

Aortic Repair in Landing Zone 2: From Chimney Technique to Branched Graft

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Introduction

In the era of thoracic stent grafting, the incidence of extrathoracic debranching procedures has markedly increased. Aortic pathologies such as degenerative aneurysm, dissection, intramural hematoma, or penetrating aortic ulcer can now be treated with lower morbidity and mortality rates compared to traditional open arch debranching, which required median sternotomy and aortic cross-clamping. The development of thoracic endovascular aortic repair (TEVAR) has therefore revolutionized the treatment of complex thoracic lesions, reducing perioperative trauma and improving clinical outcomes. Nevertheless, when the proximal sealing zone extends into the aortic arch, particularly in zone 2 according to Ishimaru’s classification, the involvement of the left subclavian artery (LSA) becomes a critical issue [1].

Total endovascular techniques eliminate the need for sternotomy and further reduce surgical trauma [2,3]. The introduction of fenestrated and side-branched endografts has made it feasible to apply endovascular techniques in patients with a proximal landing zone in zone 2 (Fig. 1, Ref. [4]). However, these devices remain under development and are not readily available, especially in emergency situations, due to technical and logistical limitations. Their cost is also considerable. Although several groups have described in situ fenestrations using laser or needle techniques, or home-made modifications of endografts, these procedures are complex, not standardized, and restricted to highly specialized centers [5,6].

Clinical Relevance of Left Subclavian Artery Revascularization

In emergent cases, LSA coverage without revascularization is occasionally tolerated, but this may increase the risk

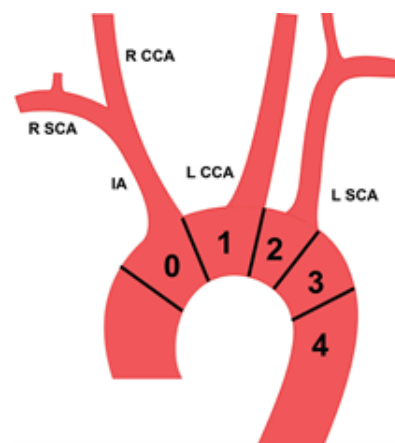


Fig. 1. Anchoring zone in the thoracic aorta disease and supraortic vessels. Zone 2 is included between left common carotid artery and subclavian artery. R SCA, right subclavian artery; R CCA, right common carotid artery; L CCA, left common carotid artery; IA, innominate artery; L SCA, left subclavian artery. Adapted from [Metzger *et al.*] [Revista Brasileira De Cirurgia Cardiovascular: órgão Oficial Da Sociedade Brasileira De Cirurgia Cardiovascular] [4], available under the Creative Commons License.

of spinal cord ischemia (SCI), stroke, or upper extremity ischemia. Elective revascularization of the LSA is therefore recommended whenever feasible. Specific indications include the presence of a left internal mammary artery (LIMA) coronary graft, a dominant left vertebral artery, or an atretic contralateral vertebral artery. Additional considerations include patients with a left upper-limb arteriovenous fistula, a left-sided axillo-femoral bypass, or hypogastric artery occlusion (Table 1).

The European Collaborators on Stent-Graft Techniques for Abdominal Aortic Aneurysm Repair (EUROSTAR) registry reported a significantly higher incidence of neurological complications (8.4%) among patients without LSA revascularization compared with those who underwent revascularization (0%) [7]. Similarly, Waterford *et al.* [8] observed stroke rates of 5.6% in unrevascularized patients versus 3.1% among those revascularized. Although not statistically significant, 26.2% of strokes after LSA cover-

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Table 1. Reasons for not covering the origin of the subclavian artery.

Previous coronary artery bypass grafting with a left internal mammary artery (LIMA) graft
Absent/atretic contralateral vertebral artery
Dominant left vertebral artery
Presence of a functional left arm arteriovenous fistula
Left-sided axillary-femoral bypass
Hypogastric artery stenosis or occlusion

age occurred in the posterior circulation. Recent data from D’Oria *et al.* [9] and Delafontaine *et al.* [10] confirmed that both open and endovascular LSA reconstructions are safe and effective, with similar perioperative and mid-term outcomes [11].

Techniques for Zone 2 Repair

Hybrid Procedure: TEVAR + Left Carotid-Subclavian Bypass

The carotid–subclavian bypass remains a reliable method for LSA revascularization during zone 2 TEVAR. The supraclavicular approach provides excellent exposure, with a transverse incision approximately 2 cm above the clavicle. After identification of the anterior scalene muscle and careful preservation of the phrenic nerve, the left subclavian artery is exposed. Following systemic heparinization, a 7- or 8-mm Dacron graft is anastomosed end-to-side to the left common carotid artery and tunneled beneath the scalene fat pad. The distal anastomosis is then performed end-to-side on the left subclavian artery. To prevent type II endoleak, a vascular plug can be placed at the origin of the subclavian artery. The procedure is completed by deploying a thoracic endograft covering the LSA origin (Fig. 2). This hybrid approach combines durability with minimal invasiveness and demonstrates excellent long-term patency rates [12].

Chimney Technique in the Left Subclavian Artery (ChTEVAR)

The chimney technique, initially developed as a bailout solution, has become an established alternative for urgent situations. It enables rapid, fully endovascular repair with simultaneous LSA revascularization. Access is typically gained through the left radial or brachial artery, where a covered or bare stent is advanced into the LSA and positioned parallel to the main thoracic stent-graft. After deployment of the aortic device, the chimney stent is released to maintain LSA perfusion while extending the proximal seal zone. Correct preoperative sizing and precise deployment are essential to prevent endoleaks or compression of the subclavian stent [13] (Fig. 3).

Off-the-Shelf Branched Endografts

The advent of off-the-shelf branched endografts has further expanded the scope of endovascular repair in zone 2. The Gore Thoracic Branch Endoprosthesis (TBE) is the first de-

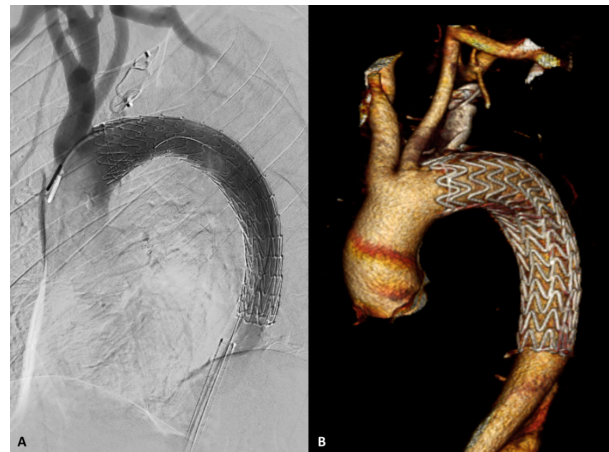


Fig. 2. Intraoperative angiogram (A) and post-procedural 3D reconstruction (B) of TEVAR with a previous left carotid-subclavian bypass and plug at the origin of the subclavian artery. All iconographic documentation is taken from the Poli-clinico Tor Vergata Hospital’s radiology archive, and consent for publication is included in the patient’s electronic record, available upon request. TEVAR, thoracic endovascular aortic repair; 3D, Three-Dimensional.

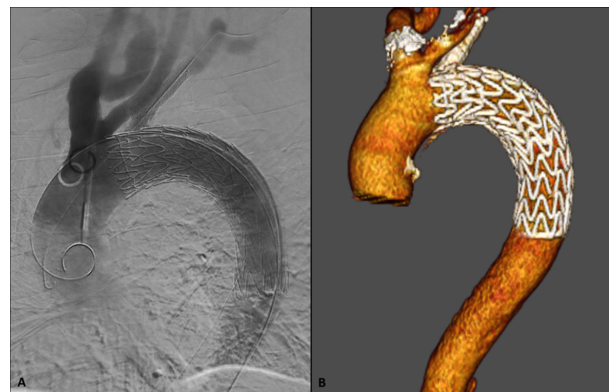


Fig. 3. Intraoperative angiogram (A) and post-procedural 3D reconstruction (B) of ChTEVAR for aortic traumatic rupture in an emergent setting. All iconographic documentation is taken from the Poli-clinico Tor Vergata Hospital’s radiology archive, and consent for publication is included in the patient’s electronic record, available upon request. ChTEVAR, Chimney Technique in the Left Subclavian Artery.

vice approved by the Food and Drug Administration (FDA) for use in lesions requiring proximal sealing in zone 2. It consists of a modular aortic component and a side-branch module designed to revascularize the LSA. Access is typically obtained through bilateral femoral punctures and a left brachial approach, using a through-and-through wire for precise alignment. Despite limited long-term data, initial clinical experience demonstrates high technical success, low endoleak rates, and excellent branch patency [14]. Fig. 4 illustrates a typical case treated with a ready-made branched intraluminal graft.



Fig. 4. Intraoperative angiogram (A) and post-procedural 3D reconstruction (B) of endovascular exclusion of a thoracic aneurysm with an off-the-shelf branched endograft. All iconographic documentation is taken from the Policlinico Tor Vergata Hospital's radiology archive, and consent for publication is included in the patient's electronic record, available upon request.

Clinical Considerations and Future Perspectives

Endovascular repair of the aortic arch involving zone 2 has evolved from hybrid approaches to total endovascular techniques. This review outlines the main strategies for left subclavian artery (LSA) management, from carotid–subclavian bypass and chimney techniques to the latest off-the-shelf branched endografts. Advances in device design and procedural planning have expanded treatment options while minimizing morbidity and mortality. Branched grafts are poised to become the preferred solution for zone 2 pathology. The choice between hybrid, chimney, and branched endograft techniques must be tailored to the patient's anatomy, clinical urgency, and institutional experience. Hybrid procedures remain a robust option for elective cases with favorable cervical anatomy, whereas chimney stenting provides a valuable emergency solution. Branched devices represent the frontier of total endovascular repair, combining reliability with reduced invasiveness. Future developments will likely refine device design, improve delivery systems, and expand indications toward more proximal arch pathologies.

Conclusions

Endovascular repair involving aortic zone 2 represents one of the most dynamic areas in modern vascular surgery. Multiple strategies allow for effective management of the LSA while ensuring durable aortic sealing. Hybrid bypasses, chimney configurations, and branched endografts each occupy a defined niche, reflecting a continuum of technological evolution. As device innovation continues, branched solutions are expected to become the gold standard for treating aortic pathology in this challenging anatomical zone.

Availability of Data and Materials

The data used and analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

AAM, FMO, VT and CC conceived the concept. MB, SF, MF and EM outlined the editorial and contributed to discussion. AAM drafted the manuscript. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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