

Expanding the Landing Zone for TEVAR

A discussion of the longevity and durability of commonly used extrathoracic debranching techniques.

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Thoracic endovascular aortic repair (TEVAR) is an effective treatment modality for descending thoracic aortic aneurysms, aortic dissections, and traumatic aortic transections. The application of traditional TEVAR requires a proximal and distal landing zone of at least 2 cm; however, patients who present with thoracic aortic pathology can present with a disease that extends into the aortic arch, leaving them without a suitable proximal landing zone distal to the left subclavian artery (LSA). To ensure optimal clinical outcome and minimize complications when the stent graft is placed in zones 0, 1, or 2 of the arch, a careful evaluation and plan for revascularization of the arch vessels is needed (Figure 1). The incidence of extrathoracic debranching has increased in the era of thoracic stent grafting because of reduced morbidity rates as compared with traditional arch debranching procedures that require a median sternotomy and aortic cross clamping. This article discusses the longevity and durability of the most commonly utilized extrathoracic debranching techniques.

TEVAR LANDING IN ZONE 2

Especially in an emergent setting, the LSA can be covered without revascularization. However, in patients who have undergone coronary artery bypass grafting with a left internal mammary artery (LIMA) graft, LSA revascularization is mandatory. Other indications include absent/atretic contralateral vertebral artery, dominant left vertebral artery, presence of a functional left arm arteriovenous fistula or left-sided axillary-femoral bypass, and hypogastric artery stenosis or occlusion that can increase the risk for spinal cord ischemia (SCI). Although the LSA was historically covered with impunity, zone 2 sealing without LSA revascularization can result in upper extremity ischemia, SCI, and vertebrobasilar insufficiency. In nonurgent settings, elective revascularization of the

LSA may reduce morbidity and optimize outcome. The most convincing support for routine LSA revascularization comes from the EUROSTAR registry, which reported a significantly higher incidence of SCI or stroke (8.4%) in patients without LSA revascularization compared to patients with revascularization (0%; $P = .49$).¹ In a recent systemic review, Waterford et al reported that the overall stroke rate for TEVAR with LSA coverage without revascularization was 5.6% versus 3.1% when revascularization was performed.² Although this difference did not reach statistical significance, 26.2% of the strokes after LSA coverage occurred in the posterior circulation, with only one patient who underwent preoperative revascularization developing a stroke in this territory. As such, the investigators concluded that routine revascularization of the LSA should be performed in elective cases.

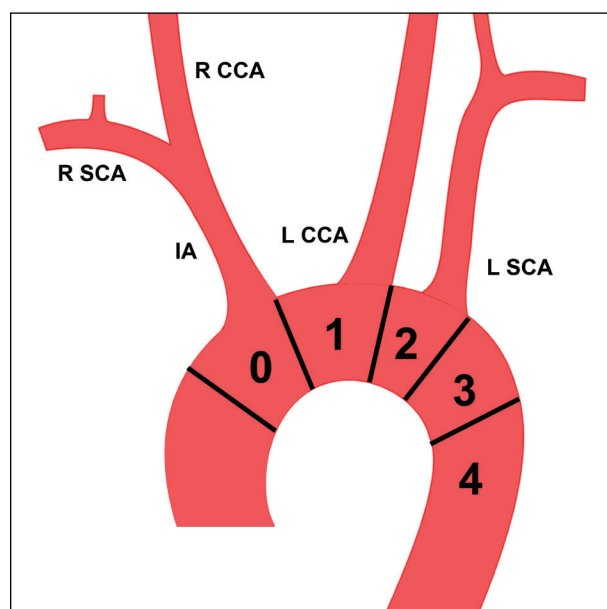


Figure 1. The zones of the aortic arch.

The Society of Vascular Surgery acknowledges the overall lack of long-term data regarding LSA management during TEVAR, but gives the following recommendations based on the best available evidence, as assessed by the grading of recommendations assessment, development, and evaluation (GRADE) system:

1. In patients who need elective TEVAR where achievement of a proximal seal necessitates coverage of the LSA, routine preoperative revascularization is suggested (GRADE 2, level C).
2. In select patients who have an anatomy that compromises perfusion to critical organs, routine preoperative LSA revascularization is strongly recommended (GRADE 1, level C).
3. In patients who need urgent TEVAR for life-threatening acute aortic syndromes where achievement of a proximal seal necessitates coverage of the LSA, LSA revascularization should be individualized and addressed expectantly on the basis of anatomy, urgency, and availability of surgical expertise (GRADE 2, level C).³

Left Carotid-Subclavian Artery Bypass

Carotid-subclavian artery bypass surgery is a relatively straightforward procedure with exceptional results (Figure 2). It does not require extensive dissection of the proximal subclavian artery, making it the preferred technique for patients with a left vertebral artery originating very proximally off of the LSA. Exposure is performed through a supraclavicular incision just lateral to the clavicular head of the sternocleidomastoid muscle.

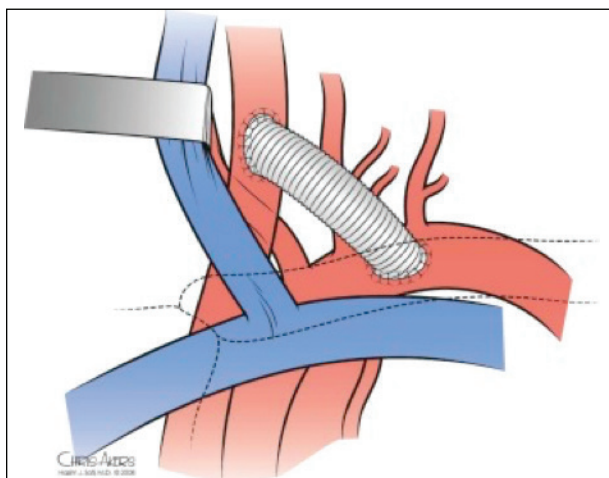


Figure 2. A carotid-subclavian bypass. Reproduced with permission from Desai S, Safi HJ. Brachiocephalic artery: surgical treatment. In: Cronenwett JL Johnston KW, eds. *Rutherford's Vascular Surgery*. 8th ed. Philadelphia: Elsevier Saunders; 2014:1615–1626.

Dissection through the platysma and subcutaneous tissue is carried down to the level of the jugular vein, which is reflected medially, giving access to the common carotid artery. The vagus nerve and the sympathetic chain are posteriorly identified and preserved. The scalene fat pad is mobilized, taking care to divide the lymphatic vessels to expose the subclavian artery. The phrenic nerve runs along the surface of the anterior scalene muscle and should be identified to avoid injury. On the left side, the thoracic duct runs posteriorly to the left carotid artery and internal jugular vein. When visualized, the thoracic duct should be ligated to avoid postoperative lymphoceles.

A prosthetic graft is the conduit of choice in carotid-subclavian bypasses. Ziomek et al compared the overall patency rates of different conduits used for carotid-subclavian bypasses.⁴ Five-year patency rates were significantly higher with prosthetic grafts compared to autogenous vein grafts (94.1% vs 58.3%, respectively; $P < .01$). The 5-year stroke rate was 6% for patients who received prosthetic grafts and 39% for those who received vein grafts ($P < .05$). Law et al reported similar superiority of prosthetic grafts with a 5-year patency rate of 95.2% for polytetrafluoroethylene, 83.9% with Dacron, and 64.8% with saphenous vein grafts.⁵ Given these results and the overall high-flow nature and large vessel diameter involved with this reconstruction, a general consensus has developed that prosthetic grafts are superior to autogenous vein grafts with respect to patency rates. Externally supported prosthetic grafts are frequently used to help prevent kinking.

Left Carotid-Subclavian Artery Transposition

Carotid-subclavian artery transposition allows revascularization of the LSA without the use of any prosthetic graft materials (Figure 3). However, transposition requires more extensive dissection to gain proximal control and mobilize a sufficient length of the subclavian artery to allow tension-free anastomosis to the carotid artery. Because of these limitations, transposition is contraindicated in patients with an early origin of the vertebral artery and in those with a patent LIMA coronary bypass graft.

Transposition can be performed through a short medial transverse incision made just above the level of the clavicle. Surgical dissection is carried down between the heads of the sternocleidomastoid muscle, the omohyoid muscle is divided, and the jugular vein is retracted laterally. On the left side, the thoracic duct must be identified and ligated. Dissection of the common carotid artery (CCA) is performed, making sure to preserve the vagus nerve. The vertebral vein is divided to gain access

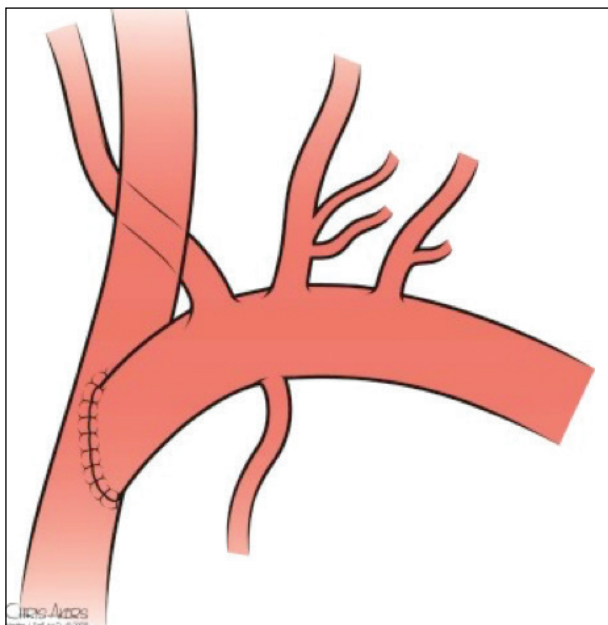


Figure 3. A carotid-subclavian transposition. Reproduced with permission from Desai S, Safi HJ. Brachiocephalic artery: surgical treatment. In: Cronenwett JL Johnston KW, eds. *Rutherford's Vascular Surgery*. 8th ed. Philadelphia: Elsevier Saunders; 2014:1615–1626.

to the subclavian artery, which is controlled as proximally as possible into the mediastinum and must be done proximal to the vertebral artery to preserve posterior cerebral circulation. The subclavian artery is then divided to perform an end-to-side anastomosis to the CCA. Loss of control of the transected proximal end can be disastrous, requiring a thoracotomy to obtain control, so care must be taken to secure the proximal stump.

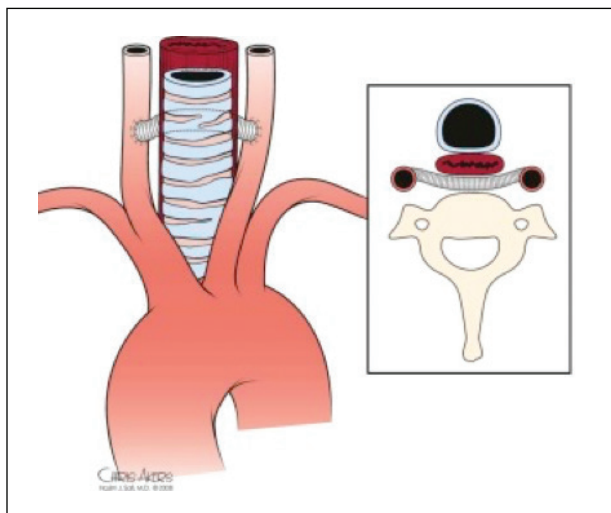


Figure 4. A carotid-carotid crossover bypass. Reproduced with permission from Desai S, Safi HJ. Brachiocephalic artery: surgical treatment. In: Cronenwett JL Johnston KW, eds. *Rutherford's Vascular Surgery*. 8th ed. Philadelphia: Elsevier Saunders; 2014:1615–1626.

When performed successfully, transposition has excellent outcomes with good patency rates. Schardey et al reported an overall patency rate of 100% in 108 patients over 70 months.⁶ However, complications were noted in 15% of patients, and 3% resulted in permanent disability. Similarly, Duran et al reported a patency rate of 96.3% at 53.8 months in 126 patients who underwent transposition.⁷

TEVAR LANDING IN ZONE 1

Carotid-Carotid Crossover Bypass

Unlike the LSA, which some have argued does not need routine revascularization, graft coverage of the left common carotid artery (LCCA) without further intervention could be catastrophic. When TEVAR is extended into zone 1 of the aortic arch, the LCCA needs to be revascularized to prevent neurovascular compromise. This can be performed with a carotid-carotid crossover bypass with or without revascularization of the LSA at the same time (Figure 4). Although an anterior or presteral tunneling of the bypass graft can be performed, this can cause complications if the patient requires a tracheostomy or sternotomy in the future. Additionally, the superficial nature of these tunnels increases the risk of skin erosion overlying the bypass and is cosmetically displeasing. To minimize these risks, a retropharyngeal tunnel provides a shorter and more direct bypass tract and can be performed by passing a finger medial to the CCA and behind the esophagus. A nasogastric tube can facilitate identification of the esophagus and the retropharyngeal space, which is bluntly dissected and developed.

Although long-term results of these bypasses are not available, carotid-carotid crossover bypasses in the setting of occlusive disease (OD) have been previously studied. Ozsvath et al reported primary and secondary patency rates of 88% and 92%, respectively, at 3 years in 24 carotid-carotid crossover bypasses.⁸ In another study evaluating 16 patients, Berguer and Gonzalez reported a 6.2% stroke risk with a high 5-year patency rate of 94%.⁹

Subclavian-Subclavian and Axilloaxillary Artery Bypass

Axilloaxillary bypass has been long described and studied for the treatment of brachiocephalic or subclavian OD. Although less utilized than a carotid-subclavian bypass, axilloaxillary bypass may provide another option in select patients who have anatomic constraints that prevent the previously mentioned bypasses. Several physicians expressed initial concern about the longevity of this arterial reconstruction given its subcutaneous, long, transsternal position, but several studies have

since shown acceptable long-term results. In the largest series, Mingoli et al published their 24-year experience with axilloaxillary bypass grafting in 68 patients treated for innominate or subclavian OD who had concomitant ipsilateral carotid artery stenosis. They reported a low mortality rate of 1.6% and 10-year primary and secondary patency rates of 82.8% and 84.3%, respectively.¹⁰

Despite its reported durability, the axilloaxillary artery bypass should remain a secondary option only when CCA-subclavian artery bypass artery is not feasible. In a series of 67 patients undergoing CCA-LSA bypass versus axilloaxillary bypass, AbuRahma et al reported similar overall mortality (3% vs 8%, respectively; P = nonsignificant), but both primary (93.8% vs 66%, respectively) and secondary patency rates (93.8% vs 84.6%, respectively) were significantly greater for CCA-LSA bypass at 10 years as compared with axilloaxillary bypass.¹¹

Although not extensively studied in the setting of TEVAR, some physicians have performed axilloaxillary bypass grafting with a jump graft to the LCCA. We do not know the long-term patency rates for these grafts, but this approach is a potential option when the stent graft is extended into zone 1 of the aortic arch (Figure 5).

TEVAR LANDING IN ZONE 0

Completely extrathoracic debranching techniques for zone 0 sealing with TEVAR are limited. Criado et al described a right femoroaxillary graft combined with a carotid-carotid crossover bypass and LCCA-subclavian artery bypass as a possible debranching solution.¹² Although possible in theory, the entire cerebral circulation would depend on the retrograde flow through a long bypass from one leg; this approach seems suboptimal, and no physicians have described performing this revascularization. Another possible hybrid option for TEVAR landing in zone 0 is an ascending aorto-innominate

snorkel followed by a right to left carotid-carotid bypass and left carotid subclavian bypass. There is a paucity of data on this kind of hybrid reconstruction and the long-term patency is unknown. Ferrero et al reported results for 11 patients who underwent TEVAR with zone 0 landing, with 10 patients undergoing ascending aorta bypass to right common carotid artery (RCCA)-LCCA-LSA and one patient with RCCA-LCCA-LSA bypass with innominate stent grafting.¹³ The investigators reported a technical success rate of 100% with 9.1% perioperative mortality, 0% stroke rate, and 0% SCI, demonstrating its feasibility as a possible solution.

OUTCOMES OF ARCH DEBRANCHING IN THE SETTING OF TEVAR

LSA revascularization in the setting of TEVAR has excellent results. Several investigators have reported outcomes after combined TEVAR and extra-anatomic revascularization. In a review of 70 patients, Woo et al reported excellent clinical outcomes after LSA revascularization versus no revascularization with postoperative stroke rates of 0% versus 8.6%, respectively, although this difference did not reach statistical significance (P = .6). Patency was excellent, with all carotid-subclavian bypasses remaining patent throughout follow-up.¹⁴ In another large single-institution review of 145 patients who underwent TEVAR and LSA coverage with selective revascularization, Lee et al reported a 100% technical success rate associated with LSA bypass.¹⁵ In this study, the investigators reported excellent clinical outcomes in both revascularized and unrevascularized patient groups, with similar rates of stroke (3.1% vs 3.5%; P > .99), paraplegia (3.1% vs 0%; P = .22), and mortality (6.3% vs 1.8%; P = .21), respectively.

Scali et al compared outcomes of subclavian artery revascularization in the setting of TEVAR versus OD.¹⁶ Over a mean follow-up of 16.1 months, patency rates were comparable between the TEVAR and OD groups at 1 year (94% vs 93%, respectively) and at 3 years (94% vs 73%, respectively; log-rank P = .41). Five-year survival estimates were also similar between the two groups (74% for TEVAR vs 76% for OD; P = .4), concluding that overall outcome of subclavian revascularization is similar when performed in the setting of OD or TEVAR.

Lotfi et al reported their results in 23 carotid-carotid bypasses, eight carotid-carotid-LSA bypasses, and 16 carotid-LSA bypasses.¹⁷ They reported a perioperative mortality rate of 10% (5% in elective and 30% in emergent cases). One stroke occurred with TEVAR landing in zone 0, four strokes in zone 1, and one stroke in zone 2 with an overall ischemic stroke rate of 12%. The rate of paraplegia was 6%. Two extra-anatomic bypasses occlud-

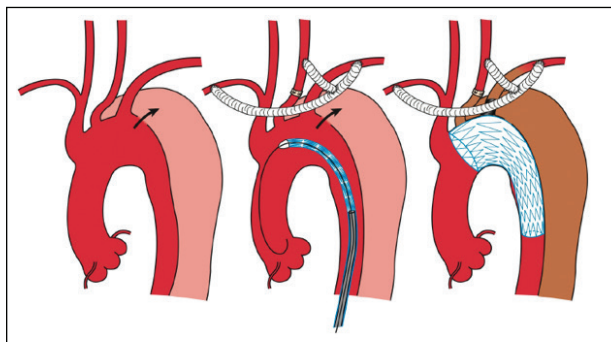


Figure 5. An axilloaxillary artery bypass. Reproduced with permission from Kuratani T. Best surgical option for arch extension of type B dissection: the endovascular approach. *Ann Cardiothorac Surg.* 2014;3:292–299.

ed during follow-up, resulting in a posterior circulation and lacunar stroke, and one bypass (carotid-carotid-LSA) was noted to have high-grade stenosis requiring revision. The overall bypass graft patency rate was 96%.

Ferrero et al reported results in four patients with zone 1 landing and 12 patients with zone 2 landing.¹³ Technical success was 100% in both groups. For zone 1, there was a 0% perioperative mortality, stroke, and SCI rate, and for zone 2, perioperative mortality was 16.7%, the stroke rate was 0%, and the SCI rate was 8.4%. The investigators noted that these hybrid procedures are associated with significant perioperative mortality and morbidity, but they provide a viable alternative to open surgical repair.

In a meta-analysis of hybrid procedures, Moulakakis et al reviewed 26 studies involving 820 patients who underwent aortic arch debranching.¹⁸ In their pooled patient group, zone 0 was involved in 41.7%, zone 1 in 28.9%, and zone 2 in 29.4% of patients with a technical success rate of 92.8%. Over a mean follow-up of 22.1 months, endoleaks were observed in 16.6% and retrograde type A dissection was found 4.5% of patients. The investigators reported 11.9% perioperative mortality, a 7.6% stroke rate, and a 3.6% SCI rate. Although no direct statistical comparison was performed, these rates were comparable to rates for patients who underwent open elephant trunk arch replacement (perioperative mortality, 9.5%; stroke, 6.2%; SCI, 5%). The investigators concluded that aortic debranching allowed for high technical success with a relatively low mortality risk in this subset of patients considered unfit for traditional open surgery.¹⁸

CONCLUSION

More recently, several physicians have reported making custom fenestrations in the thoracic stent graft via retrograde access to the origin of the LSA, followed by laser or needle fenestration through the graft and subsequent stent grafting. Others have utilized parallel grafts in the arch to maintain perfusion to the cerebral vessels while extending the landing zone. Although the longevity and durability of these techniques are not known, they provide an almost completely endovascular solution to TEVAR sealing in zone 2. Several ascending arch devices are currently being investigated that provide continued perfusion to the arch vessels through either fenestrations or branches. These devices may provide durable solutions to aortic pathology that extend into zones 0, 1, and 2.

Until these devices become readily available on the market, extrathoracic debranching allows physicians to apply TEVAR to an extended array of aortic pathology involving the arch. Using data from OD as surrogate markers, these extrathoracic bypasses are safe, durable options to expand the landing zone in the setting of TEVAR. ■

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