probes, to create fenestrated branched thoracic stent graft at the time of initial transfemoral TEVAR.[9,10] Reports suggest high technical success with satisfactory short and mid-term patency.[10–14]

In this article, we report a case where laser in situ fenestration technique was utilized in conjunction with catheter-directed mechanical thrombectomy to achieve delayed revascularization of LSCA, following emergent frozen elephant trunk reconstruction of type A aortic dissection.

CASE REPORT

A 75-year-old male presented with an acute onset of sharp chest pain. Stanford type A aortic dissection was diagnosed on the computed tomography angiography (CTA), with the dissection extending from the aortic root, down to the right external iliac artery and left common iliac artery (Fig. 1). The patient also had pericardial effusion and aortic regurgitation, necessitating an emergent aortic root and arch replacement with frozen elephant trunk procedure, with distal aortic anastomosis proximal to LSCA, followed by an antegrade deployment of 37 × 15 mm cTAG thoracic endograft (Gore and Associates, Flagstaff, AZ), covering LCSA. Innominate artery (IA) and left common carotid artery (LCCA) were bypassed from ascending aorta with a bifurcated Hemashield graft (MAQUET Holding B.V. & Co. KG, Rastatt, Germany). The distal end-to-end anastomosis of 12 mm limb was performed to IA and 8 mm limb to an intrathoracic segment of LCCA (Fig. 2).

On postoperative day 6, the patient developed altered mental status. The patient had palpable left carotid pulses; however, CTA revealed a pseudoaneurysm of the LCCA bypass and a dissection distally extending to the proximal internal carotid artery (ICA), causing severe compression of the true lumen and flow limitation to the left ICA (Fig. 3). This long segment of left carotid pseudoaneurysm and dissection was repaired using a hybrid approach. The left carotid bifurcation was exposed with a standard carotid endarterectomy incision, and an 8 mm Dacron interposition graft was placed from the cervical portion of the proximal LCCA to the left proximal undissected segment of the ICA. The external carotid artery (ECA) had robust back bleeding, from cross facial collaterals. Rather than reimplanting or bypassing to the ECA from the interposition graft, a simple ligation was performed. Then, a 7 mm × 10 cm Viabahn self-expanding covered stent (Gore and Associates, Flagstaff, AZ) was introduced retrograde from the cervical exposure. It was deployed across the pseudoaneurysm, bridging the intrathoracic bypass graft to the cervical interposition graft (Fig. 4).

Following the carotid repair, altered mental status resolved. However, as the patient continued recovery and physical therapy progressed, he started experiencing significant lightheadedness and left upper extremity weakness during left arm exercises. Duplex ultrasound showed a reversal of blood flow in the left vertebral artery (LVA), consistent with subclavian steal syndrome.

While LSCA revascularization was indicated, LCCA was no longer an optimal inflow source, as the proximal segment of LCCA had been replaced with a graft, then re-lined with a covered stent. Therefore, a decision was made to perform in situ fenestration of the thoracic stent graft across the LSCA origin. A supraclavicular incision was made to protect the LVA with a neuroclip (Fig. 5A). Through the left brachial artery access, the subacute thrombus in the proximal LSCA was removed with an Indigo thrombectomy catheter (Penumbra, Alameda, CA) (Fig. 5B, C). With the support of a 7Fr Tourguide steerable sheath (Medtronic,

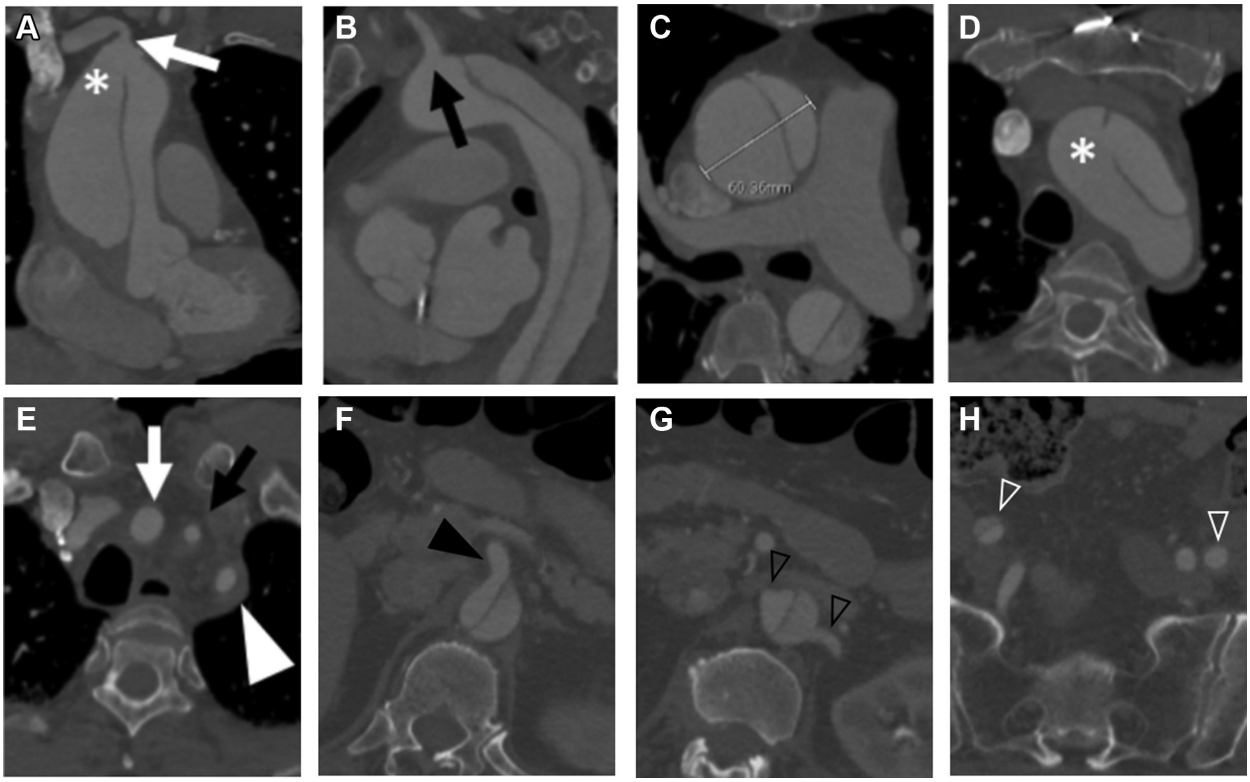

Fig. 1. CTA at presentation showing **(A)** Innominate origin, *white arrow*; **(B)** LCCA, *black arrow*; **(C)** dissection in the aneurysmal ascending aorta; **(D)** proximal entry tear at the level of the innominate origin, *white asterisk*; **(E)** undissected aortic arch branches, LSA, *white arrowhead*; **(F)** SMA supplied by the true lumen, **(G)** right renal, *black triangle*, supplied by the true lumen, left renal, *black triangle*, by the false; **(H)** right external iliac artery was dissected, *white triangle*. *white arrow*, IA; *black arrow*, LCCA; *white arrowhead*, LSA; *white asterisk*, entry tear; *black arrowhead*, SMA; *white triangles*, right and left external iliac arteries; *black triangles*, right and left renal arteries.

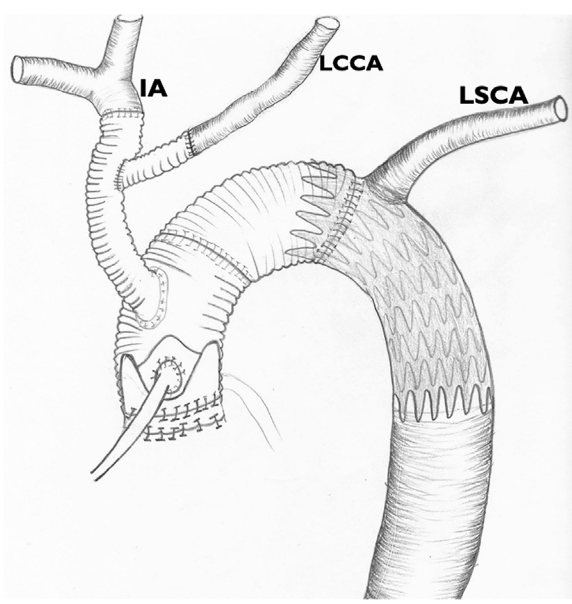

Fig. 2. Frozen elephant trunk with replacement of aortic valve, ascending aorta and aortic arch, bypass grafts to IA and LCCA.

Minneapolis, MN), a 2.3 mm 0.035 laser atherectomy probe (Spectranetics, Colorado Springs, CO) was advanced through the thrombus to reach the thoracic stent graft. While maintaining a perpendicular orientation of the laser probe to the thoracic stent graft, gentle forward pressure was applied with the activation of laser, until the fabric was penetrated (Fig. 5D). A 0.035 wire was advanced into the descending thoracic aorta through the laser catheter. The fenestration was dilated with a 4 mm noncutting angioplasty balloon and a balloon-expandable 9 × 38 mm iCast covered stent (Atrium, Hudson, NH) was placed across the fenestration into LSCA with subsequent balloon flaring of the proximal end (Fig. 5E). Selective angiography showed no evidence of residual thrombus, and the LVA protection clip was released. Completion imaging demonstrated an antegrade flow through the LCSA and LVA, with no evidence of stenosis or endoleak (Figs. 5F and 6). Postoperatively, the patient had a return of left radial pulse and a complete resolution of dizziness and LUE weakness.

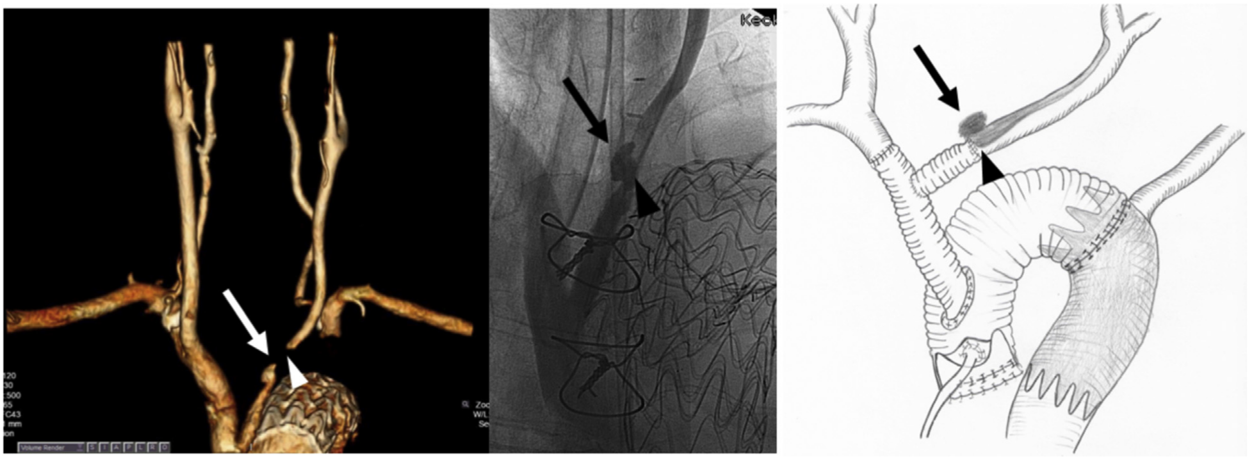

Fig. 3. Anastomotic pseudoaneurysm and L carotid dissection *arrow*, anastomotic pseudoaneurysm; *arrowhead*, LCCA dissection and stenosis.

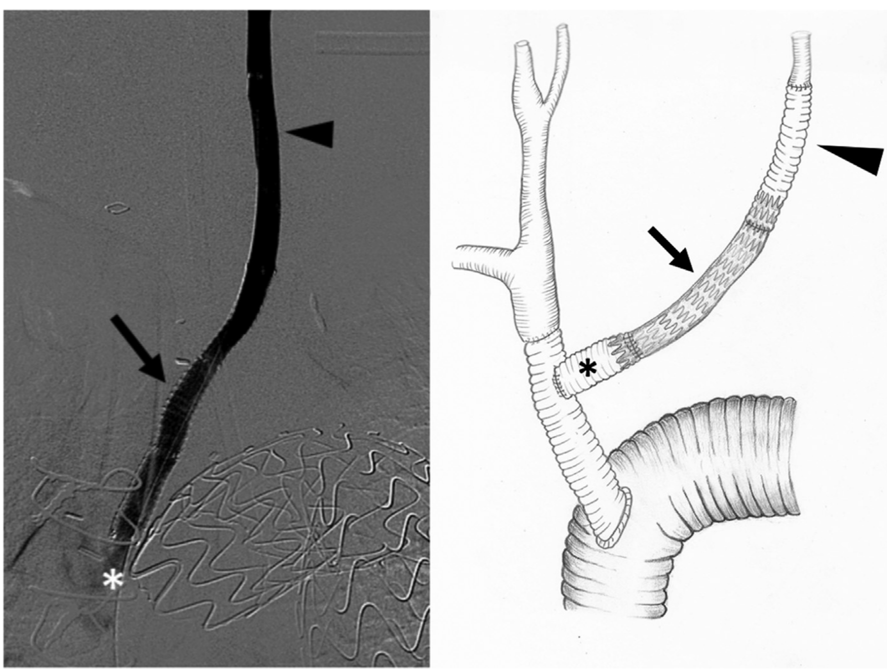

Fig. 4. Hybrid repair of the left carotid artery *arrow*, bridging stent; *arrowhead*, distal graft; *asterisk*, proximal graft.

The patient continued rehabilitation and was discharged home on postoperative day 36.

DISCUSSION

In the absence of strong indications for LSCA flow preservation, such as previous coronary bypass using left internal mammary to left anterior descending artery, left dominant vertebral artery, left vertebral artery terminating as posterior inferior cerebellar artery, or previous left arm fistula creation, there is no consensus regarding the management of LSCA flow during emergent open or endovascular aortic arch repair.[3,4] This is due to the lack of randomized controlled trials directly comparing routine and selective revascularization of LSCA. A variety of revascularization options regarding techniques (cervical versus sternotomy; bypass versus transposition) and timing (staged versus concomitant; before versus after aortic reconstruction) make determination of the optimal approach difficult. The Society of Vascular Surgery practice guideline recommending routine LSCA revascularization in all elective TEVAR

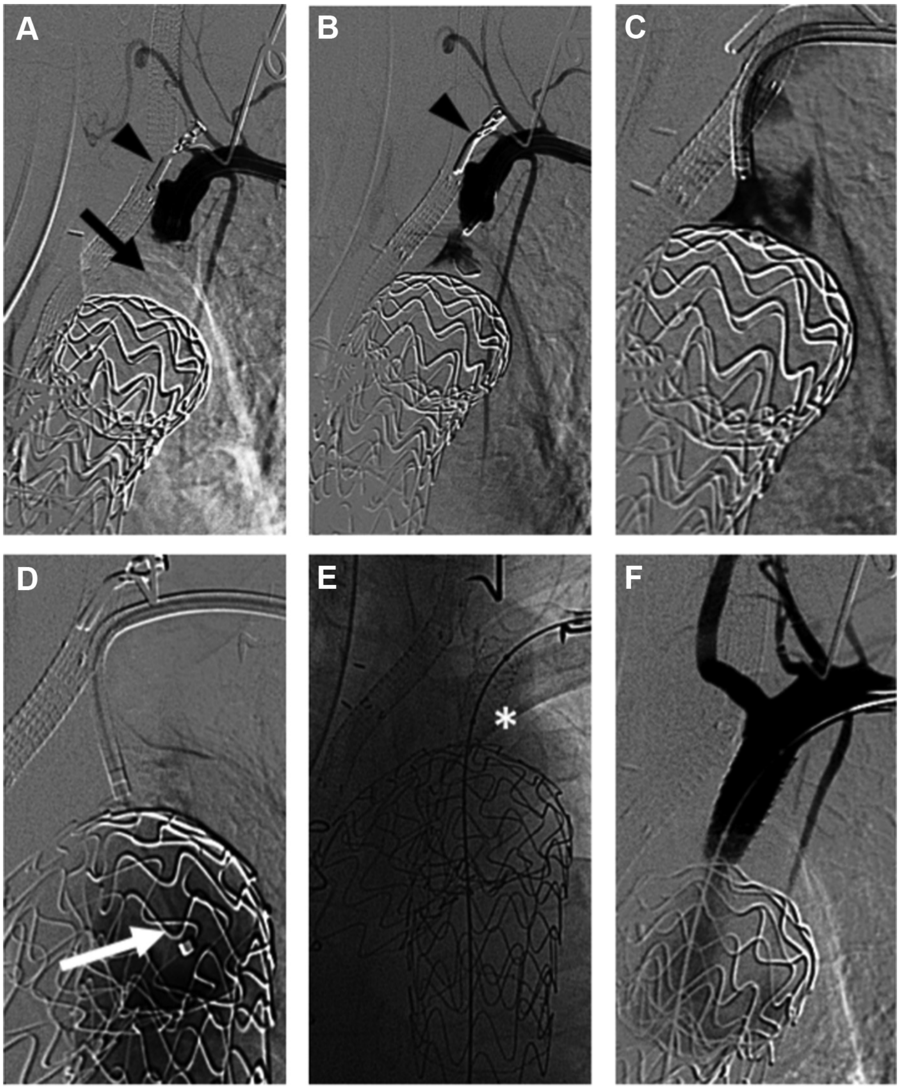

Fig. 5. **(A)** LVA protection with a Yasargil neuroclip (*black arrowhead*) and thrombus in proximal LSCA (*black arrow*), **(B, C)** catheter thrombectomy, **(D)** laser probe in the stent graft lumen (*white arrow*) through the steerable sheath, **(E)** guide wire and iCast stentgraft (*asterisk*), **(F)** Completion angiography with Yasargil neuroclip removed.

was based on the results of a systematic review suggesting that coverage of LSCA without revascularization is associated with a significantly higher rate of arm and vertebrobasilar ischemia and a trend toward, albeit statistically nonsignificant, a higher rate of anterior circulation stroke, and spinal cord ischemia.[1,2] A recent Cochrane review compared outcomes of LSCA revascularization with coverage in TEVAR patients, concluding that additional procedures for LSCA revascularization were not associated with significantly increased risk of stroke, spinal cord ischemia or mortality, but it was underpowered to draw definitive conclusions regarding the benefit of LSCA revascularization for upper extremity ischemia.[3] Therefore, the optimal treatment strategy remains controversial.[4] In some centers, prophylactic staged or concomitant LSCA revascularization is a part of the standard protocol during the index TEVAR,[15,16] whereas others advocate selective LSCA revascularization only in symptomatic patients.[17]

Reconstruction of LSCA in open aortic arch reconstruction can be just as variable. Frozen elephant trunk method, commonly used to treat type A aortic dissections, combines an open reconstruction of the ascending aorta, as well as the arch, with a deployment of the stent graft under circulatory arrest. Since the initial elephant trunk

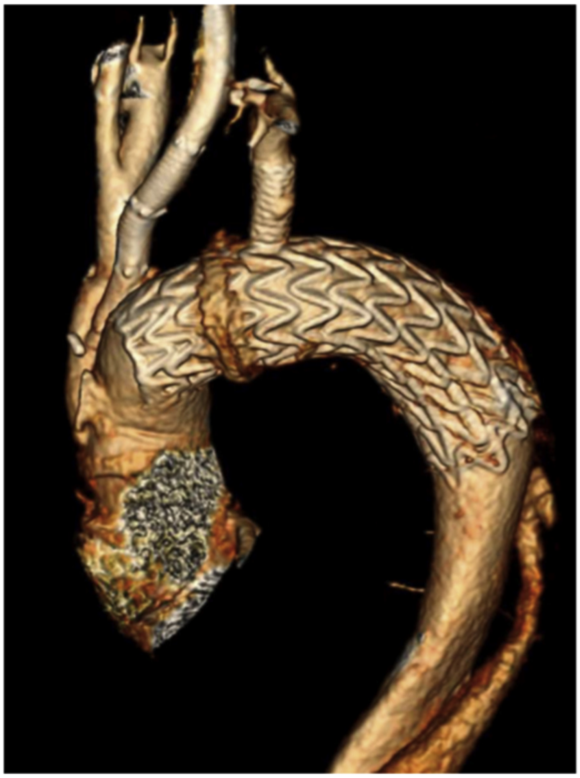

Fig. 6. 3D reconstruction of LCCA hybrid repair and LSCA in situ laser fenestration with branch stenting.

technique reported by Borst et al., a number of technical variations have been reported, particularly in the configuration of arch branch vessel reconstructions.[5–7,18,19] While the reimplantation or bypass grafting to the supra-aortic trunk vessels can be performed during the arch reconstruction, the patient anatomy can make exposure and revascularization of LSCA challenging with the median sternotomy approach.[5–7] In the absence of the above-mentioned indications for LSCA preservation, LSCA ligation or coverage with arch repair can be a safer option. Following LSCA coverage during open arch repair or TEVAR, the most common technique for LSCA revascularization is using LCCA as the inflow source through the cervical approach,[8] but in situations where LCCA cannot be used, in situ fenestration of thoracic stent-graft can be a useful alternative technique.

The first report of in situ fenestration of thoracic stent graft was using a needle puncture technique for the LSCA revascularization.[13] In their report, a sheath was introduced directly into the LSCA via a supraclavicular incision and advanced toward the aortic arch to touch the stent graft. A spinal needle was used to penetrate the graft fabric, followed by a dilation of the fenestration with a balloon.[13] The subsequent in-vitro study raised a concern that a needle or wire puncture technique can result in fabric tear, increasing the risk of future type 3 endoleak. Compared to needle fenestration of stent grafts, laser preserves the integrity of the fenestration edges and results in lesser fabric tears after balloon dilation. Endograft fabrics were tested in vitro trials for both needle penetration and balloon dilation, as well as laser penetration, with 3–5 sec of application of laser energy (45 mJ/mm^2 fluence at a rate of 25 pulses per second). Laser usually results in 2.5–3 mm fenestrations and has clean and sealed fenestration edges that were stable after the application of a balloon.[10,20] Laser fenestration was mostly tested for polyester thoracic grafts. While there are theoretical chemical concerns of laser-induced toxic substance formation upon interaction with polytetrafluoroethylene graft material, the clinical significance of this remains unclear.[9] As such, we carefully protected the left vertebral artery during our case, and the patient remains free of complications from laser fenestration of the PTFE graft.

Reports of in situ fenestration show satisfactory short to midterm durability.[10–14] Some technical issues can arise due to type 3 aortic arch anatomy, as well as LSCA tortuosity and angulation. Technical tips to in situ fenestration include the use of through-and-through wire to straighten out the vessel tortuosity, use of precurved guidewires, and endovascular loop so-called ‘‘Squid capture’’ technique.[21,22] In our case, the angle of the LSCA origin to the distal aortic arch was near perpendicular, and therefore, no adjunctive technique mentioned above was used. Coverage of LSCA with a stent graft usually results in thrombus formation up to the origin of the vertebral artery. In delayed setting, protection of the vertebral artery and reduction of thrombus burden using suction thrombectomy catheters can be useful in safe in situ fenestration.

CONCLUSION

In situ laser fenestration is a feasible alternative technique for LSCA revascularization after the emergent arch repair, requiring coverage of LSCA, especially when LCCA is not a suitable inflow source for open revascularization. It can be safely performed in a delayed setting with left vertebral artery protection and catheter-directed thrombectomy. Long-term durability, including branch patency, and type 3 endoleak rates associated with in situ laser fenestration, remains to be determined.

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