# Technical tips and clinical experience with the Cook Triple inner arch branch stent-graft

Emanuel R. Tenorio MD PhD[1], Andrea Vacirca, MD PhD[1], Thomas Mesnard, MD[1], Titia Sulzer[1], Aidin Baghbani-Oskouei, MD[1], Aleem K. Mirza, MD[1], Ying Huang[1], MD PhD[1], and Gustavo S. Oderich[1], MD.

*Department of Cardiothoracic & Vascular Surgery, Advanced Aortic Research Program at the University of Texas Health Science Center at Houston, McGovern Medical School, Houston, TX*

**Conflict of interest disclosure**: Dr. Gustavo S. Oderich has received consulting fees and grants from Cook Medical, W. L. Gore, Centerline Biomedical, and GE Healthcare (all paid to Mayo Clinic and The University of Texas Health Science at Houston with no personal income). Other co-authors: no disclosure.

**Address for correspondence:** Gustavo S. Oderich MD; Memorial Hermann Medical Plaza, The University of Texas Health Science Center at Houston, McGovern Medical School, 6400 Fannin Street, Suite 2850, Houston TX 77030; e-mail: gustavo.oderich@uth.tmc.edu.

**Abstract**

Open surgical repair remains the gold standard for treatment for aortic arch diseases, but these operations can be associated with wide heterogeneity in outcomes and significant morbidity and mortality, particularly in elderly patients with severe comorbidities or those who had prior arch procedures via median sternotomy. Endovascular repair has been introduced as a less invasive alternative to reduce morbidity and mortality associated with open surgical repair. The technique evolved with new device designs using up to three inner branches for incorporation of the supra-aortic trunks. This manuscript summarizes technical tips and clinical experience with the triple inner arch branch stent graft for total endovascular repair of aortic arch pathologies.

**Keywords:** A-branch; aortic arch pathologies; total endovascular arch repair; three-inner branches.

## Introduction

Since the first thoracic endovascular aortic repair procedure performed by Nikolaos Volodos on March 24, 1987, for the treatment of a post-traumatic thoracic aortic aneurysm(1), endovascular techniques have evolved and disseminated worldwide becoming the first line of treatment for most descending thoracic aortic aneurysms and dissections. This less invasive alternative to open surgical repair allowed treatment of higher risk patients who were previously considered unsuitable candidates.(2, 3) Although several stent-grafts are approved for use in the descending thoracic and abdominal aorta, branch stent-grafts remain mostly investigational. Due to its anatomical and physiological limitations, the aortic arch has been considered one of the last frontiers yet to be conquered by endovascular repair.(4) Technical challenges are many as the device approaches the aortic annulus, including the naturally curved and angulated aortic arch; the variable origin of the supra-aortic trunks and the relative short distance to the coronary ostia and aortic valve. Other factors such as coronary grafts, atherosclerotic debris, mechanical aortic valves, and the presence of kinked ascending grafts or presence of short suitable landing zones may prohibit treatment by endovascular techniques. The natural angulation of the arch curvature may render stents difficult to maneuver, making alignment of branches and fenestrations impossible. Because of hostile hemodynamic forces and respiratory motion, long-term durability requires special stent designs resistant to fatigue, fracture, migration, and kinks.(5)

All the above may explain why open surgical repair remains the gold standard for treatment of aortic arch pathologies in most patients who are deemed low or intermediate risk. Additionally, improvements in cerebral protection with deep hypothermia, retrograde and antegrade cerebral perfusion have lowered the risk of neurological complications associated with open surgical repair.(6) However, despite these improvements, there are significant outcome

variations among centers. Open surgical repair is especially challenging among elderly, frail patients and those with multiple comorbidities or who have undergone prior ascending or arch procedures via median sternotomy.(7, 8) Concurrently, total endovascular approaches have been increasingly utilized to treat aortic arch pathologies, initially as an alternative in higher risk patients. Increasing experience and refinements in stent-graft design and delivery systems, along with improved patient selection, have lowered the morbidity and mortality of these procedures, rivaling the outcomes of open surgical repair in lower-risk patients.(9, 10) Increasing clinical experience in the western world with total endovascular aortic arch repair has been gained using double or triple inner branch stent-grafts (A-branch, William Cook Europe, Bjaeverskov, Denmark). Although the first designs included two inner branches, thus requiring a left subclavian artery (LSA) debranching, a triple branch device with a preloaded catheter has gained wide application. This article summarizes technical tips and clinical experience with the Cook A-branch stent-graft with three inner-branches.

**Triple inner branch stent-graft**

The triple inner-branch stent graft or Cook A-branch stent-graft is designed with one or two proximal sealing stents and two antegrade and one retrograde inner branches intended to incorporate the innominate artery (IA), left common carotid artery (LCCA), and LSA. The IA and LCCA o'clock positions are fixed (o'clock position at 12:30 and o'clock position at 11:30, respectively), while the LSA o'clock position is variable to fit the patient's anatomy. Each inner branch is coupled with a diamond-shaped fenestration to facilitate catheterization. A preloaded catheter can be used for access to the retrograde LSA only, LSA/LCCA, or LSA/IA inner branch via the femoral approach. The pre-loaded catheter is routed primarily into the LSA branch but can be allowed to maintain access into the LCCA or IA if a total femoral approach is planned.

The device is self-oriented, so that the diamond-shaped fenestrations and inner branches face the outer arch curvature, which is facilitated by a pre-shaped cannula and a four-step release mechanism (**Figure 1**). Although the A-branch stent-graft is a custom-made device, the predictable location of supra-aortic trunk vessels and the "adaptability" of access to the inner branches via diamond-shaped fenestrations can be translated into off-the-shelf concepts.(11) Features that facilitate adaptability include the predictable orientation towards the outer curvature of the aorta, the tapered middle segment of the arch inner branch stent-graft and wider access provided by larger diamond shaped fenestrations. The design requires less precision during implantation, while providing continued perfusion to the supra-aortic trunks and simplifying catheterization of the inner branches.

**Clinical and anatomical considerations**

Multidisciplinary approach involving members of vascular surgery, cardiac surgery, interventional cardiology and cardiovascular anesthesia is recommended for treatment of complex arch pathology. In order to determine feasibility for a complete endovascular approach, certain anatomic criteria need to be met. Most of these patients have prior ascending repair with prosthetic graft which serves as proximal landing and sealing zone for an endograft, making it crucial that the ascending graft is long and free of kinks to allow a minimum of 2 cm and ideally 4cm.

Computed Tomographic Angiography (CTA) remains the most important imaging modality for assessment of anatomic feasibility for ascending aortic and arch branched endovascular repair. Ideally the study should be gated to eliminate artifact and variations in diameter assessment in the ascending aorta. A centerline of flow measurements is used to estimate lengths, usually based on the outer aortic curvature instead of the center lumen, which is

typically used for the thoracic and renal-mesenteric aortic segments. Echocardiography is obtained to assess adequacy of the aortic valve. While an endovascular approach to arch repair may ultimately offer an approach with the least perioperative morbidity, challenges remain in device design and implantation to achieve optimal long-term results. Specific concerns for endovascular repair include adequate seal, long-term device durability, device alignment, stroke, aortic valve issues and mortality.

***Seal Zone***

Over the last decade outcomes from endovascular aneurysm repair studies have repeatedly demonstrated that an adequate seal zone must be present in order to achieve long-term device success.(12, 13) In the arch, an adequate seal zone is comprised of neck diameters consistent with healthy tissue (< 38mm for native aorta and <42mm for polyester graft), minimal tapering, a length of >25mm that is free of excess calcification and thrombus, and aortic angulation < 60°. Although some reports have advocated more liberal use of larger aortic diameters (40 or 42mm) as sealing zone, these are associated with higher risk of retrograde type A dissection. Haulon and colleagues identified that aortic diameter > 38 mm is associated with higher mortality and rate of complications, including retrograde type A dissection.(14) Selection of patients within proper proximal sealing zones reduces the risk of Type I endoleaks, device migration and increases the likelihood of long-term performance. In the case of aortic arch treatment, landing the device within a healthy seal zone is challenged by the relatively short ascending aorta. Due to the catastrophic consequences that can occur due to loss of device seal and/or device migration in the aortic arch, maximizing the length of seal beyond the standard 25mm may be warranted to account for aortic growth, remodeling, and potential disease progression. Sealing zones of > 4cm are ideal in the ascending aorta based on length from the

sino-tubular junction (STJ) to the start of the aneurysm. The minimum requirement using the outer curvature of the aortic wall is 25mm. Of specific concern is the high pulsatility of the aortic arch, subjecting the stents to more significant fatigue loading conditions. Pulsatility of the vessels in this region has been reported to be 2-3 times higher than the pulsatility seen in the descending thoracic and abdominal aorta. Additionally, branch vessel motion relative to the aorta due to cardiac pulsation and respiration will have to be quantified to address long-term durability. These motions could lead to device complications such as graft wear, stent fracture, and stent kink, all of which could be detrimental to device performance. Although a prosthetic graft offers the ideal proximal landing zone and avoids the risk of retrograde dissection, these grafts must be straight and of enough length to allow at least one full stent apposition and prevent risk of endoleak. Milne and colleagues reported that 71% of patients with prosthetic grafts in the ascending aorta were considered suitable candidates for arch branch devices. In that study, the most common exclusion criteria were short graft length (71%), kink (24%, **Figure 2**) or diameter >38 mm (5%).(15) Patients with coronary grafts may also have unsuitable landing zones for endovascular repair.

***Access***

Most aortic arch branched devices require delivery systems with an outer diameter of 22 to 26 French, requiring a 7.5 to 9mm of healthy external iliac artery diameter. In the setting of severe tortuosity, narrowing, severe calcifications, or prior stents, a planned iliac conduit offers a suitable alternative to avoid the risk of inadvertent disruption of the iliac arteries. In addition to access to the iliac vessels, the brachial and axillary arteries should be assessed for dissection, narrowing or aneurysmal degeneration that can affect the suitability of stenting into the supra-aortic trunks.

***Device Alignment***

The ability to accurately align and deploy an arch stent graft is essential. Implementing designs with self-aligning features of the inner branches to the target vessels will minimize the need for excessive manipulation of the device in the aortic arch, thus reducing the risk of stroke due to emboli. Due to the length of the delivery systems utilized for transfemoral access, the ability to precisely control the device end of the delivery system is limited, further highlighting the need for "auto" aligning features. Additionally, a controlled release of the stent graft from the delivery system is warranted, with the minimal motion of the device occurring. The motion of the device during release can lead to catastrophic events, including coronary artery coverage and/or misalignment of the inner branches with the great vessels. In this direction, cardiac output reduction has been considered an essential adjunctive to precisely deploy the cook a-branch. Currently, cardiac output reduction with rapid ventricular pacing or partial inflow atrial occlusion with the placement of a semi-compliant balloon in the inferior vena cava have been the most used and most described. Recently, Tsilimparis and colleagues described the use of a modified Valsalva maneuver – Munich Valsalva Implantation Technique – as an alternative for cardiac output reduction.(16)

***Aortic Valve***

Due to the relative proximity of the aortic valve to the aortic arch and branch vessels, it is of utmost importance to design endovascular devices and delivery systems that will limit valve interaction and be atraumatic to the valve when interactions do occur. While in current TAVI procedures, wire guides, catheters, and sheaths are placed across the valve routinely, these procedures have been associated with stroke and valve damage. Additionally, current EVAR systems are large in diameter, and delivery system tips are relatively stiff, potentially increasing

the risk of valve damage, especially in cases where the system must be left across the aortic valve for extended periods of time. Finally, because these procedures are modular and may require crossing the aortic valve multiple times in order to place each component, which will further expose the valve to potential injury. It will be essential to valve health that endovascular repair options limit valve involvement and encompass atraumatic materials such that minimal damage occurs.

***Target vessels***

A non-aneurysmal, non-dissected target vessel is required for endovascular repair of aortic arch. There is some variation in maximum required diameter. The innominate artery can be incorporated using a flared stent-graft, usually with diameter up to 20mm. For the left carotid artery and left subclavian arteries, stent-graft diameters range between 8 to 14mm. Some of these limitations can be overcome by surgical debranching of the supra-aortic trunk vessels, such as in the case of patients with dissections that extent into the carotid arteries (**Figure 3**).

***Stroke***

Neurologic complications remain a major concern with any procedure to treat aortic arch pathology, including open surgical and endovascular repair. Major contributing factors to stroke during these procedures include emboli due to device, delivery system and/or wire manipulation, air emboli released from the delivery system, and coverage of branched vessels. Additionally, special care must be taken to ensure that the systems are entirely void of air upon sheath withdrawal to avoid any potential air emboli. For this purpose, flushing the device with CO2, followed by flushing of the CO2 with heparinized saline, has been recommended to decrease the risk of air emboli.(17) Additionally, the use of direct carotid exposure for sequential clamping during catheter manipulations probably decreases the risk of emboli on the ipsilateral side while

providing excellent support for the advancement of the bridging stent grafts. A porcelain aorta with severe calcifications or a thrombus-laden arch is fraught with a formidable risk of stroke and poor apposition of the endograft in the sealing zone, making these contraindications for total endovascular repair (**Figure 4**). The risk of stroke can be related to the etiology of the aortic arch pathology. For example, post-dissection aneurysms may harbor a lower atherosclerotic burden as compared to degenerative aneurysms.

***Specific device qualifications***

The criteria for this device are summarized below:(18, 19)

1. Ascending aortic length ≥ 50 mm (measured from STJ to origin of innominate artery)
2. Sealing zone in the ascending aorta ≥ 40mm in length and ≤ 38 mm diameter for native aorta or ≤ 42 mm for polyester graft
3. Sealing zone in the innominate artery ≥ 20 mm in length and ≤ 20 mm in diameter
4. Access able to accommodate 22F or 24F sheaths

**Clinical experience**

Tenorio and colleagues recently published a global experience with the triple inner branch stent-graft using the A-branched Cook device. The study included a total of 39 patients, with an early mortality rate of 5% and combined major and minor stroke rate of 2.5% each, achieving 100% technical success. The mean diameter at the proximal sealing zone was 34±3 mm (34, 31-36 mm); the diameter of the proximal sealing zone was larger among patients who had stent-grafts implanted into native aorta compared to surgical grafts (35±3 mm vs. 33±3 mm, p=.02). There was no difference in oversizing for stent-grafts implanted in native aorta vs. surgical grafts (17±5% vs. 18±4%, p=.32). The mean length from STJ to IA was 74±15 mm (74, 64-89 mm). Twenty-three patients (59%) had devices designed with two proximal sealing stents,

and 16 patients (41%) had devices with one proximal sealing stent. The device configuration with two sealing stents was more common among patients who had the proximal sealing zone into the native aorta (90% vs. 46%, p=.01). The most common axial positions were 12:30 o'clock for IA branches in 16 patients (42%), 11:30 o'clock for LCCA branches in 12 patients (32%) and 12:00 or 12:30 o'clock for LSA branches in 12 patients (32%, **Figure 5**). Chronic post-dissection arch aneurysms accounted for 64% of the study population.(20)

Despite the great results regarding early mortality and stroke rates, the authors found high rates of secondary procedures been cervical access complications, along with target vessel endoleaks, were the most common reasons for early secondary interventions. Strategies to reduce access-related secondary procedures certainly include meticulous hemostasis and closure, but higher intraoperative activated clotting times and a generally lower threshold for hematoma decompression in the neck may inevitably predispose these access sites to more frequent reinterventions. Therefore, in an attempt to reduce the risk of cervical access issues, the use of percutaneous approaches via femoral and axillary access or total femoral access have been proposed. The development of steerable sheaths has allowed direct access to the inner branches and sequential stenting of the LCCAs and, in some cases, the IA.(21) Experience with percutaneous axillary artery for TAAA FB-EVAR has also prompted its use for arch repair.(22, 23) More recently, a report led by Mougin et al described the first three-vessel, totally percutaneous aortic arch repairs using inner branches in two patients. Incorporation of all three vessels was accomplished from the femoral approach for the LCCA and LSA and the right axillary artery for the IA, avoiding the need for cervical incisions and its potential complication risks (**Figure 6**).(24) We have modified this technique to perform a total trans-femoral percutaneous endovascular aortic arch repair using three-vessel inner branch stent-graft. First, we

proposed a change in the pathway of the preloaded catheter routed from the LSA to IA, instead to LCCA (**Figure 7**). Second and most important, we have uses two co-axial systems in parallel (6Frx90cm Shuttle and 8.5x90cm steerable sheaths) via a 22Frx65cm DrySeal sheath to provide support and stability in the proximal thoracic aorta. The "push & pull" maneuver allows advancement of the sheath without undue stress in the inner branch or risk of stent dislodgement (**Figure 8**). A total trans-femoral approach can be associated with even less complication since the reports from transaxilary percutaneous access have been associated with considerable rates of open conversion and adjunctive endovascular procedures.(23)

Although none of the patients experienced neurologic deficit despite the lack of sequential carotid clamping, the question remains which patients should be selected for total percutaneous versus open cervical access techniques and how we can prevent emboli when using a percutaneous approach. Currently, it seems prudent to select patients based on underlying pathology along with the quality of the arch and supra-aortic trunks, with the ideal candidates having prior ascending aortic repair and no evidence of any atheromatous disease in the arch. Other technology, such as filters specific to aortic arch stent-grafts, is under development and may be used as adjuncts, particularly in these total percutaneous cases.

**Conclusion**

Endovascular total arch repair using the a-branch cook device provides a valuable alternative option for patients who are poor surgical candidates, and technical success is high with careful patient selection. However, the rate of early reinterventions is also relatively high, with the most frequent indications being cervical access site complications and endoleaks. Learning from current experiences of the multicenter collaborations, the anticipation of these

complications using preemptive strategies such as preparation of target vessel landing zones, and the use of a total femoral approach can potentially lower reintervention rates in the future.

## References

1. Volodos N, Shekhanin V, Karpovich I, Troian V. A self-fixing synthetic blood vessel endoprosthesis. Vestnik khirurgii imeni II Grekova. 1986;137(11):123-5.

2. Inoue K, Hosokawa H, Iwase T, Sato M, Yoshida Y, Ueno K, et al. Aortic arch reconstruction by transluminally placed endovascular branched stent graft. Circulation. 1999;100(suppl_2):II-316-Ii-21.

3. Chuter TA, Schneider DB, Reilly LM, Lobo EP, Messina LM. Modular branched stent graft for endovascular repair of aortic arch aneurysm and dissection. Journal of vascular surgery. 2003;38(4):859-63.

4. Parikh N, Trimarchi S, Gleason TG, Kamman AV, Di Eusanio M, Myrmel T, et al. Changes in operative strategy for patients enrolled in the International Registry of Acute Aortic Dissection interventional cohort program. The Journal of thoracic and cardiovascular surgery. 2017;153(4):S74-S9.

5. e Melo RG, Stana J, Prendes CF, Kölbel T, Peterss S, Stavroulakis K, et al., editors. Current State and Future Directions of Endovascular Ascending and Arch Repairs: The Motion Towards an Endovascular Bentall Procedure. Seminars in Vascular Surgery; 2022: Elsevier.

6. Czerny M, Schmidli J, Adler S, Van Den Berg JC, Bertoglio L, Carrel T, et al. Current options and recommendations for the treatment of thoracic aortic pathologies involving the aortic arch: an expert consensus document of the European Association for Cardio-Thoracic surgery (EACTS) and the European Society for Vascular Surgery (ESVS). European journal of cardio-thoracic surgery. 2019;55(1):133-62.

7. Urbanski PP, Luehr M, Di Bartolomeo R, Diegeler A, De Paulis R, Esposito G, et al. Multicentre analysis of current strategies and outcomes in open aortic arch surgery: heterogeneity is still an issue. European Journal of Cardio-Thoracic Surgery. 2016;50(2):249-55.

8. Shrestha M, Martens A, Kaufeld T, Beckmann E, Bertele S, Krueger H, et al. Single-centre experience with the frozen elephant trunk technique in 251 patients over 15 years. European Journal of Cardio-Thoracic Surgery. 2017;52(5):858-66.

9. Spear R, Haulon S, Ohki T, Tsilimparis N, Kanaoka Y, Milne C, et al. Editor's choice–subsequent results for arch aneurysm repair with inner branched endografts. European Journal of Vascular and Endovascular Surgery. 2016;51(3):380-5.

10. Verscheure D, Haulon S, Tsilimparis N, Resch T, Wanhainen A, Mani K, et al. Endovascular treatment of post type A chronic aortic arch dissection with a branched endograft: early results from a retrospective international multicenter study. Annals of surgery. 2021;273(5):997-1003.

11. Bosse C, Kölbel T, Mougin J, Kratzberg J, Fabre D, Haulon S. Off-the-shelf multibranched endograft for total endovascular repair of the aortic arch. Journal of vascular surgery. 2020;72(3):805-11.

12. AbuRahma AF, Campbell J, Stone PA, Nanjundappa A, Jain A, Dean LS, et al. The correlation of aortic neck length to early and late outcomes in endovascular aneurysm repair patients. Journal of vascular surgery. 2009;50(4):738-48.

13. Schanzer A, Greenberg RK, Hevelone N, Robinson WP, Eslami MH, Goldberg RJ, et al. Predictors of abdominal aortic aneurysm sac enlargement after endovascular repair. Circulation. 2011;123(24):2848-55.

14. Haulon S, Greenberg RK, Spear R, Eagleton M, Abraham C, Lioupis C, et al. Global experience with an inner branched arch endograft. The Journal of Thoracic and Cardiovascular Surgery. 2014;148(4):1709-16.

15. Milne CP, Amako M, Spear R, Clough RE, Hertault A, Sobocinski J, et al. Inner-branched endografts for the treatment of aortic arch aneurysms after open ascending aortic replacement for type A dissection. The Annals of thoracic surgery. 2016;102(6):2028-35.

16. Tsilimparis N, Abicht J-M, Stana J, Konstantinou N, Rantner B, Banafsche R, et al. The munich valsalva implantation technique (MuVIT) for cardiac output reduction during TEVAR: vena cava occlusion with the valsalva maneuver. Journal of Endovascular Therapy. 2021;28(1):7-13.

17. Kölbel T, Rohlffs F, Wipper S, Carpenter SW, Debus ES, Tsilimparis N. Carbon dioxide flushing technique to prevent cerebral arterial air embolism and stroke during TEVAR. Journal of Endovascular Therapy. 2016;23(2):393-5.

18. Spanos K, Haulon S, Eleshra A, Rohlffs F, Tsilimparis N, Panuccio G, et al. Anatomical suitability of the aortic arch arteries for a 3-inner-branch arch endograft. Journal of Endovascular Therapy. 2021;28(1):14-9.

19. Spanos K, Panuccio G, Rohlffs F, Heidemann F, Tsilimparis N, Kölbel T. Technical aspects of branched thoracic arch graft implantation for aortic arch pathologies. Journal of Endovascular Therapy. 2020;27(5):792-800.

20. Tenorio ER, Oderich GS, Kölbel T, Dias NV, Sonesson B, Karelis A, et al. Multicenter global early feasibility study to evaluate total endovascular arch repair using three-vessel inner branch stent-grafts for aneurysms and dissections. Journal of vascular surgery. 2021;74(4):1055-65. e4.

21. Settembrini AM, Kölbel T, Rohlffs F, Eleshra A, Debus ES, Panuccio G. Use of a steerable sheath for antegrade catheterization of a supra-aortic branch of an inner-branched arch endograft via a percutaneous femoral access. Journal of Endovascular Therapy. 2020;27(6):917-21.

22. Bertoglio L, Mascia D, Cambiaghi T, Kahlberg A, Melissano G, Chiesa R. Percutaneous axillary artery access for fenestrated and branched thoracoabdominal endovascular repair. Journal of vascular surgery. 2018;68(1):12-23.

23. Bertoglio L, Conradi L, Howard DP, Kaki A, Van den Eynde W, Rio J, et al. Percutaneous transaxillary access for endovascular aortic procedures in the multicenter international PAXA registry. Journal of vascular surgery. 2022;75(3):868-76. e3.

24. Mougin J, Azogui R, Guihaire J, Tyrrell MR, Oderich GS, Fabre D, et al. "First in Man" Total Percutaneous Aortic Arch Repair With 3-Inner-branch Endografts: A Report of Two Cases. Annals of Surgery. 2021;274(6):e652-e7.

## Notes

### *Conflict of interest*

Dr. Gustavo S. Oderich has received consulting fees and grants from Cook Medical, W. L. Gore, Centerline Biomedical, and GE Healthcare (all paid to Mayo Clinic and The University of Texas Health Science at Houston with no personal income). Other co-authors have no conflict of interest to disclose.

### *Funding*

No funding was received to support this research.

### *Authors' contributions*

Emanuel R. Tenorio, Andrea Vacirca, Thomas Mesnard, Aidin Baghbani-Oskouei and Titia Sulzer worked on manuscript writing. Aleem K. Mirza, Ying Huang and Gustavo S. Oderich worked on manuscript revision.

All authors read and approved the final version of the manuscript.

***Figure legends***

**Figure 1.** Schematic illustration of the plan for total endovascular arch repair showing the route of the preloaded catheter (**A**); Illustration of the device with three inner branches (**B**); Photography of the four-step release mechanism of the three inner branches stent-graft (**C**).

**Figure 2.** Illustration showing a severe kink in a previous ascending aortic graft that can preclude the use of endovascular stent-graft (**A**); Examples of ascending aortic grafts without kink with enough landing zone (**B** and **C**).

**Figure 3.** Illustration showing a right carotid-subclavian bypass with stenting as the first stage, creating an adequate lending zone for the right innominate/carotid artery for a total arch endovascular repair.

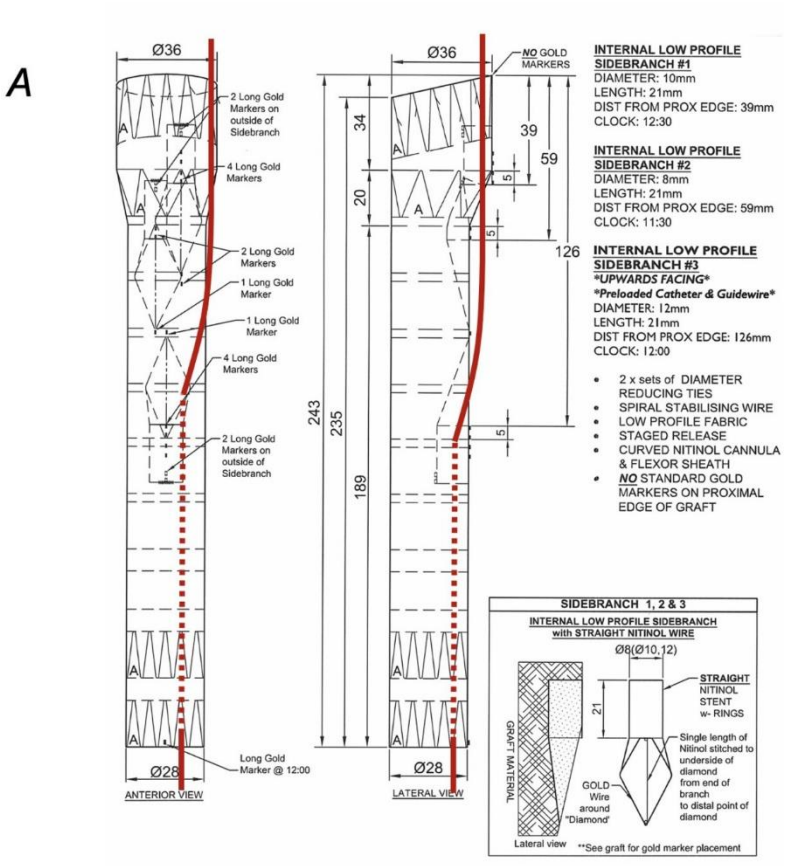
**Figure 4.** Illustration with a thrombus-laden arch (**A**); Computed tomography angiography (CTA) and 3D reconstruction showing porcelain aorta (**B**); CTA showing a type III arch with thrombus and calcinations (**C**); CTA showing "shaggy aorta" (**D**).

**Figure 5.** Illustration showing o'clock position distribution for the innominate artery (*yellow dots*), left common carotid artery (*green dots*) and left subclavian artery (*purple dots*) in the three-vessel inner branch stent-graft with one or two proximal sealing stents. STJ, Sinotubular junction.[20]

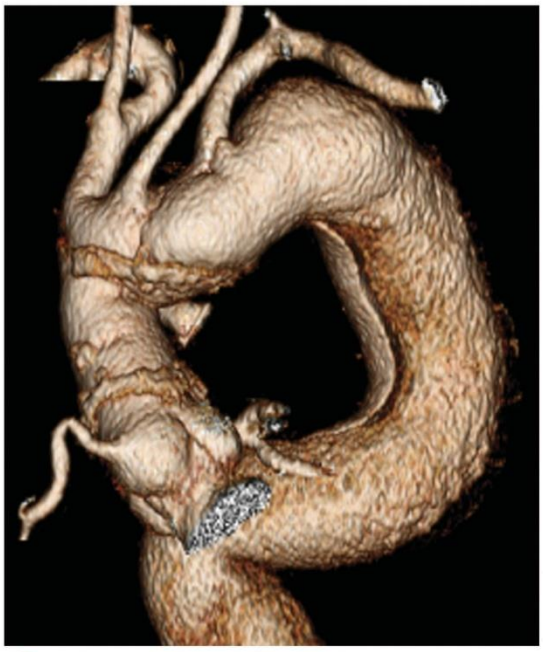
**Figure 6.** Total percutaneous aortic arch repair with three-inner branch stent grafts. The first inner branch intended for the innominate artery was accessed via the percutaneous axillary access (**A-C**). The left common carotid and left subclavian arteries were accessed from the femoral approach (**D-E**). Closure of the axillary access with ProGlide sutures and a short, covered stent graft from the downstream 5Fr brachial access (**F**).

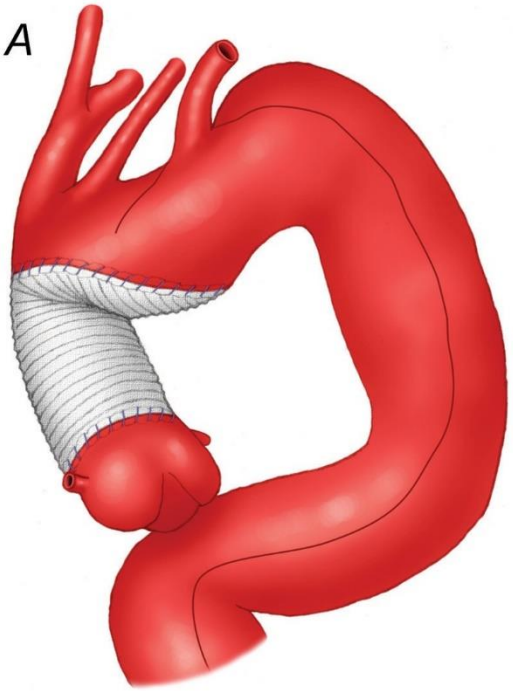
**Figure 7.** Schematic illustrations show the preloaded catheter routes for total percutaneous aortic arch repair using the total femoral approach (**A**) or axillary plus femoral approach (**B**).

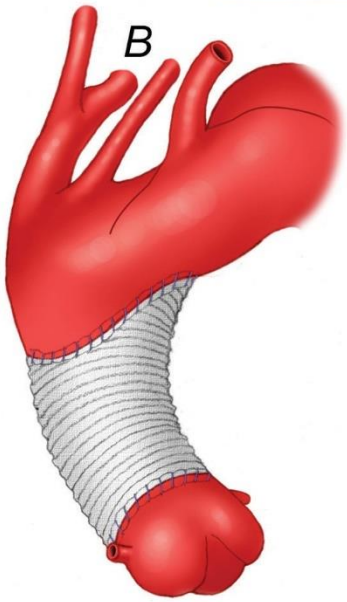
**Figure 8.** Total trans-femoral percutaneous endovascular aortic arch repair using three-vessel inner branch stent graft. The stent graft was introduced via the right femoral access over the Lundquist wire and positioned in the ascending aorta. Using temporary rapid ventricular pacing, the three-vessel inner branch stent graft was deployed precisely distal to the sinotubular junction (**A-B**). A 6Frx110cm shuttle sheath was advanced into the innominate artery (IA) branch. Using a VS1 catheter, a 0.014 wire was advanced and snared via the same right femoral sheath, establishing through-and-through right femoral access via the IA branch. The 6Fr shuttle sheath was advanced via the IA branch and married into the dilator of a with an 8.5Frx90cm steerable sheath. Using a "push & pull" maneuver, the 8.5Frx90cm steerable sheath was advanced and positioned inside the IA branch (**C-D**). The repair was extended into the right common carotid artery (RCCA) using two 8Lx79 mm balloon-expandable stent grafts, which were post-dilated proximally to 14 mm. The same steps were repeated for the left common carotid artery (LCCA) with the placement of 8Lx79 mm balloon-expandable stent graft in the LCCA, which was post-dilated proximally to 14 mm (**E**). Finally, the left subclavian artery (LSA) was selectively catheterized with a Glidewire and Kumpe catheter, which was exchanged for Amplatz wire. Stenting from the retrograde LSA branch to the proximal LSA was performed using two 13x50 mm overlapping self-expandable stent-graft (**F**). The repair was extended distally into Zone 5 in the thoracic aorta using a 30-30-200-mm Alpha thoracic stent-graft (**G**)


A
Ø36
2 Long Gold Markers on outside of Sidebranch
4 Long Gold Markers
2 Long Gold Markers
1 Long Gold Marker
1 Long Gold Marker
4 Long Gold Markers
2 Long Gold Markers on outside of Sidebranch
Long Gold Marker @ 12:00
Ø28
ANTERIOR VIEW
Ø36
NO GOLD MARKERS
34
20
243
235
189
39
59
126
5
Ø28
LATERAL VIEW
INTERNAL LOW PROFILE SIDEBRANCH #1
DIAMETER: 10mm
LENGTH: 21mm
DIST FROM PROX EDGE: 39mm
CLOCK: 12:30
INTERNAL LOW PROFILE SIDEBRANCH #2
DIAMETER: 8mm
LENGTH: 21mm
DIST FROM PROX EDGE: 59mm
CLOCK: 11:30
INTERNAL LOW PROFILE SIDEBRANCH #3
*UPWARDS FACING*
*Preloaded Catheter & Guidewire*
DIAMETER: 12mm
LENGTH: 21mm
DIST FROM PROX EDGE: 126mm
CLOCK: 12:00
2 x sets of DIAMETER REDUCING TIES
SPIRAL STABILISING WIRE
LOW PROFILE FABRIC
STAGED RELEASE
CURVED NITINOL CANNULA & FLEXOR SHEATH
NO STANDARD GOLD MARKERS ON PROXIMAL EDGE OF GRAFT
SIDEBRANCH 1, 2 & 3
INTERNAL LOW PROFILE SIDEBRANCH with STRAIGHT NITINOL WIRE
Ø8(Ø10,12)
21
STRAIGHT NITINOL STENT w- RINGS
Single length of Nitinol stitched to underside of diamond from end of branch to distal point of diamond
GOLD Wire around "Diamond"
GRAFT MATERIAL
Lateral view
**See graft for gold marker placement
B

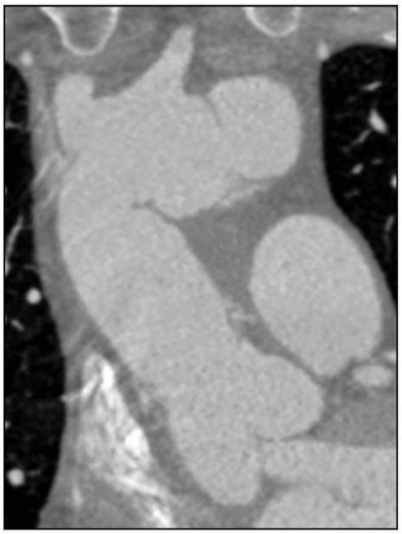

C
Warning
Infra-Renal Fixation
No uncovered top stent
4TH RELEASE MECHANISM
Deploys Distal Attachment & Releases Distal Reducing Ties
3RD RELEASE MECHANISM
Deploys Proximal 12:00 wire & Releases Proximal Reducing Ties
2ND RELEASE MECHANISM
Deploys Two Inner Curve Proximal Wires
1ST RELEASE MECHANISM
Releases Spiral Stabilising Wire

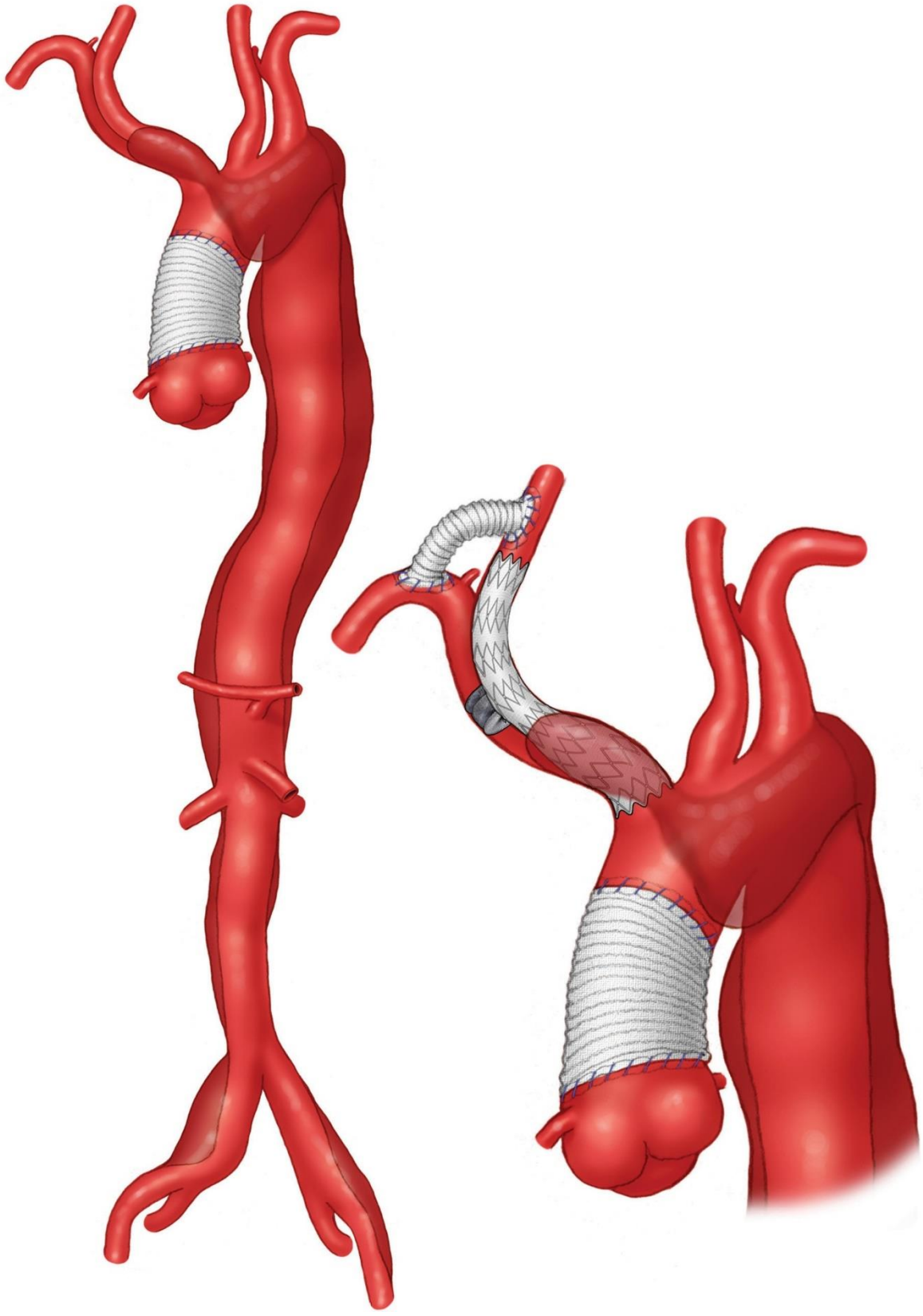


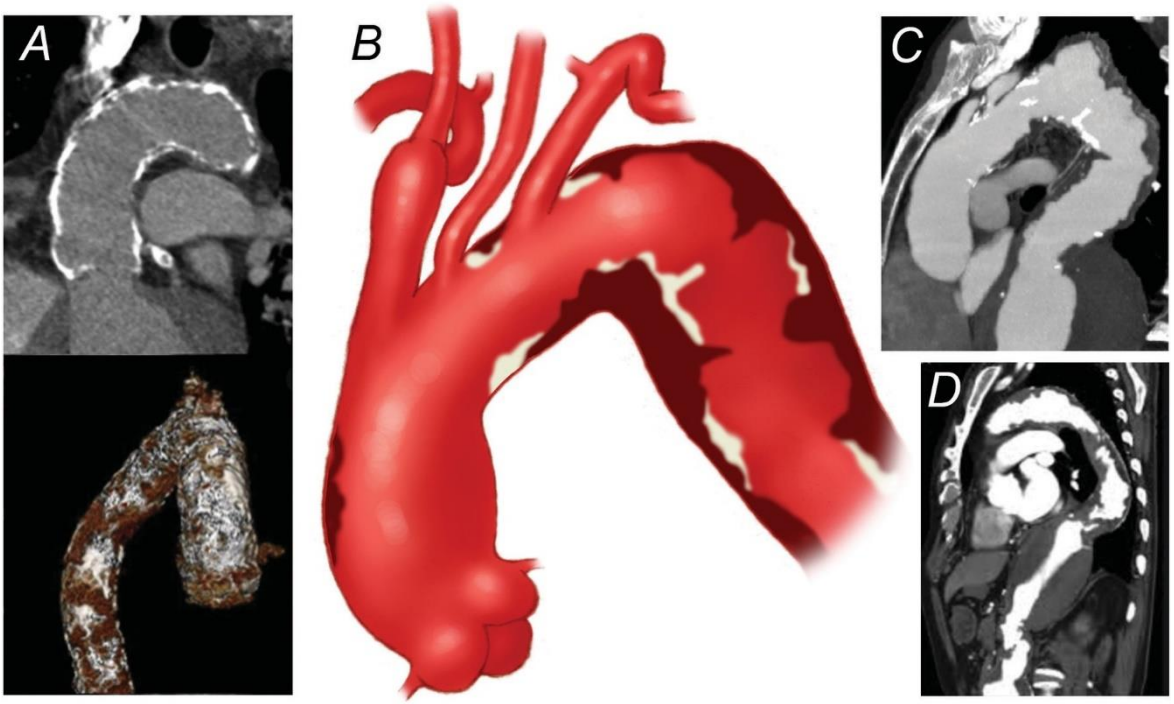

A

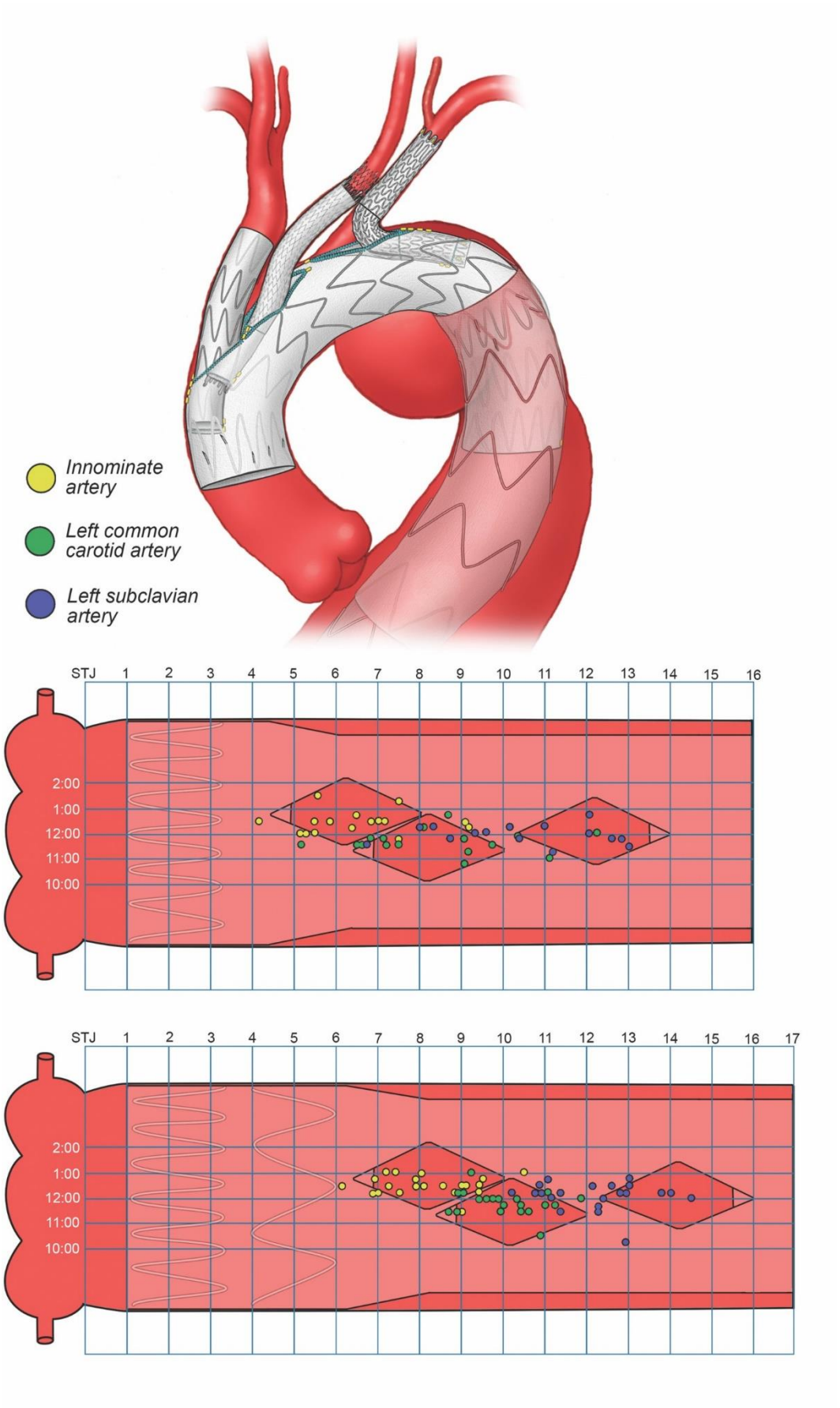

B

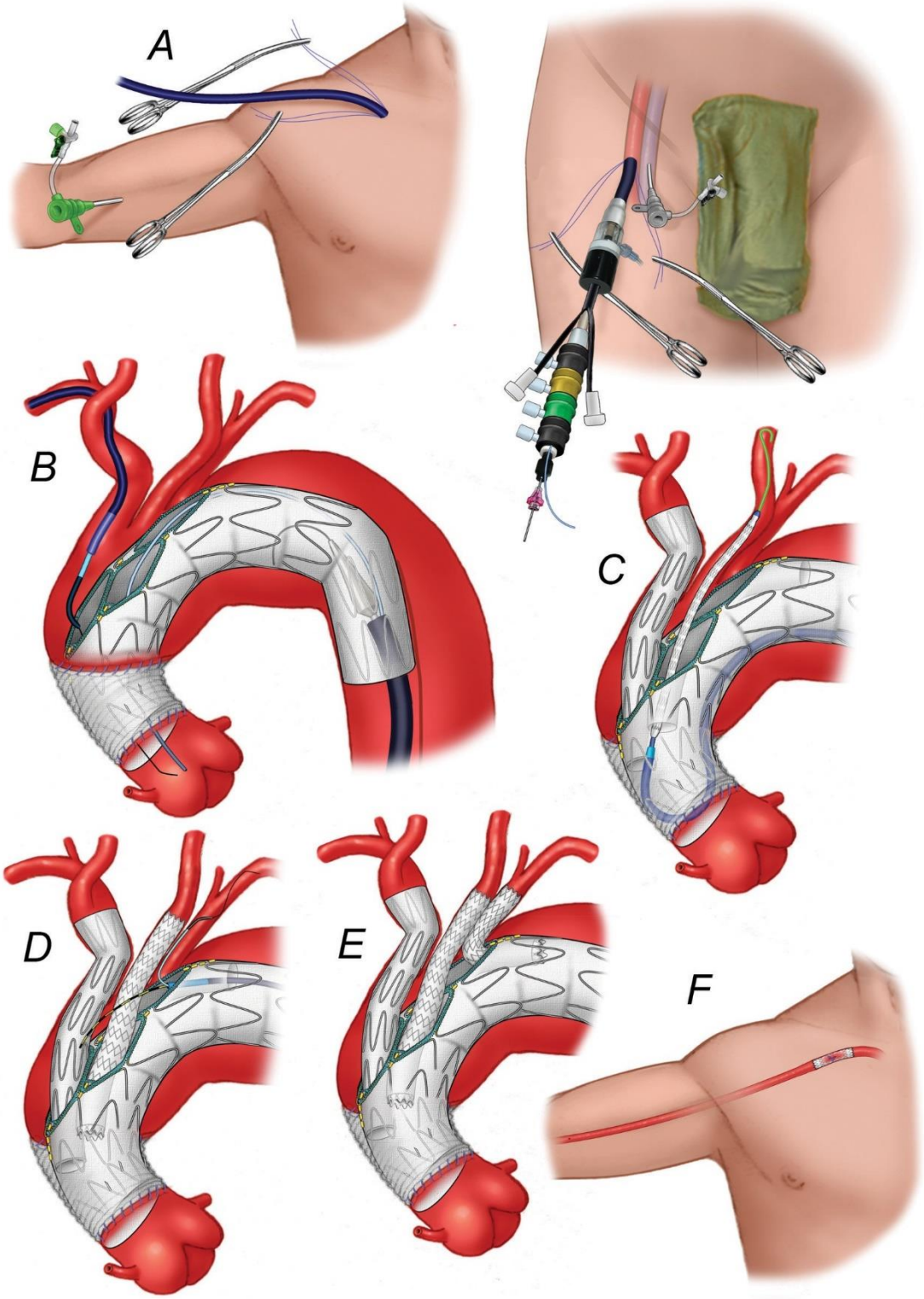

C

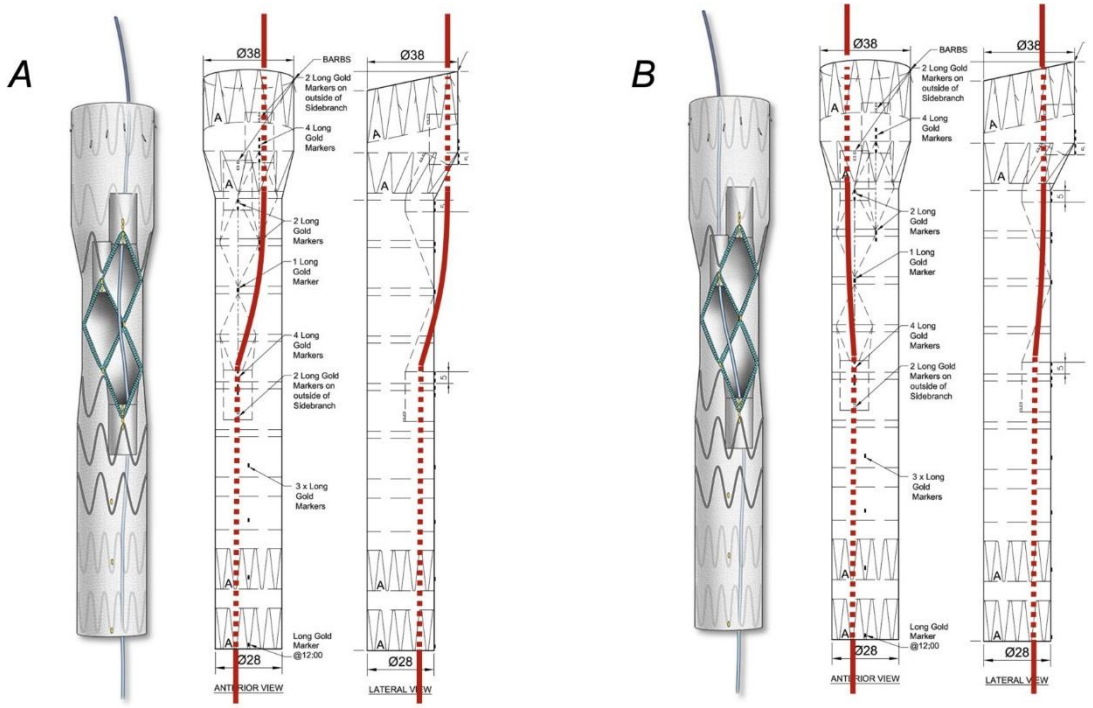





A
B
C
D


Innominate artery
Left common carotid artery
Left subclavian artery
STJ 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
2:00
1:00
12:00
11:00
10:00
STJ 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
2:00
1:00
12:00
11:00
10:00


A
B
C
D
E
F


A
Ø38
BARBS
2 Long Gold Markers on outside of Sidebranch
4 Long Gold Markers
2 Long Gold Markers
1 Long Gold Marker
4 Long Gold Markers
2 Long Gold Markers on outside of Sidebranch
3 x Long Gold Markers
Long Gold Marker @12:00
Ø28
ANTERIOR VIEW
LATERAL VIEW
B
Ø38
BARBS
2 Long Gold Markers on outside of Sidebranch
4 Long Gold Markers
2 Long Gold Markers
1 Long Gold Marker
4 Long Gold Markers
2 Long Gold Markers on outside of Sidebranch
3 x Long Gold Markers
Long Gold Marker @12:00
Ø28
ANTERIOR VIEW
LATERAL VIEW