How I do it: Established and novel methods for left subclavian revascularization with thoracic endovascular aortic repair

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ABSTRACT

Left subclavian artery revascularization at the time of thoracic endovascular aortic repair has been the subject of discussion for over a decade. Contemporary viewpoints suggest that revascularization should be performed where possible to decrease the risk of perioperative stroke, spinal cord ischemia, and, to a lesser degree, loss of upper extremity function. In this article, we present traditional methods as well as descriptions of newer options and technology for preservation of left subclavian artery flow during thoracic endovascular aortic repair. (J Vasc Surg Cases Innov Tech 2024;10:101367.)

keywords: Subclavian artery revascularization; Thoracic branched endoprothesis; Carotid to subclavian bypass; Subclavian transposition; Laser fenestration

Thoracic endovascular aortic repair (TEVAR) has almost entirely supplanted open surgical repair for the majority of aortic pathologies. Type B aortic dissection, thoracic aortic trauma, and aneurysmal disease all frequently require TEVAR positioning in zone 2 of the aorta (at the left carotid artery) or more proximally. Covering the left subclavian artery (LSA) has far more reaching implications than simply reducing the blood flow to the left arm. Left arm ischemia is a very rare complication from coverage of the LSA owing to the rich collateral network around the upper extremity and flow to the left arm is usually maintained by compensatory blood flow through the circle of Willis in the brain, with reversal of flow down the left vertebral artery into the arm.[1] More common, however, is the serious and feared complication of spinal cord ischemia with resultant paraparesis or even permanent paraplegia.[2] The LSA is an important route of collateral blood supply to the spinal cord, which derives a segmental blood supply from the descending branches of the thoracic aorta, such as the intercostal arteries.

During TEVAR, the segmental feeding arteries to the spinal cord are routinely covered and excluded from blood flow by the stent graft. If extensive coverage is performed (>20 cm of the descending thoracic aorta), and especially if the LSA is covered, then the risk for spinal cord ischemia is significant and has been estimated to be as high as 12.1%.[3] In the absence of LSA coverage, this artery is capable of providing perfusion to the spinal cord through a complex network of collaterals to prevent spinal cord ischemia, the so-called collateral network concept.[4]

Stroke is a significant additional concern, with patients undergoing TEVAR without routine LSA revascularization demonstrating clearly higher rates of stroke (14.3%) than patients undergoing TEVAR with LSA revascularization (1.9%).[5] The mechanism is not entirely clear because not all strokes seem to be related directly to the coverage of the LSA. The vertebral artery, which arises from the LSA, is jeopardized during coverage of the LSA and, therefore, posterior circulation stroke might be expected to occur in the distribution of the left vertebral artery.[6] Despite this unclear mechanism of stroke, however, certainly in patients with a dominant left vertebral artery and a smaller right vertebral artery, well-documented arguments exist to try to revascularize or preserve the LSA if possible. Patient consent has been obtained for use of images.

PREOPERATIVE EVALUATION

The Society for Vascular Surgery published guidelines for management of the LSA with TEVAR repair,[7] in which the authors recommended routine LSA revascularization for patients undergoing TEVAR who require coverage of the LSA by the stent graft. This 14-year-old document remains relevant in terms of the fundamental recommendations with respect to the LSA; in that routine preoperative revascularization of the LSA be pursued in elective situations, especially in patients with anatomy that compromises perfusion to critical organs (Table I) and that urgent or emergency TEVAR, necessitating coverage of the LSA, should prompt an individualized strategy for LSA revascularization.

The length of coverage of descending thoracic aorta has remained an important factor in the decision to revascularize the LSA, with some authors stating that long thoracic segment coverage (>20 cm) has been considered an absolute indication for revascularization.[2,8,9]

The type of revascularization may be influenced by patient and environmental factors. Patient factors that may make the performance of a surgical carotid-to-subclavian bypass (CSB) or transposition challenging

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Table I. Selected anatomical conditions that may compromise perfusion to brain, spinal cord, heart or left arm and for which left subclavian artery (LSA) revascularization is strongly recommended

Presence of patent left internal mammary artery to coronary artery bypass graft
Termination of the left vertebral artery at the posterior inferior cerebellar artery or other discontinuity of the vertebrobasilar collaterals
Absent or diminutive or occluded right vertebral artery
Functioning arteriovenous shunt in the left arm
Prior infrarenal aortic repair with ligation of lumbar and middle sacral arteries
Planned long-segment (≥20 cm) coverage of the descending thoracic aorta where critical intercostal arteries originate
Hypogastric artery occlusion
Presence of early aneurysmal changes that may require subsequent therapy involving the distal thoracic aorta

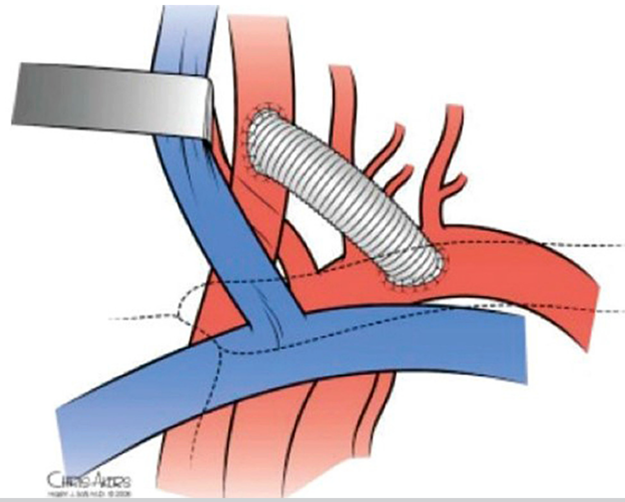

Fig 1. Left carotid subclavian bypass. (Reproduced with permission from Cronenwett JL, Johnston KW, eds. *Rutherford's Vascular Surgery.* 8th ed. Philadelphia: Elsevier Saunders 2014:1615-1626.)

include previous radiation to the cervical region, tracheostomy, modified radical neck dissection or previous neck surgery, unstable cervical spine, severe obesity or stiff neck precluding adequate surgical exposure, and high bleeding risk, for example, severe renal failure or anticoagulation use. Environmental factors include the presence of a cervical brace or collar, presence of polytrauma requiring other procedures, especially clavicular or cervical spine fractures, and the presence of central venous access and other intravenous lines. In our experience, we do believe that laser fenestration holds significant advantage in the trauma and emergency situation for the following reasons: (a) very rapid revascularization can be pursued (<30 minutes after TEVAR deployment in most situations), (b) avoidance of the need for a neck incision because oftentimes cervical clearance in trauma can be challenging to manage, (c) avoidance of the need for prosthetic material for bypass, and (d) phrenic nerve injury and lymphatic leak can be totally avoided.

SURGICAL TECHNIQUE

The first part of this article describes the two classic surgical operations for LSA revascularization—CSB and subclavian transposition. The latter part of the article will focus on newer endovascular modalities such as commercially available thoracic branched grafts and off-label techniques that are used for emergency and no-option patients such as chimney/snorkel grafts and fenestration techniques.

CSB and subclavian transposition. CSB is the most widely performed procedure for revascularization of the LSA, likely owing to familiarity of the exposure and relative ease of technical performance of the operation. CSB is associated with excellent long-term durability and outcomes and is generally accepted as the reference standard for LSA revascularization.[10] With the neck turned to the right side, a transverse incision is made a fingerbreadth above the clavicle, extending from the medial head of the sternocleidomastoid and laterally to the midclavicle. In our experience, we have not found it necessary to divide the medial head of sternocleidomastoid to dissect the jugular vein. This is then retracted medially to create a retrojugular plane to the common carotid artery. The subclavian artery is best dissected starting laterally and, once through the scalene fat pad, the phrenic nerve is identified running lateral to medial over the anterior scalene muscle, which is divided on the clavicle to reveal the subclavian artery. Typically, the bypass is created with a short, 8-mm prosthetic conduit with the subclavian anastomosis placed first, wherever comfortable to perform relative to the phrenic nerve, tunneled in the retrojugular plane onto the common carotid artery (Fig 1).[11] The main thoracic duct is not often encountered during this lateral dissection of the subclavian artery but smaller branches must be controlled well to avoid lymphatic leak.

Subclavian-to-carotid transposition is a less often performed revascularization method that avoids the use of a prosthetic conduit and additionally does not require separate embolization or management of the proximal subclavian artery. Contraindications are rare, but generally accepted to be the presence of an early origin of the vertebral artery and the presence of a patent left internal mammary to coronary artery bypass graft.[11] The vertebral artery can be transposed separately during this operation, but this approach can be quite challenging to perform if the artery is very proximal in the chest. The incision is placed between the two heads of

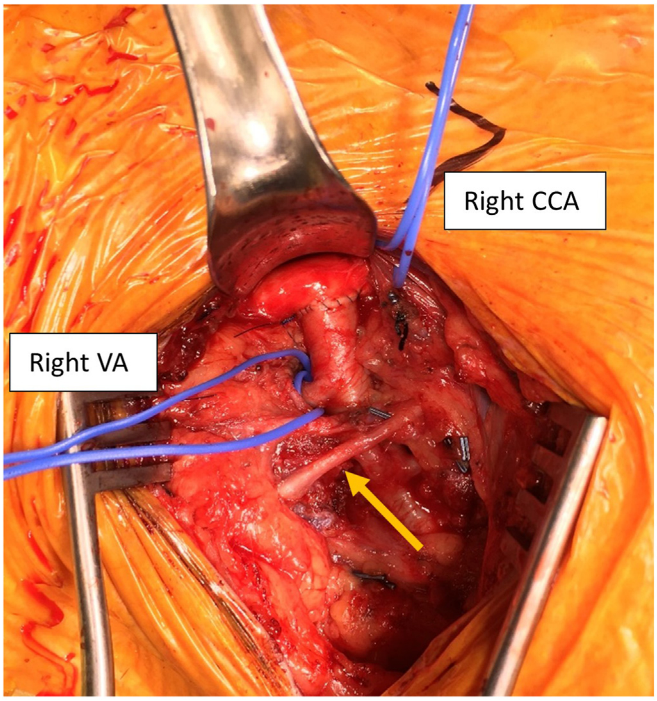

Fig 2. Right subclavian transposition to the carotid artery. Note phrenic nerve marked by the yellow arrow. *CCA*, Common carotid artery; *VA*, vertebral artery.

sternocleidomastoid muscle, more medially than the approach for CSB. Subplatysmal flaps are created and the omohyoid muscle is divided. The common carotid artery is mobilized fully to allow medial retraction with careful attention to ligation of the thoracic duct. The vertebral artery is then exposed on the posterior superior aspect of the subclavian artery by ligation of the vertebral vein. The internal mammary artery is preserved, and the subclavian artery is dissected as medially as possible. This maneuver allows for adequate length to perform a tension-free anastomosis to the carotid artery, as well as allowing a short arterial stump at the level of planned TEVAR coverage. When transecting the subclavian, we prefer a Derra-Satinsky clamp because this instrument allows us to place this as proximal as possible. Once the subclavian artery is transected, we sew the artery closed with a two-layered closure, the first layer being a horizontal mattress suture and the second being a straight over-and-over suture left loose until the clamp is removed slowly. Pledgets are not routinely used if the artery quality is adequate. Hemostasis is ensured before cutting the sutures, which are usually left long as a handle in case additional suture placement is needed. The anastomosis is best performed if the carotid artery is rotated a little anteriorly to allow the subclavian anastomosis to be performed on the lateral and posterior surface of the carotid artery (Fig 2).

Table II. Anatomical criteria for on-label use of Gore thoracic branched endoprosthesis (TBE) device

Intended aortic diameters of 31-37 mm (40-mm device)
Intended aortic diameter of 34-42 mm (45-mm device)
Aortic inner diameter range of 16-42 mm
Proximal covered length from distal edge of left CCA to distal edge of LSA ≥15-36 mm
Iliofemoral access of ≥7.5 mm
For patients with prior ascending aorta or aortic arch repair with a surgical graft; ≥2 cm landing zone proximal to the distal anastomosis
Left subclavian inner diameter 6-18 mm
Left subclavian minimum length of 2.5-3.0 cm

CCA, Common carotid artery; *LSA*, left subclavian artery.

For both of these operations, we have not found it necessary to leave a drain routinely, as long as the field is free from lymphatic leak at the end of the procedure and meticulous hemostasis, including reversal with protamine, where necessary, has been ensured.

Thoracic branched endoprosthesis. This device is available commercially for the treatment of pathologies requiring treatment of the thoracic aorta including the LSA who are at high risk for debranching subclavian procedures, including morbid obesity, potential for duct/nerve injury, and carotid stenosis. Off-label uses for this device include the treatment of zone 1 arch disease with branch into the carotid (rarely) or zone 0 arch with innominate branch. Relatively tight anatomical criteria dictate clinical feasibility of the device (Table II), with one review finding that only 28% of patients with type B aortic dissection who required zone 2 TEVAR met all the anatomical requirements for the device.[12]

Similar access considerations should be applied for complex large sheath endovascular repair including adequate iliofemoral access to accept up to a 26F sheath for the larger thoracic branched endoprosthesis (TBE) device. Radial or brachial access is important to snare and maintain through-and-through access for portal cannulation and device orientation. The device is then loaded on the main stiff wire and also the snared through and through wire as it is advanced into the aortic arch. Identification of wire wrap within the distal thoracic aorta by wire separation is key to successful docking of the subclavian stent with the portal. Fig 3 shows correct wire separation without wire wrap.

Alignment of the portal with the subclavian may require rotation of the graft and clearly is performed most preferably in the distal thoracic aorta rather than the aortic arch, to try to mitigate arch embolism, until the wire wrap has resolved. Angiography and deployment in zone 2 is then performed and the device deployed. It is our preference to lower the systolic blood

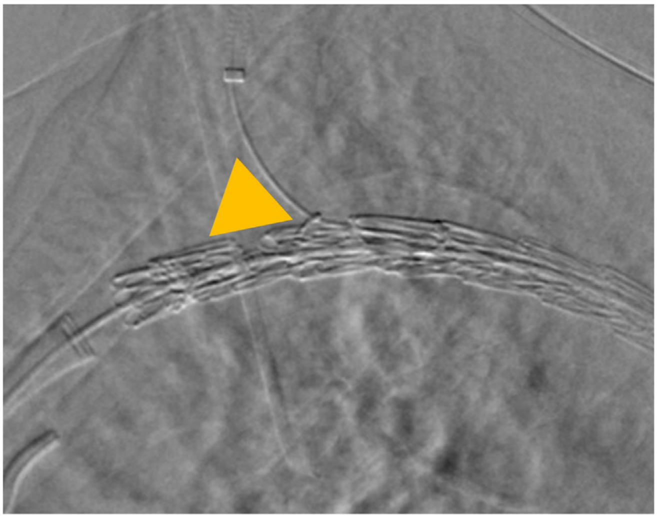

Fig 3. Zone 2 thoracic branched endoprosthesis (TBE) deployment with correct portal alignment with subclavian artery. The yellow triangle signifies the critical view demonstrating space between the portal wire and the thoracic endograft.

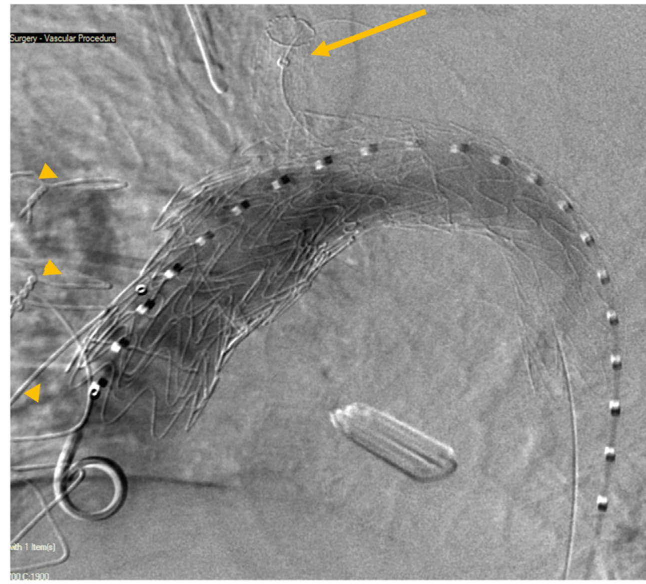

Fig 4. Thoracic branched endoprosthesisTBE) (yellow arrow) with proximal aortic extension into a previous ascending aortic graft with debranched innominate and carotid (yellow arrowheads) that was performed at the time of initial type A acute aortic dissection repair.

pressure of <90 mm Hg during TEVAR deployment. Once corrected for parallax and fully deployed, the subclavian branch is then introduced from femoral access with the olive tip of the stent docked into a guiding 5F sheath from the upper extremity access to ensure smooth passage through the portal into the subclavian artery. Imaging of the vertebral artery protects against inadvertent coverage and additional stents can be placed if longer subclavian coverage is needed. In Fig 4, a proximal extension into a previous ascending aortic graft with prior innominate and left carotid debranching was performed, which greatly assisted in complete endovascular arch treatment of type B after type A aortic dissection. Of note, to obtain maximum within-graft coverage when performing ascending repair, it is recommended to place the debranching graft(s) as low as possible and laterally oriented on the ascending aortic repair.

Chimney and periscope techniques during TEVAR. These techniques in contemporary practice are most often used as bailout techniques during emergency procedures or in cases where arch branch vessels cannot be revascularized easily by standard means or is associated with undue surgical risk. Examples of these situations include many of the patient selection criteria as for TBE, for example, as discussed elsewhere in this article. Isolated subclavian chimney or periscope stenting is less common and is frequently encountered in conjunction with other arch chimney stenting, such as the left carotid.[13] Left upper extremity access as well as bilateral femoral access is established, and a wire placed from the left arm into the ascending aorta or alternatively snared through and through to the brachial access. The latter maneuver allows for more flexibility if a caudally directed periscope is planned, as opposed to an antegrade chimney, originating from the transverse arch into the subclavian artery (Fig 5).

A sheath is placed from the subclavian artery into the ascending or descending aorta, depending on the direction of the chimney/periscope, and the proposed balloon-expandable covered stent positioned approximately 10 mm outside of the TEVAR graft. The TEVAR graft is then positioned and deployed with the systolic blood pressure lowered to <90 mm Hg and the chimney/periscope graft is then deployed. Simultaneous TEVAR and chimney stent balloon molding are then performed at the landing zone to reduce gutter leak. Given the issues with durability and concerns for continued gutter leak compromising the seal zone,[14] chimney and periscope techniques have largely been relegated to bailout maneuvers in the setting of planned complex endovascular repair to the arch (Fig 6).

Laser fenestration during TEVAR. Given the unknown durability of this approach, this technique is restricted to emergency presentations and for patients who are not candidates for open surgery, who do not meet the criteria for TBE and who are at high risk for cervical debranching procedures. The setup is similar to chimney/snorkel techniques with experience from these procedures paving the way for successful laser

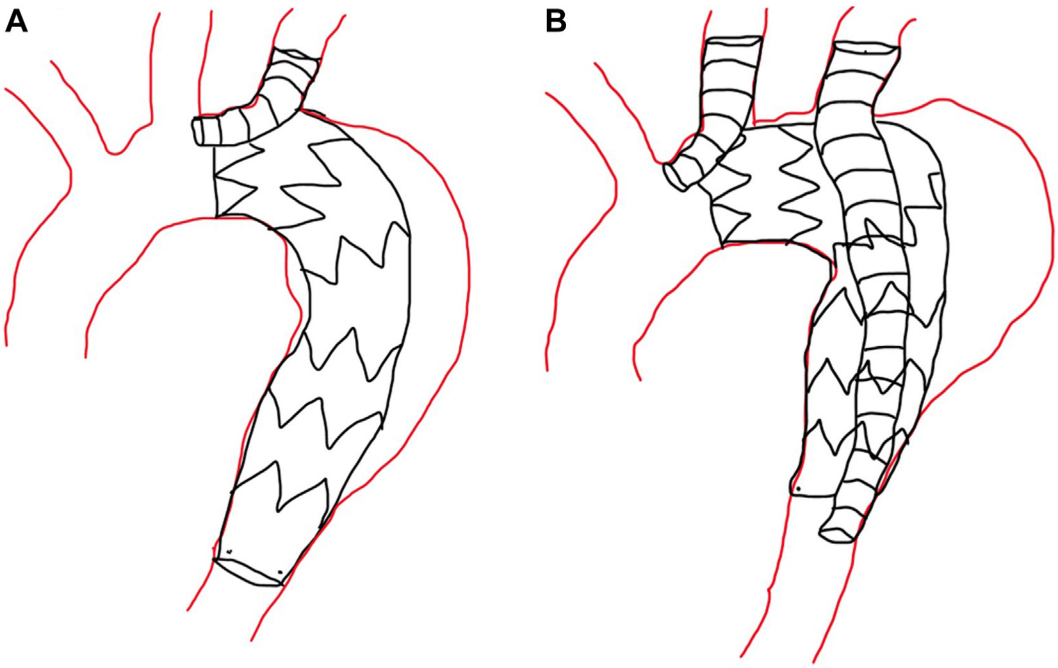

Fig 5. Schematic drawings of two configurations for the left subclavian artery (LSA) revascularization. **(A)** Antegrade chimney stent and **(B)** retrograde periscope stent.

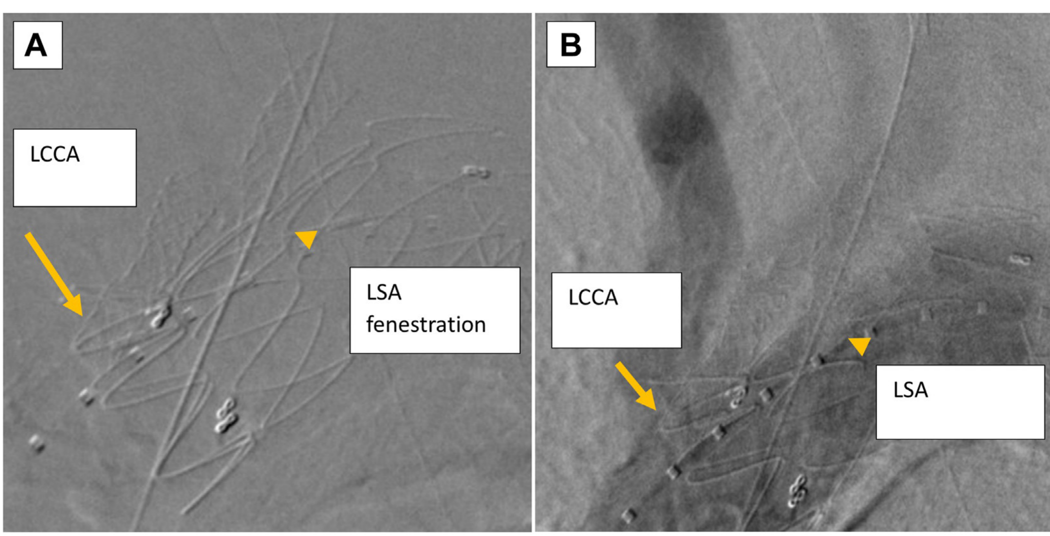

Fig 6. **(A and B)** Left common carotid artery (*LCCA*) chimney bailout (yellow arrow) at the time of planned left carotid and LSA laser fenestration (yellow arrowhead) for zone 2 aortic pseudoaneurysm repair. Note LCCA chimney stent extends 1 cm past thoracic endovascular aortic repair (TEVAR) graft fabric. *LSA*, left subclavian artery.

fenestration. Left arm brachial access is established with a wire placed into the ascending aorta, as well as bilateral femoral access. Single, rather than double, femoral access can also be pursued, if desired, with either a double puncture to the femoral artery or buddy wire technique for placement of pigtail catheter next to the TEVAR graft. A steerable sheath is placed near the orifice of the subclavian artery with full heparinization established before manipulation of any wires or catheters into the aortic arch. The systolic blood pressure is

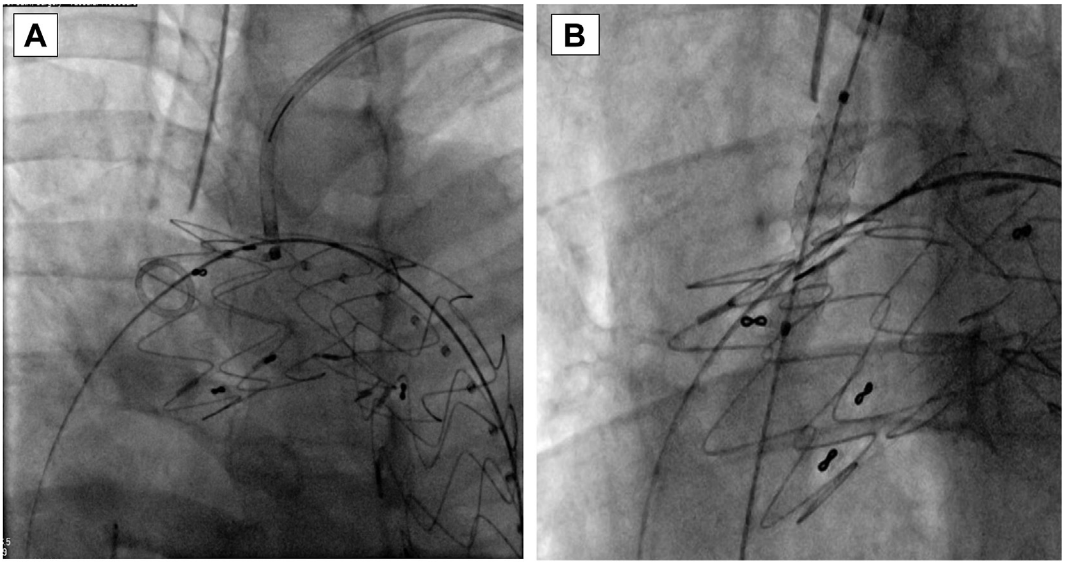

Fig 7. **(A)** Laser fiber orientation perpendicular to the graft fabric using a steerable sheath. **(B)** Covered balloon-expandable stent placement with minor waist at fenestration.

lowered to <90 mm Hg and the TEVAR graft is positioned and deployed. Usually, balloon molding is not undertaken owing to the possibility of graft migration and significant blood pressure spiking, even with the use of trilobed balloons. A 2.3-mm laser fiber (Philips, Amsterdam, the Netherlands) is advanced retrograde through the brachial access and positioned over the subclavian orifice. Using a steerable sheath to obtain perpendicular orientation of the laser fiber to the graft fabric, two views—coronal and down the barrel—are obtained, confirming adequate alignment of the laser with the graft fabric (Fig 7). These views are critical to prevent the laser fiber from sliding off the graft fabric and failing to achieve graft penetration. We routinely look for movement of a stent strut near the site of proposed laser fenestration when probing the graft with the laser tip to ensure that the laser is abutting the graft. A short burst of energy at 40 mJ is applied with forward pressure and the laser fiber will be felt perforating the fabric. Confirmation of intraluminal passage occurs over a wire placed into first the ascending then descending thoracic aorta with a pigtail catheter rotated within the seal zone. The catheter should spin freely if within the graft lumen, in a similar fashion to endovascular aneurysm repair gate cannulation and verification. We then perform balloon dilation to the fenestration with a 5 $\times$ 40-mm semi-compliant balloon (Medtronic Inc., Minneapolis, MN) followed by VBX covered balloon-expandable stent placement (W. L. Gore & Associates, Flagstaff, AZ), leaving 5 mm of stent into the aortic lumen. In cases of large diameter subclavian arteries, the fenestration is dilated to not >8 mm and then an appropriate large diameter balloon is placed in the stented subclavian artery and dilated, flaring the stent to match the subclavian diameter (Fig 8).

More proximal branches can be laser fenestrated in a similar manner, as can be seen in Fig 8. In this particular case, a large aortic pseudoaneurysm at zone 2 related to a previous motor vehicle collision required TEVAR into zone 1. In addition to left brachial surgical access, left carotid surgical access was obtained and a short 7F sheath placed, directed towards the aortic arch. Under somatosensory evoked potential and electroencephalographic monitoring, the left carotid was test clamped with no changes detected. Zone 1 TEVAR then proceeded in the manner described elsewhere in this article. With the left carotid clamped distal to the sheath, laser fenestration was performed to the left carotid with covered balloon-expandable stent placed. The subclavian artery fenestration was then performed. Finally, the carotid sheath was removed and flushed to remove any debris then finally the arteriotomy was repaired and flow restored. Techniques to perform total endovascular arch treatment provide creative solutions in patients who have no other options, but are beyond the scope of this particular article.

CONCLUSIONS

Left subclavian revascularization should be considered in all appropriate patients who are scheduled to undergo TEVAR with LSA coverage to prevent spinal cord ischemia and stroke and to preserve left arm perfusion. Classic open cervical debranching operations such as CSB and subclavian transposition should be the standard against which all other techniques are measured. In our institution, for cases where debranching poses a

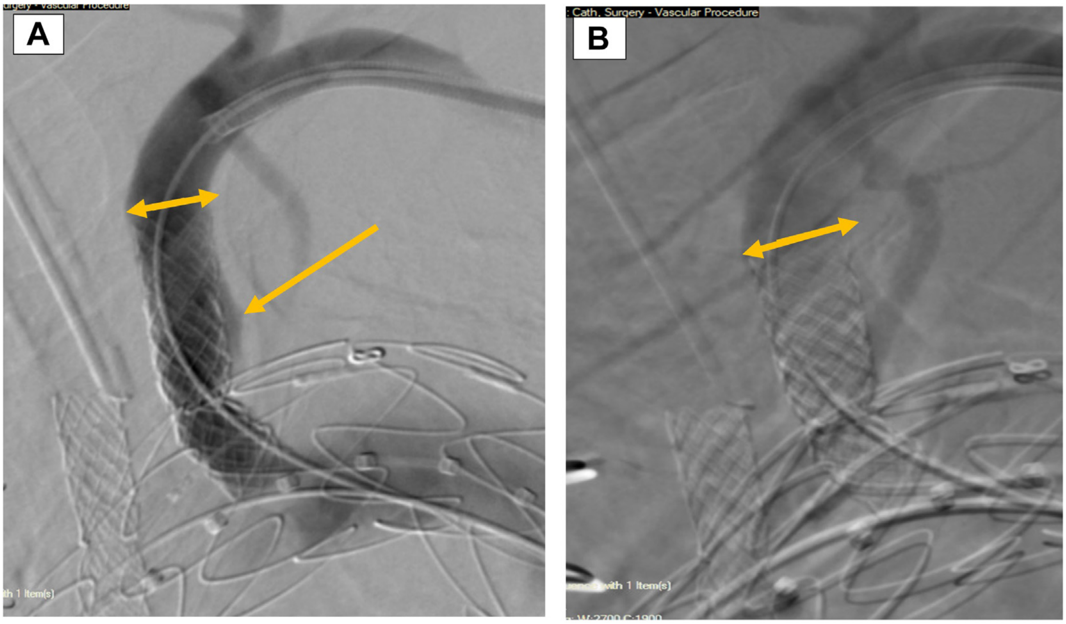

Fig 8. (A) Contrast outside of the stent can be seen owing to undersizing relative to the left subclavian artery (LSA). **(B)** Postdilation with a 12-mm balloon outside of the fenestration resolved leak.

high risk of complications, alternative endovascular approaches can be pursued including TBE, if anatomical criteria are met, or laser fenestration when TBE is not feasible. Chimney and snorkel techniques, in our opinion, should be used as a bailout maneuver during planned arch branch endovascular reconstruction and ideally limited to a single branch vessel, if possible.

DISCLOSURES

None.

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