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REVIEW ARTICLE

Supra-aortic trunk anatomy and the limits of off-the-shelf endografts: a narrative review

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ABSTRACT

OBJECTIVE: To review and synthesize current evidence on the anatomical considerations of supra-aortic trunks (SATs) and their impact on the feasibility and design of off-the-shelf (OTS) and custom-made endografts in endovascular aortic arch repair.

METHODS: A narrative review was conducted using PubMed and Scopus databases, focusing on studies evaluating SAT morphology, spatial orientation, and device applicability. Studies addressing clock-face orientation, vessel diameters, inter-branch distances, and anatomical suitability for branched or fenestrated devices were included.

RESULTS: Anatomical studies revealed significant variation in SAT configuration, particularly inter-vessel spacing and clock-face orientation. While some consistency in takeoff angles exists, only a subset of patients met the criteria for current OTS devices. Proposed configurations in planning studies—particularly those involving a large left common carotid artery scallop and left subclavian artery fenestration or inner branches—may cover up to 85–97% of cases. Still, challenges remain due to arch angulation, large ascending diameters, and rotational misalignment in tortuous anatomy. Custom-made devices provide high anatomical conformity but are impractical in urgent settings due to production delays.

CONCLUSIONS: Anatomical variability remains a key limitation in the broader application of OTS devices for total endovascular aortic arch repair. However, strategic graft design may allow a limited set of configurations to accommodate most patient anatomies. Standardized preoperative measurements and continued refinement of device designs are essential to improving procedural success and expanding clinical applicability.

Keywords: BEVAR; FEVAR; Endovascular complex repair; Renal stent occlusion

INTRODUCTION

Endovascular treatment of aortic arch pathology is one of the most technically demanding areas in contemporary vascular surgery. Historically, open surgical repair involving cardiopulmonary bypass and deep hypothermic circulatory arrest has been the standard approach, though it carries substantial perioperative risk, particularly in elderly or comorbid patients.[1,2] In recent decades, technological advancements and improved operator experience have led to the emergence of branched and fenestrated endografts as viable alternatives for managing complex arch lesions, including aneurysms and dissections.[2,3]

The aortic arch poses unique challenges to endovascular repair due to its anatomical complexity and hemodynamic environment. Endograft stability and efficacy depend on

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precise placement within highly curved and angulated segments, with the supra-aortic trunks (SATs) involved: the brachiocephalic trunk (BCT), left common carotid artery (LCCA), and left subclavian artery (LSA). Unlike endovascular repair in more distal thoracic or abdominal locations, coverage or manipulation of SATs during arch procedures carries substantial risk of stroke, spinal cord ischemia, and upper limb ischemia.[4,5] Therefore, preserving or revascularizing these vessels is central to procedural planning.[5,6]

Various techniques have been developed to preserve SAT flow, including extra-anatomic debranching and single-branched endografts, as well as in situ techniques such as laser fenestration or chimney grafting.[2,3,5] More recently, branched arch endografts with one to three inner branches have expanded the applicability of total endovascular solutions, allowing preservation of antegrade flow to all three SATs while minimizing the need for surgical adjuncts.[1,3] However, the success of these devices relies heavily on anatomical compatibility, particularly regarding SAT distances, angles, and clock-face orientations.[1,4,6]

Several studies have tried to characterize SAT morphology in both healthy and diseased aortas to guide endograft planning and design.[4,6,7] These analyses underscore the variability in SAT origin, diameter, and spatial relationship to the ascending aorta, all of which must be carefully considered to ensure safe and effective endograft deployment.

METHODS

A narrative review was conducted to summarize the most relevant literature and expert experience on the role of the SAT position in the planning and execution of endovascular aortic arch repair.

A focused search of PubMed and Scopus was conducted to identify English-language studies published through March 2025. Keywords included: aortic arch anatomy, supra-aortic trunk, branched arch endograft, fenestrated endograft, endovascular arch repair, inner branches, and SAT morphology. Additional articles were identified by manually screening the reference lists of selected studies.

Eligible studies included anatomical imaging analyses, technical reports, clinical case series, and device planning studies that described supra-aortic trunk configuration, measurements, and their implications for endovascular repair. Emphasis was placed on articles reporting SAT clock-face orientation, diameters, inter-vessel spacing, and arch types, as well as suitability for single, double, or triple-branched endografts.

Findings are presented thematically to highlight anatomical constraints, device applicability, and evolving endovascular strategies.

RESULTS

Twelve studies with relevant insights on supra-aortic trunk anatomy and off-the-shelf endografts were included in this review. Nine articles were retrospective studies, 6 of which were single-center and 3 were multicenter. There was one prospective multicenter study and two systematic reviews, one of which included a complementary meta-analysis.

1. SAT Morphology and Anatomical Suitability

Anatomical studies have shown mixed findings regarding the consistency of SAT orientation. While some report stable clock-face takeoff angles—averaging 12:30 for the BCT, 12:00 for the LCCA, and 12:15 for the LSA — others show substantial variability in origin, orientation, and inter-vessel spacing.[1,6,8,9] One study reported SAT diameters increasing proportionally with aortic size.[6] Some studies showed a distance between the LCCA and LSA lower than 15 mm in 80% of cases. Furthermore, only 28% of patients undergoing zone 2 TEVAR for type B dissection met all anatomical criteria for a single side-branch device, primarily due to inadequate LCCA-LSA distance.[4,10]

2. Current available devices and techniques

Fenestrated thoracic endovascular aortic repair (f/TEVAR) represents a custom-made (CMD) solution for endovascular aortic repair. Several companies customize such grafts based on reconstructed images from preoperative CT scans. These techniques can be combined with additional debranching procedures, primarily for left subclavian artery (LSA) preservation.[11] Technical success in f/TEVAR is reported as high, estimated at 98.3%.[11] Reported technical failures include endograft malposition and retrograde type A aortic dissection (TAAD). Target vessel (TV) patency ranged between 96% and 100%.[11]

Branched thoracic endovascular aortic repair (b/TEVAR) accounts for both CMD and OTS solutions. Currently available OTS branched grafts include only one branch, typically designated for the BCT or LSA. In Portugal, currently available off-the-shelf branched grafts include the Gore Thoracic Branch Endoprosthesis (W.L. Gore and Associates, Flagstaff, Arizona) and the Nexus Aortic Graft System (Jotec GmbH, Hechingen). Due to their nature, single-branched grafts intended for the BCT most often require additional debranching to preserve the LCCA and LSA.[11] CMD-branched grafts are available from several companies. Technical success and TV patency is high, up to 98.7% and 98.9%, respectively.

Parallel graft (PG) techniques represent a non-CMD approach. These techniques are mostly reserved for acute cases, in which the patient cannot wait for a CMD device.[11] The technical success rate is lower, at 76.4%, and the main concern of these techniques is gutter endoleak, which can occur in 25.7% of cases.[11] Despite this complication, TV patency is reportedly high, up to 99.3%.

Physician-modified techniques (PMEG) may also be an alternative in acute cases. These grafts may be prepared on table, or in situ. Due to high technical variability, there is a lack of consistent data; however, overall reported technical success rates vary between 80% and 98.6% for on-table techniques and 89.3% for in situ techniques.[11]

3. Future directions on off-the-shelf devices

Design simplification and the push for OTS devices have driven several planning studies. One study identified two main scallop-and-fenestration configurations that would theoretically apply to 85.8% of cases.[12] Similarly, Bosse et al.

Table 1. Different OTS proposed grafts

Study	Gouveia e Melo et. al	Bosse et. al	Spanos et. al	Mougin et. al
Device configuration	LCCA 30×20 mm scallop at 12:00 + 8mm LSA fenestration, 6 mm apart from scallop	12mm BCT branch at 12:30 + 8-10 LCCA branch at 11:30	3-inner-branch graft, 90-mm spacing, suitable in 79% of prior 2-branch patients	LCCA 10x30mm scallop at 12:00 + retrograde LSA branch at 12:00

found that five modular configurations with different aortic diameters that could serve most double-branch custom-made TEVAR cases.[13] Spanos et al. showed that a 3-inner-branch device with a 90-mm branch separation was suitable in 79% of patients previously treated with 2-branch endografts, with the main exclusion criterion being LSA diameter <6 mm and insufficient distance between the BCT and LSA.[1] Mougin et al. proposed a standardized OTS device with a retrograde LSA branch and LCCA scallop, found suitable in 64.8% of zone 2 TEVAR cases.[5] D'Onofrio et al. reported favorable 3-year outcomes from a multicenter study on the Nexus bi-modular off-the shelf device with a single retrograde branch. Technical success was 100%, with no device-related deaths between years 1 and 3, and a cumulative survival rate of 71% at 3 years.[14]

4. Design Challenges and Limitations

Despite promising feasibility rates, many studies point to design limitations in OTS endografts. Gouveia e Melo et al. emphasized that tortuous arch anatomy could impair proper rotational alignment of fenestrations, particularly in fixed-design grafts. [12] Similarly, several authors noted that large ascending aortic diameters, arch angulation, and short inter-branch distances remain key exclusion factors across devices. [12,13]

5. Total versus partial arch incorporation

There is currently no robust evidence regarding outcomes in partial versus total arch involvement. However, despite a relatively low incidence of 3.2%, retrograde type A dissection remains a potential complication. It has been proposed that achieving a longer proximal landing zone within the ascending thoracic aorta may help stabilize the intimal layer and reduce the risk of this adverse event.[15]

DISCUSSION

Endovascular treatment of the aortic arch has transitioned from a conceptual frontier to a clinical reality in selected patients. Although not yet recommended as first-line therapy in current guidelines, endovascular arch repair offers an effective and safe alternative, especially in patients unfit for open or hybrid repair.[16] The continued evolution of this field is evident as the number of published cases and studies has doubled over a 3-year span, reflecting both growing interest and expanding experience among specialized centers.[17]
Fenestrated and branched TEVAR techniques are associated with high technical success rates (over 98%) and acceptable perioperative risk, while non-CMD approaches, though effective in select settings, demonstrate lower technical success rates.[11] The reduced technical success in non-CMD techniques may reflect a higher incidence of intraoperative endoleak. Notably, up to 50% of these early endoleaks appear to resolve during follow-up and do not significantly influence early mortality.[18,19] Non-CMD techniques remain a valuable option in urgent or emergent settings, where custom-made devices are typically unavailable. Approximately 20% of reported cases involved urgent interventions, with a particularly high proportion among patients treated with the PG technique.[11] Early mortality across all techniques remains low, and midterm follow-up shows acceptable survival rates. Aorta-related mortality remained below 4% across all techniques.[11] Nonetheless, long-term data remain scarce, and caution should be exercised when interpreting these midterm outcomes.[1,11]

Neurologic complications, particularly stroke and spinal cord ischemia, represent the most serious adverse events associated with endovascular arch repair. Risk factors for cerebral embolic events include extensive aortic atheroma, proximal landing zones (zones 0 and 1), and LSA revascularization procedures.[20] This underscores the need for improved cerebral protection strategies, such as embolic filters and air management techniques, particularly in complex arch cases. Until dedicated cerebral protection devices are widely available, the elevated risk of cerebrovascular events in f/bTEVAR warrants careful patient selection based on aortic anatomy and procedural planning.

The decision between total versus partial involvement of the arch remains a debate and an underexplored theme. Extending the proximal landing zone to zone 0 may contribute to a reduction in the incidence of retrograde type A dissection, although this remains a theoretical consideration.[15] An additional parallel rationale can be drawn from thoracoabdominal aortic repair, where a supraceliac landing zone is frequently selected, even when a more distal landing is technically feasible, in order to increase long-term durability. Applying this rationale to the aortic arch, a more proximal landing zone may similarly promote more durable outcomes, though this remains speculative. However, this increases manipulation on the SAT, leading to potential complications, such as an increased incidence of stroke.

Re-intervention remains a critical issue, primarily due to persistent or recurrent endoleaks. Re-intervention rates are approximately 9% for f/bTEVAR and between 5.5% and 7.2% for PG and PMEG techniques.[11] Target-vessel patency exceeded 98% for all methods, while type Ia endoleak rates were under

6% for CMD and up to 19% for non-CMD techniques.[11] The need for distal extensions or staged interventions in patients with extensive aortic involvement likely contributes to these rates. Nonetheless, staging is often necessary to reduce SCI risk, which may justify secondary procedures.

Anatomical variability of SATs continues to limit the universal applicability of devices. Whether a truly "standard aortic arch anatomy" exists remains debatable. Although some consistency in SAT clock-face origin exists, variability in inter-vessel distances and aortic diameter necessitates individualized planning.[12,13] While CMDs offer optimal anatomical tailoring, their utility in acute cases is restricted by production delays. OTS solutions are under increasing development, aimed at providing prompt access while maintaining anatomical compatibility.

Techniques such as PMEGs and PGs remain essential in urgent or off-label scenarios. However, these methods are associated with increased risks of stroke, endoleak, and re-intervention when compared with dedicated fenestrated or branched devices. PMEGs are particularly vulnerable to long-term durability concerns due to mechanical stress from unsupported fenestrations in high-flow zones, such as the ascending aorta and aortic arch. Parallel grafts, while fast to deploy, are similarly limited by higher complication rates. Consequently, CMDs remain the preferred option when time and patient anatomy permit, while ongoing development of OTS branched configurations may expand applicability in both elective and emergent settings.

CONCLUSION

Endovascular repair of the aortic arch is increasingly feasible and has evolved into a mature and effective strategy for selected patients, particularly those at high surgical risk. While f/bTEVAR techniques demonstrate superior technical performance and clinical outcomes, non-CMD approaches offer reasonable alternatives in urgent or anatomically complex scenarios. However, anatomical variability remains a significant limitation, particularly for the applicability of OTS devices. Although current OTS solutions show promising early results, their use is still constrained by the variable anatomies. Emerging data suggest that a limited number of well-designed configurations could accommodate a broader range of anatomies and significantly expand the applicability of total endovascular repair. Future studies should focus on graft design, long-term durability, and neurologic safety through better cerebral protection strategies. In parallel, standardizing anatomical assessment and procedural planning will be essential to support the wider adoption of OTS technologies and ensure safe extension of endovascular repair to a broader patient population.

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