Technical Note

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Externalized Guidewires to Facilitate Fenestrated Endograft Deployment in the Aortic Arch

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Abstract

Purpose: To describe a precannulated fenestrated endograft system utilizing externalized guidewires to facilitate aortic arch endovascular repair and to report its use in 2 patients with challenging anatomy. **Technique:** For distal arch repair, a fenestration for the left subclavian artery (LSA) is made onsite in a standard thoracic endograft tailored to the patient anatomy; it is precannulated with a nitinol guidewire (NGw), which is passed from the femoral artery and externalized from the left brachial artery prior to endograft delivery system introduction over a parallel stiff guidewire. Steps are then taken to remove guidewire intertwining, prevent NGw wrapping around the delivery system, and orient the LSA fenestration superiorly when the delivery system moves into the arch. Gentle traction on the ends of the NGw during endograft deployment facilitates proper fenestration alignment. A covered stent is deployed in the LSA fenestration. The technique is illustrated in a patient with congenital coarctation of the aorta and descending aortic aneurysm. For total arch repair, endograft fenestrations are made for all 3 arch branches; the left common carotid artery (LCCA) and LSA fenestrations are each cannulated with NGws, which travel together from the femoral artery, pass through a LSA snare loop, and are exteriorized from the LCCA. After endograft deployment, the innominate artery fenestration is separately cannulated using right brachial access. Placement of a parallel externalized hydrophilic guidewire passing through the LCCA fenestration (but not the LSA snare loop) and removal of the LCCA fenestration NGw allows exteriorization of the LSA fenestration NGw from the left brachial artery by pulling the LSA snare. Covered stents are deployed in all 3 fenestrations. The technique is presented in a patient with type B aortic dissection. **Conclusion:** Use of the precannulated fenestrated endograft system described is feasible and has the potential to make aortic arch endovascular repair simpler, more reliable, and safer.

Keywords

aortic arch, arch aneurysm, coarctation of aorta, covered stent, endovascular aneurysm repair, fenestrated stent-graft, fenestration, physician-modified stent-graft, type B dissection

Introduction

Endovascular repair is an effective way of treating aortic arch pathology,[1] and fenestrations in the endografts can help preserve flow into supra-aortic branches destined to be covered by the device.[2–5] Precise deployment of these fenestrated arch endografts is important to correctly orient the fenestrations toward the branches for which they are intended. The fenestrations must then be cannulated if covered stents are to be deployed through them into the side branches to achieve a seal at each location. This process requires manipulation of wires, catheters, and even partially deployed endografts in the aortic arch, all of which can cause embolization of atherothrombotic material. It is therefore desirable to have a system that allows full deployment of a fenestrated arch endograft immediately after introduction, facilitates correct orientation of the fenestrations, and minimizes subsequent manipulations to cannulate these openings. Here, we describe a system that achieves these objectives by externalizing guidewires that traverse fenestrations made onsite in standard thoracic endografts prior to

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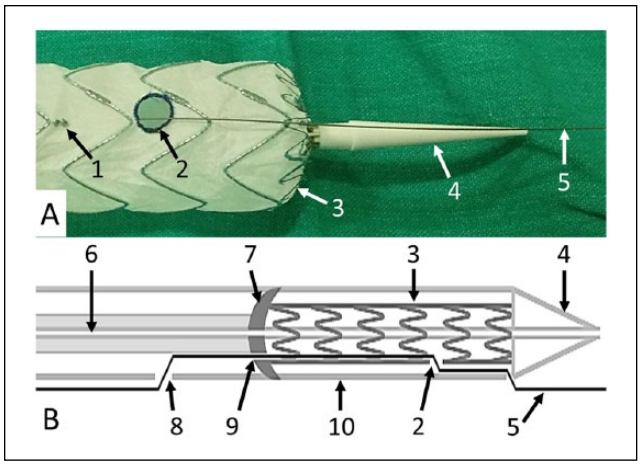

Figure 1. (A) Valiant Captivia endograft with a single fenestration cannulated with a nitinol guidewire. (B) Schematic diagram of the modified endograft delivery system. Key: (1) radiopaque figure-8 mid-body marker, (2) fenestration, (3) endograft, (4) tapered tip, (5) nitinol guidewire, (6) central guidewire lumen, (7) stent stop, (8) needle hole in introducer sheath, (9) needle hole in stent stop, and (10) introducer sheath.

their insertion. The use of the system is illustrated in 2 patients with pathology in the aortic arch and beyond in whom the use of fenestrated endografts would have otherwise been difficult.

Technique

Aortic Arch Endograft With a Single Fenestration

Aortic arch endografts with a single fenestration are useful for treating distal arch pathology where the proximal landing zone commences at the distal margin of the left common carotid artery (LCCA) origin and blood flow into the left subclavian artery (LSA) needs to be preserved; however, such endografts could also be used to preserve flow into the LCCA or the innominate artery (IA) if the more distal arch branches are revascularized by other means, such as bypass surgery.

Step 1. Endograft Modification. A Valiant Captivia thoracic endograft (Medtronic Vascular, Santa Rosa, CA, USA), selected based on careful study of the patient's computed tomography angiography (CTA) images, is fully deployed on a sterile table without releasing the tip-capture mechanism. A single fenestration for the LSA of appropriate size and location is made in between the endograft stent struts, in line with the radiopaque figure-8 mid-marker, using a thermal cautery instrument.[4] Thereafter, a radiopaque nitinol wire is sewn onto the edge of the fenestration (Figure 1A).

A needle hole is made in the introducer sheath (graft cover) just distal to the section bearing the endograft, and a 300-cm, 0.018-inch nitinol guidewire (NGw; RoadRunner, Cook Medical Inc, Bloomington, IN, USA) is passed cephalad into the sheath through the needle hole (Figure 1B); another needle hole is made in the cup-shaped stent-stop, and the same NGw is passed through it to travel through the endograft, traverse the fenestration, and continue cephalad external to the endograft (Figure 1A and B). The endograft is resheathed using umbilical tape, which must pass under the NGw in the section of endograft cephalad to the fenestration so that the wire is not embedded within the folds of the constrained endograft. The NGw will now emerge from under the tip of the introducer sheath, in line with the LSA fenestration and figure-8 mid-marker; it can be moved through the constrained endograft without much friction, allowing easy adjustment of its length on either side.

Step 2. Preliminary Catheter-Guidewire Manipulation. A 0.035-inch, angled hydrophilic guidewire (HGw; Terumo Medical, Somerset, NJ, USA) introduced from the right femoral artery (RFA) is exteriorized from the left brachial artery (LBA) using a snare (Figure 2A). The femoral end of the HGw is passed through a hole made in the outer aspect of the primary curve of a 7-F Judkins right guiding catheter, which is then tracked over it into the aortic arch to allow parallel delivery of a Lunderquist guidewire (LGw; Cook Medical) into the ascending aorta (Figure 2B). The catheter is then removed without rotation (to prevent guidewire intertwining), leaving the 2 guidewires in place (Figure 2C). Finally, a 125-cm, 5-F multipurpose catheter is passed over the HGw from the LBA so that its tip emerges from the RFA access, after which the HGw is removed (Figure 2D).

Step 3. Exteriorization of the Fenestration-Cannulating Guidewire. The sheath in the RFA is removed, and the endograft delivery system is loaded onto the LGw. However, prior to introducing it into the RFA, the cephalic end of the NGw that traverses the endograft fenestration is passed from the RFA access and exteriorized from the LBA through the multipurpose catheter, which is then removed. The NGw remains externally located at both ends throughout the procedure and can be removed at any stage by simply pulling either end. When the endograft delivery system is passed up the aorta over the LGw, the NGw is allowed to move along with it, and the resulting slack in the part of the NGw cephalic to the delivery system is eliminated by exteriorizing more of it from the LBA. The part of the NGw in the LSA is kept within a catheter or long sheath to prevent wire-induced vessel wall injury.

Step 4. Undoing Guidewire Intertwining. The NGw may twist around the LGw (Figure 2E) despite step 2; these spiral twists will come closer together and become more obvious as the endograft delivery system is advanced into the thoracic aorta and will prevent successful completion of the

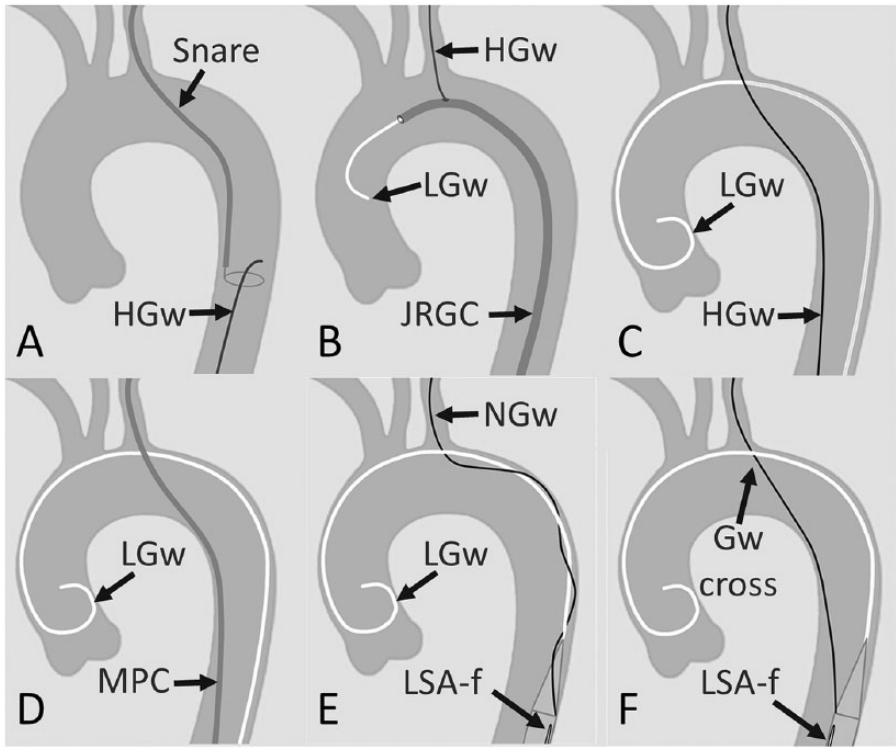

Figure 2. Setting the stage for delivery of a precannulated single-fenestrated endograft into the aortic arch. (A) A femoral hydrophilic guidewire (HGw) is snared out from the left brachial artery (LBA). (B) A Judkins right guiding catheter (JRGC), with a side-hole near the tip, is tracked over the HGw to deliver a Lunderquist guidewire (LGw) into the ascending aorta. (C) The JRGC is removed without rotation, leaving the HGw and LGw in place. (D) The HGw is replaced with a multipurpose catheter (MPC) inserted from the LBA. The nitinol guidewire (NGw) that traverses the left subclavian artery fenestration (LSA-f) is passed up this catheter and exteriorized from the LBA; the catheter is then removed. (E) Intertwining of guidewires that may be present when the endograft delivery system is introduced over the LGw into the thoracic aorta. (F) "Neutral" position obtained after corrective rotation of the endograft delivery system in the descending aorta; the guidewires now cross only once. The fenestration and the NGw emerging from it are oriented toward the inner curve of the aorta.

procedure. Guidewire intertwining, if evident on left anterior oblique view fluoroscopy, is eliminated by rotating the endograft delivery system when its tip is in the mid-descending thoracic aorta. The direction of rotation (clockwise or counterclockwise) is determined by trial and error; rotation in the appropriate direction will lead to progressive reduction in guidewire intertwining seen on fluoroscopy. Once intertwining is completely removed, the 2 guidewires will cross each other only once, in the aortic arch (Figure 2F). The NGw will now emerge from the medial aspect of the delivery system (toward the inner curve of the aortic arch), in line with the fenestration and figure-8 mid-marker (Figure 2F). This position of the delivery system can be considered the "neutral" position, which is of relevance in subsequent steps of the procedure.

Step 5. Ensuring Superior Orientation of the Endograft Fenestration in the Aortic Arch. As the branch artery takes off from the arch's superior aspect, it is necessary to position the delivery system such that the endograft fenestration is oriented superiorly when it enters the arch. This is achieved by the following maneuver. First, the plane of the aortic arch is determined by selecting the precise right anterior oblique angulation of the image intensifier in which the curve of the LGw in the thoracic aorta appears on edge (ie, the parts of the LGw in the ascending and descending aorta are superimposed). Next, the aortic arch is viewed en face by fluoroscopy in the left anterior oblique angulation perpendicular to the previous view. In this view, the delivery system is rotated by about 180° from the "neutral" position described above, such that the endograft fenestration and the figure-8 mid-marker are positioned laterally (toward the outer curve of the thoracic aorta, Figure 3A). Advancement of the delivery system from this position into the aortic arch without further rotation will result in the endograft fenestration being oriented superiorly (Figure 3E).

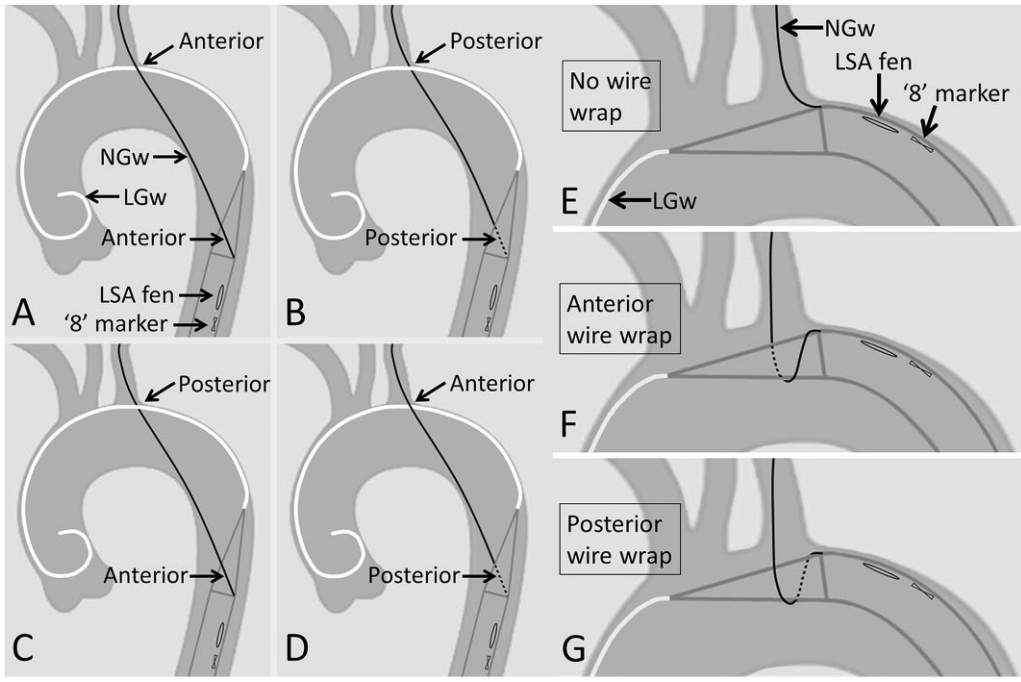

Figure 3. (A–D) Combinations of ways in which the fenestration-cannulating nitinol guidewire (NGw) can cross (1) the Lunderquist guidewire (LGw) in the aortic arch and (2) the tapered tip of the endograft delivery system in the descending aorta. (E) When the crossings are both anterior or both posterior, the NGw will not wrap around the tapered tip of the endograft delivery system when the latter moves into the aortic arch. (F, G) However, when the crossings are opposite to each other, wire wrap will result. LSA-fen, left subclavian artery fenestration; "8" marker, figure-8 radiopaque marker.

Step 6. Avoiding Wire Wrap Around the Tapered Tip of the Delivery system. The 180° rotation of the delivery system away from the "neutral" position causes the NGw to cross the tapered tip of the delivery system in the descending aorta (Figure 3A–D); this could potentially result in wire wrap around the tapered tip when the delivery system is advanced into the aortic arch (Figure 3F and G), precluding successful completion of the procedure. Wire wrap can be avoided by the following maneuver. If the NGw crosses anterior to the LGw in the aortic arch, the 180° rotation of the delivery system should be clockwise so that the NGw crosses anterior to the tapered tip of the delivery system (Figure 3A). Conversely, if the NGw crosses posterior to the LGw in the aortic arch, the 180° rotation should be counterclockwise so that the NGw crosses posterior to the tapered tip (Figure 3B); this will prevent wire wrap when the delivery system is moved into the aortic arch. Situations to be avoided are the posterior-anterior combination (Figure 3C), which results in anterior wire wrap (Figure 3F), and the anterior-posterior combination (Figure 3D), which results in posterior wire wrap (Figure 3G).

Step 7. Avoiding Snagging of the Guidewire Around the Endograft Tip. Once the introducer sheath is advanced past the LSA origin, the NGw will bend backward sharply (Figure 4D) and may snag a stent strut at the tip of the endograft when the latter is deployed. NGw snagging can be avoided by unsheathing the FreeFlo (uncovered stent) and a bit of the first covered stent segment of the endograft when the tip of the introducer sheath is located under the LSA origin, while applying gentle traction on both ends of the NGw. This allows the NGw to peel off the proximal edge of the aortic endograft. The unsheathed part of the endograft remains unexpanded at this stage, and the delivery system can be moved further ahead if required while maintaining gentle traction on both ends of the NGw.

Step 8. Completion of the Procedure. After ascertaining that the proximal edge of the endograft is at the distal margin of the LCCA origin and that the fenestration is oriented toward the LSA, the endograft is fully deployed (Figure 4E), and the delivery system is removed. Gentle traction is maintained on both ends of the NGw throughout; this prevents formation of a redundant guidewire loop (which could snag stent struts) and may help orient the endograft fenestration toward its target vessel. A catheter is advanced over the NGw from the LBA into the endograft through the fenestration; the NGw is changed to a stiff 0.035-inch guidewire

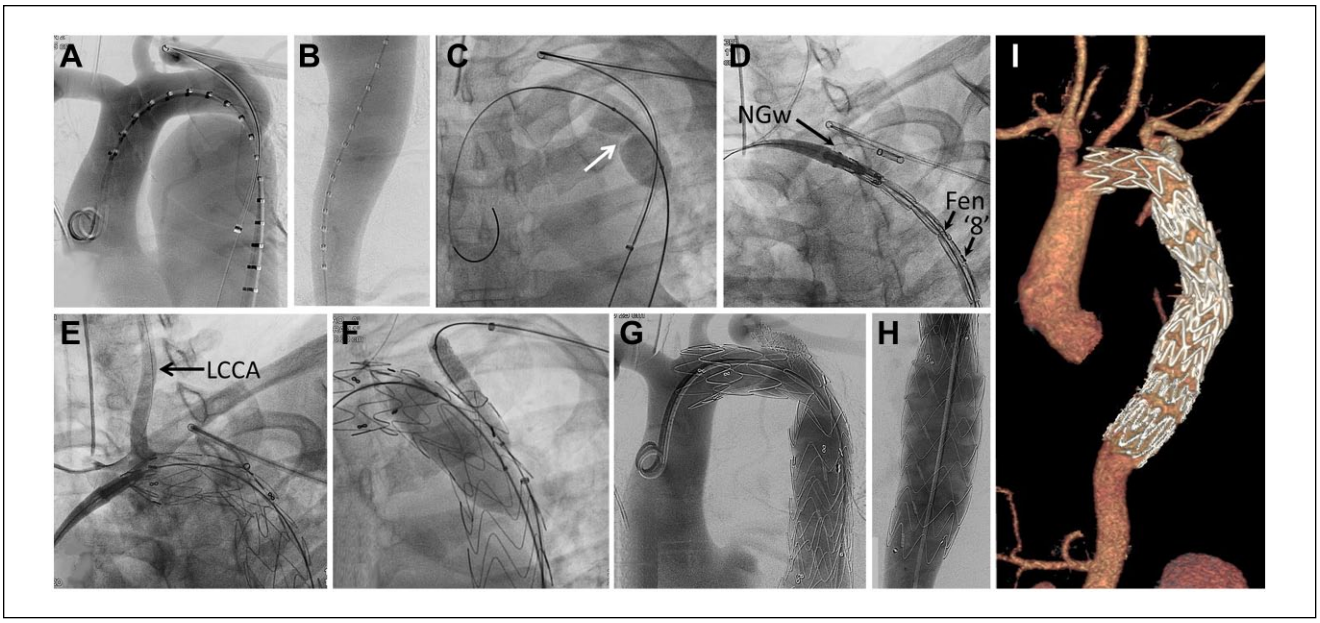

Figure 4. Case 1. (A, B) Baseline angiograms show coarctation of aorta with large post-stenotic fusiform aneurysm of the descending aorta and sharply angulated takeoff of the left subclavian artery (LSA). (C) Balloon dilation of the aortic coarctation (arrow). A long 7-F left brachial artery sheath is in the descending aorta. (D) Advancement of the endograft delivery system into the aortic arch: the fenestration-cannulating nitinol guidewire (NGw) is seen curving back sharply without wrapping around the tapered tip of the delivery system; the fenestration (Fen) and figure-8 marker ('8') are oriented toward the outer curve of the aortic arch. (E) Endograft deployment starting at the distal margin of the left common carotid artery (LCCA) that is visualized by contrast injection. The NGw has peeled off the aortic endograft due to applied traction and courses straight upward into the LSA from the fenestration. (F) Simultaneous balloon dilation of the aortic coarctation and the fenestration stent. (G, H) Postintervention angiograms show expanded coarctation segment, excluded descending aortic aneurysm, and preserved flow into the LSA through a stented fenestration. (I) Follow-up computed tomography angiography reconstruction obtained 14 months after the initial procedure and 6 months after bridging endograft deployment show similar findings.

whose tip may be positioned in the ascending aorta if required. A long 7-F sheath can then be advanced from the LBA access into the endograft to allow deployment of an appropriate balloon-expandable covered stent in the fenestration. The rest of the procedure is completed in standard fashion.

Case 1

The above technique is illustrated in a 31-year-old obese (body mass index 36.8 kg/m^2) male smoker with hypertension and diabetes who was incidentally found to have congenital coarctation of the aorta (peak systolic pressure gradient 38 mm Hg) and a post-stenotic fusiform descending thoracic aortic aneurysm (maximum transverse diameter 6.8 cm) that extended downward to 8 cm above the celiac artery origin (Figure 4A and B). Endovascular treatment was planned despite the young age of the patient as he had medical comorbidities and was keen to avoid open repair. Preservation of flow into the LSA was desirable as extensive endograft coverage of the descending aorta was required. However, the complex anatomy and sharply angulated takeoff of the LSA precluded use of a chimney graft and made correct orientation of a fenestrated endograft difficult; use of an externalized guidewire to facilitate the latter was therefore considered.

The procedure was performed under general anesthesia after obtaining written informed consent that included the use of a physician-modified endograft. An 8-mm circular fenestration was made with its center 35 mm from the proximal edge of a 26×164-mm Valiant Captivia thoracic endograft as described earlier (Figure 1A). RFA, LBA, and right radial artery accesses were obtained percutaneously. Three Proglide sutures (Abbott Vascular, Santa Clara, CA, USA) were deployed in the RFA and tied at the end of the procedure. After baseline angiography and pressure measurements, the aortic coarctation was dilated using a 20-mm-diameter Maxi LD balloon (Cordis Corporation, Bridgewater, NJ, USA; Figure 4C). The delivery system was advanced into the aortic arch without wire wrap as described earlier (Figure 4D). A 6-F diagnostic catheter introduced from the right radial artery was used to delineate the LCCA angiographically during endograft deployment (Figure 4E). A 7×38-mm V12 covered stent (Atrium

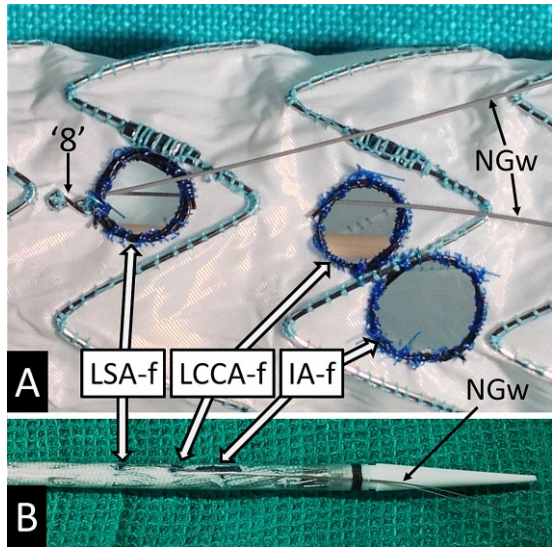

Figure 5. (A) Valiant Captivia endograft with fenestrations made for the left subclavian artery (LSA-f), left common carotid artery (LCCA-f), and innominate artery (IA-f); the LSA-f and LCCA-f are made in line with the figure-8 radiopaque marker ("8"), and the 0.014-inch nitinol guidewires (NGw) pass through them. (B) After resheathing the endograft, the 2 NGws exit the top of the introducer sheath together and in line with the LSA-f and LCCA-f.

Medical/Maquet Cardiovascular, Hudson, NH, USA) was deployed within the LSA fenestration. Simultaneous balloon dilation was performed using a 22-mm Maxi LD balloon in the coarctation segment and a 7-mm balloon in the LSA stent (Figure 4F). An overlapping 34×150-mm Valiant endograft without proximal FreeFlo was deployed in the lower descending aorta. A good angiographic result was obtained (Figure 4G,H) with no endoleak and preserved flow into all the aortic arch branches; the peak systolic pressure gradient across the coarctation segment fell to 15 mm Hg. The procedure took 137 minutes, including 54 minutes of fluoroscopy. The postoperative period was uneventful except for LBA access site thrombosis, which was successfully resolved by aspiration using a 6-F guiding catheter introduced from the left radial artery. There were no neurological deficits or other complications. A spinal drain was not used during or required after the procedure.

The patient remained well and asymptomatic, though a type II endoleak through coarctation-related collateral channels was noted. Eight months after the procedure, the patient presented acutely with left lower limb pain and numbness, with absent distal pulses in this limb. CTA revealed separation of the 2 descending aortic endografts with type III endoleak, suggesting inadequate overlap between the 2 aortic endografts when deployed. Thrombus from the repressurized aneurysm sac had probably embolized downstream, causing left lower limb ischemia. Using percutaneous RFA access as before, a 34×202-mm Zenith thoracic endograft (Cook Medical) was deployed bridging the 2 existing endografts and successfully abolishing the endoleak. The LSA stent was noted to be patent and undistorted, with normal flow through it. The left lower limb ischemia resolved completely with anticoagulant therapy. The patient has been asymptomatic since then; CTA at 6 months after the second procedure (Figure 4I) revealed structural integrity of the endografts, a patent LSA stent, and reduction in aneurysm size. The type II endoleak seen earlier was the only endoleak present.

Aortic Arch Endograft With Multiple Fenestrations

In cases where an endograft has to be deployed starting from zone 0, fenestrations are required for all 3 arch branches unless other techniques of preserving side branch flow are utilized. Correctly deploying and cannulating a triple fenestrated endograft can be challenging, especially if the aortic anatomy is unfavorable; therefore, it would be helpful if the technique described earlier for an endograft with a single fenestration could be extended to an endograft with 2 or 3 fenestrations. However, this would involve the use of additional guidewires (one for each fenestration), which could wrap or intertwine in myriad ways. This problem can be solved by 2 measures:

1. Dispensing with a guidewire for the IA fenestration. The IA origin is commonly very close to the LCCA origin, so if the LCCA fenestration of the endograft falls into place correctly, it is very likely that the IA fenestration will do so too. Also, the IA is large, so the likelihood of a large IA fenestration ending up overlying the wide IA origin is high.
2. Making guidewires traversing the LCCA and LSA fenestrations travel together, thereby eliminating any additional wrapping or intertwining problems.

Step 1. Endograft Modification. Based on patient CTA data, 3 fenestrations are made in a Valiant Captivia endograft with the LCCA and LSA fenestrations in line with each other and with the figure-8 mid-marker (Figure 5A). As the IA origin is usually close and slightly posterior to that of the LCCA, fenestrations for these 2 arteries are made obliquely adjacent to each other but separated by a stent strut. Needle holes are made as described earlier in the introducer sheath and stent stop, and two 300-cm, 0.014-inch RoadRunner NGws are passed through each hole; one NGw (placed with its hard end cephalad to help distinguish the 2 wires) traverses the LCCA fenestration and the other (soft end cephalad) traverses the LSA fenestration. When the endograft is

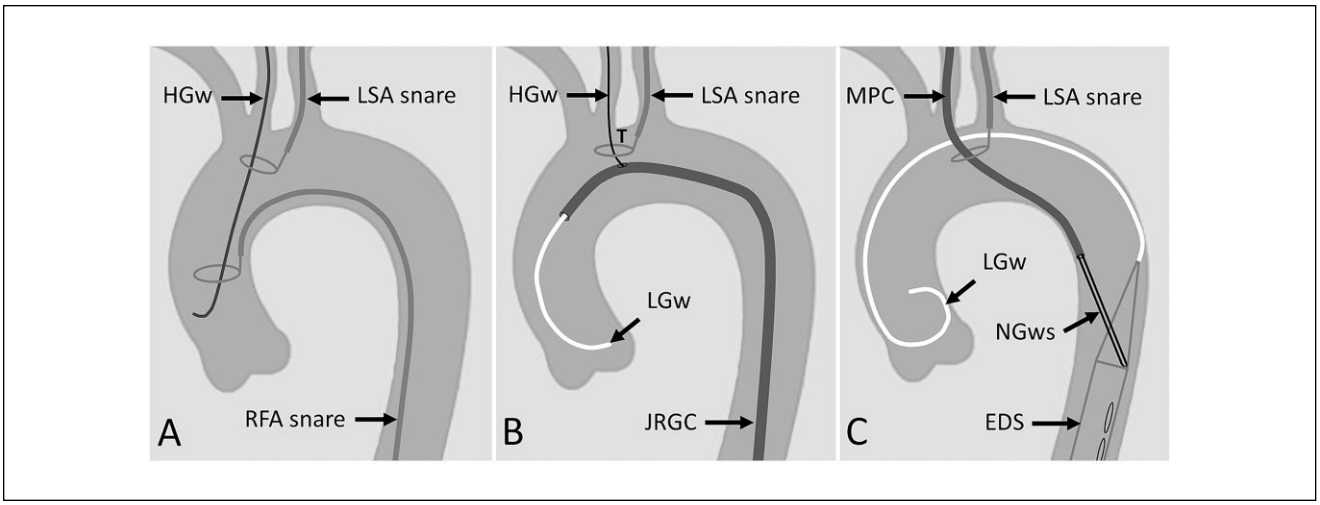

Figure 6. Setting the stage for delivery of a triple-fenestrated precannulated endograft into the aortic arch. (A) A hydrophilic guidewire (HGw) introduced from the left common carotid artery (LCCA) is passed through a left subclavian artery (LSA) snare loop in the aortic arch; it is then caught by another snare in the ascending aorta and exteriorized from the right femoral artery (RFA). (B) A Judkins right guiding catheter (JRGC) with a side hole near its tip is tracked over the HGw from the RFA and enables delivery of a Lunderquist guidewire (LGw) into the ascending aorta without the latter passing through the LSA snare loop or the triangle (T) formed by the LSA snare, the HGw, and the outer curve of aortic arch. (C) The endograft delivery system (EDS) is introduced into the aorta over the LGw, while the 2 nitinol guidewires (NGws) that traverse the fenestrations in the endograft pass through a multipurpose catheter (MPC) that was earlier passed over the HGw from the LCCA and exteriorized from the RFA.

resheathed, the 2 NGws emerge together from under the tip of the introducer sheath in line with the LCCA and LSA fenestrations (Figure 5B).

Step 2. Preliminary Catheter-Guidewire Manipulation. A HGw inserted from a percutaneous LCCA access is passed through the loop of a 6-F LSA snare (introduced from a left axillary or brachial access) in the proximal aortic arch; the tip of the HGw is then caught in the ascending aorta with another 6-F snare introduced from the RFA (Figure 6A) and exteriorized; as before, the femoral end of the HGw is passed through a side hole made in a 7-F Judkins right guiding catheter, which is then tracked over the HGw into the aortic arch to allow parallel delivery of a LGw into the ascending aorta (Figure 6B); this arrangement ensures that the LGw does not pass through the loop of the LSA snare or through the triangle formed by the LSA snare, the HGw, and the outer curve of aortic arch ("T" in Figure 6B), both of which will cause problems later. The guiding catheter is then removed without rotation, leaving the 2 wires in place. Finally, a 100-cm, 5-F multipurpose catheter is passed over the HGw from the LCCA so that its tip emerges from the RFA access, after which the HGw is removed.

Step 3. Exteriorization of the Fenestration-Cannulating Guidewires. This step is similar to that described for endografts with a single fenestration, the only difference being that 2 NGws (instead of one) are fed into the 5-F multipurpose catheter emerging from the RFA access and are exteriorized from the LCCA (and not the LBA).

Steps 4–7. These steps are also similar to those described earlier in the single fenestration technique. It must be noted that through these steps, the 2 NGws stay together within the 5-F multipurpose catheter, which passes through the LSA snare. The catheter is retracted as the endograft delivery system is advanced (Figure 6C). Once the catheter is removed, the LSA snare will directly encircle both NGws in the aortic arch (Figure 7A–D).

Step 8. Completion of the Procedure. After full deployment of the endograft and confirming that the IA and LCCA pressures are systemic, the delivery system is removed and a 20-F sheath is introduced into the RFA over both NGws. The IA fenestration is cannulated from the right brachial approach, and a covered stent is deployed within it (Figure 7B). A 6-F Judkins right guiding catheter is introduced from the RFA over the NGw that traverses the LCCA fenestration and passed into the LCCA ostium. A parallel HGw is passed through the catheter and up the LCCA, taking care that it does not go through the LSA snare loop (Figure 7C); this HGw is then exteriorized from the LCCA sheath using a 4-F snare (Figure 7D). The NGw that traverses the LCCA fenestration and the 6-F guiding catheter are removed sequentially. The LSA snare now encircles only the NGw that traverses the LSA fenestration; pulling back on the snare, while keeping the femoral end of the NGw fixed, will allow

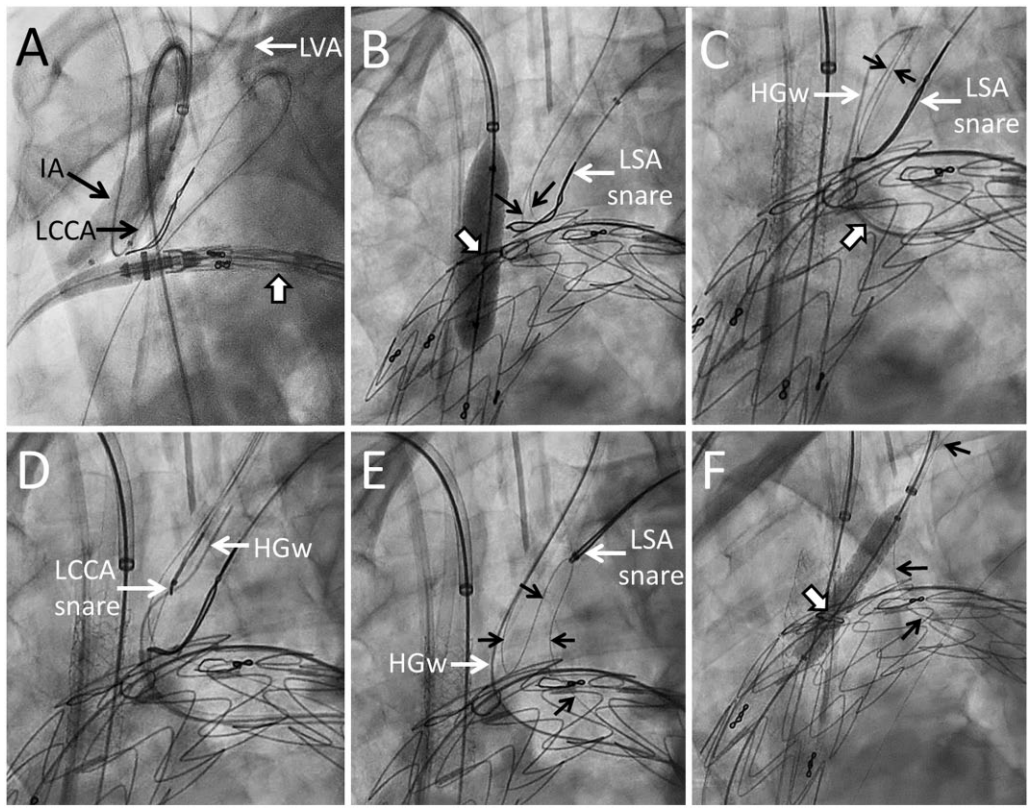

Figure 7. Case 2. (A) Balloon occlusion of the innominate artery (IA), left common carotid artery (LCCA), and left vertebral artery (LVA) during advancement of an endograft (wide white arrow) having fenestrations for each of the 3 arch branches into the aortic arch. (B) Covered stent deployment in the IA fenestration (wide white arrow); a 6-F left subclavian artery (LSA) snare encircles nitinol guidewires (NGw, black arrows) that traverse the 2 other fenestrations and are exteriorized from a LCCA sheath. (C) Introduction of a hydrophilic guidewire (HGw) into the LCCA through a guiding catheter (wide white arrow) passed from the right femoral artery over the NGw traversing the LCCA fenestration; the HGw must not pass through the 6-F LSA snare loop that encircles the NGws (black arrows). (D) HGw in the LCCA caught by a 4-F snare, which then exteriorizes it from the LCCA sheath. (E) The NGw traversing the LCCA fenestration has been removed; pulling back on the LSA snare at this stage helps exteriorize the NGw traversing the LSA fenestration (black arrows). (F) Covered stent deployment in the LCCA fenestration (wide white arrow); the NGw traversing the LSA fenestration (black arrows) can be seen coursing directly into the LSA.

exteriorization of the cephalic (soft) end of the NGw from the left upper limb access (Figure 7E). With the LCCA and LSA fenestrations cannulated from their respective target arteries, covered stents can be deployed within them (Figure 7F). The rest of the procedure is completed in standard fashion.

Case 2

The above multiple fenestration technique is illustrated in a 67-year-old hypertensive male smoker with chronic obstructive pulmonary disease and pulmonary hypertension who was diagnosed to have type B aortic dissection 4 years ago and was managed conservatively. Over the past few months, he developed hoarseness, backache, progressive dyspnea, and, more recently, orthopnea. CTA (Figure 8A and B) revealed extensive type B aortic dissection starting at the LSA and extending to the right common iliac artery; the false lumen was aneurysmal (distal aortic arch diameter 8.5 cm) and thrombus-laden, with a large entry tear adjoining the LSA. The true lumen was slit-like, and all the abdominal aortic visceral branches arose from it. There was extensive left hemothorax with partial lung collapse. Endovascular treatment was planned as he was high risk for surgery. In view of the proximity of the large proximal entry tear to the LSA origin and closeness of the arch branch origins to each other, it was decided to use a triple-fenestrated endograft, landing its proximal edge in the distal ascending aorta. The risk of cerebral embolization was considered fairly high as there was wide true-false communication very

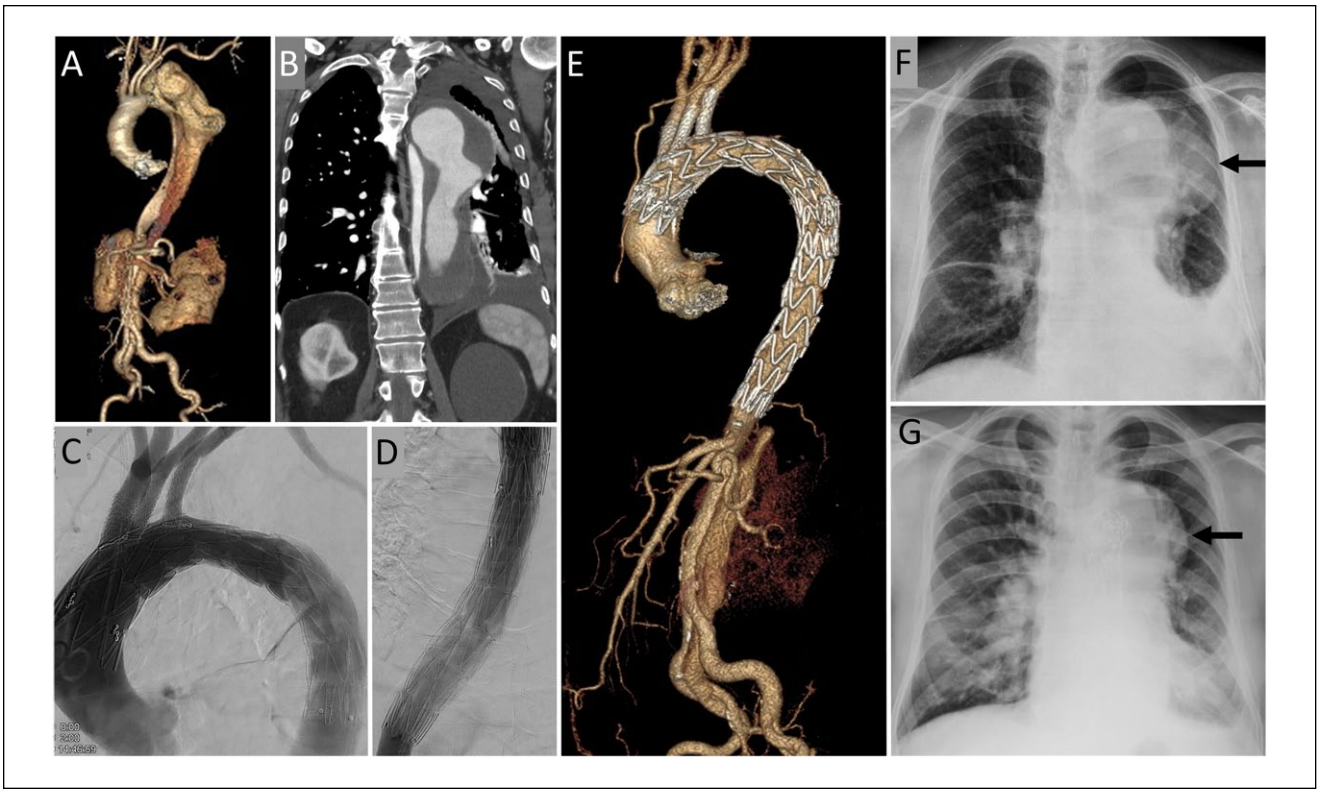

Figure 8. Case 2. (A, B) Baseline computed tomography angiography (CTA) images. (C, D) Conventional angiogram images obtained after completion of thoracic endovascular repair. (E) CTA reconstruction obtained 3 weeks after the procedure. (F) Baseline and (G) 6-month follow-up chest radiograms showing marked reduction in the prominence of the aortic shadow in the left chest (arrows) and clearing of the hemothorax with expansion of the left lung at follow-up.

close to the arch vessels and large thrombus burden in the adjacent false lumen. The treatment plan therefore included use of externalized guidewires for 2 fenestrations to facilitate rapid endograft deployment with minimal manipulation and transient balloon occlusion of the cerebral vessels during endograft delivery and deployment in the aortic arch.

The procedure was performed under general anesthesia after obtaining written informed consent that included the use of a physician-modified endograft. Circular fenestrations measuring 10, 7, and 7 mm in diameter were made for the IA, LCCA, and LSA, respectively, in a 32×192-mm Valiant Captivia thoracic endograft. NGws were passed through the last 2 as described earlier (Figure 5A). Multiple percutaneous vascular accesses were obtained, including the RFA, where 3 Proglide sutures were deployed and tied after the procedure.

The procedure was carried out as described earlier. Transient (2 minutes, 12 seconds) balloon occlusion of the proximal IA, LCCA, and left vertebral arteries was carried out during endograft delivery (Figure 6A) and deployment in the arch; additionally, rapid right ventricular pacing was instituted during endograft deployment. An overlapping 32–28×150-mm Valiant tapered endograft was deployed with its lower end just above the celiac artery ostium. A good angiographic result was obtained (Figure 8C and D), with no false lumen filling in the thoracic aorta and preserved flow into the aortic arch branches. The procedure took 320 minutes, including 136 minutes of fluoroscopy. The postoperative period was uneventful. There were no neurological deficits or other complications; a spinal drain was not used during or required after the procedure.

CTA after 3 weeks (Figure 8E) showed an excellent result, with thrombosed thoracic aortic false lumen, after which it was deemed safe to insert a chest tube and drain the left hemothorax. The patient has done well clinically over the next 10 months, with complete resolution of symptoms. Chest radiography after 6 months showed significant reduction of the thoracic aortic shadow and good expansion of the left lung (Figure 8F and G).

Discussion

Compared with the abdominal aorta, where custom-made and onsite fenestrated endografts have been used fairly extensively, the aortic arch has so far witnessed a much more limited use of fenestrated endografts. The reasons for

this discrepancy are mainly the technical difficulty of correctly deploying a fenestrated arch endograft and cannulating its fenestrations on one hand and the higher risks involved, mainly that of stroke, on the other. The 2 reasons are partly related, as incorrect endograft deployment increases subsequent manipulations, which in turn increases the risk of embolization from the aortic arch. A system that increases the margin of safety available in the deployment of fenestrated arch endografts, facilitates correct orientation of the fenestrations, and minimizes subsequent manipulations may therefore be expected to increase successful outcomes and reduce complications.

In the arch endograft system described above, the fenestrations are circular, do not have stent struts going across them, and are of comparable size to the target vessel; these features allow sealing by deployment of covered stents within the fenestrations. The fenestration-covered stent combination serves to anchor the fenestration to its target branch and preserve blood flow in it (obviating the need for surgical bypass) and prevents both type III endoleak from the fenestration and type II endoleak from the branch. Also, since sealing starts at the proximal edge of the aortic endograft, proximal arch and distal ascending aortic lesions can potentially be treated if endograft deployment begins sufficiently proximally. A small margin of safety in endograft deployment is available because even if the fenestrations are slightly off target, the precannulating NGws will enable deployment of covered stents within them. During deployment of single-fenestrated endografts, traction on the exteriorized ends of the NGw traversing the fenestration may help orient the latter toward its target vessel; in endografts having 2 NGws that traverse separate fenestrations but otherwise travel together, traction forces will act on both fenestrations and may help orient them superiorly.

Successful use of the described precannulated fenestrations requires an understanding of how guidewire intertwining and wire wrap can be avoided. The preventive steps are performed with the delivery system in the mid descending aorta, where risk of cerebral embolization due to device manipulation is low. If these steps are properly executed, the delivery system needs to move into the aortic arch just once, and after minor adjustments in position, the endograft can be fully deployed, lining the arch and trapping debris underneath it. Quick endograft delivery and deployment in the aortic arch enabled by our system makes it possible to transiently occlude the cerebral vessels during this step, which has the highest potential for cerebral embolization; however, setting up and taking down the triple-balloon occlusion system (Figure 8A) added significantly to the procedure and fluoroscopy times in case 2. Without the assistance of the above-described system of precannulated fenestrations, it may be necessary to manipulate a semiconstrained or partially deployed arch endograft to orient fenestrations correctly, which could increase the risk of cerebral embolization.

Onsite modification of standard endografts has the advantages of making a device appropriate for the patient's anatomy available rapidly and at significantly lower cost than a custom-made endograft; the disadvantages are the necessity for the physician to spend time modifying the endograft, lack of industrial quality control after device modification, and lack of a sizeable body of evidence supporting its use. Modification of commercially available devices by physicians may void any guarantee of safety by the manufacturer, and systematic evaluation of such devices is best done within a protocol approved at the institutional and/or regulatory level.

The technical complexity of the precannulated fenestrated endograft system described in this report is a limitation that may curtail its widespread acceptance. Certain anatomic variations, such as an anomalous origin of the right subclavian artery from the distal arch or direct aortic origin of a large left vertebral artery, may be a contraindication to the technique. In the presence of a bovine aortic arch, total endovascular repair using 3 endograft fenestrations as described may still be feasible; here, a sufficiently long covered stent in the LCCA fenestration would have to travel through the IA, parallel to the covered stent in the IA fenestration, before entering the LCCA. Extreme arch angulation or severe aortic tortuosity may make endograft delivery and proper orientation of fenestrations challenging, if not impossible.

The idea of exteriorization of a precannulating guidewire in arch endovascular repair is not new. Murphy et al[6] created on-table a single-branched thoracic endograft preloaded with a HGw and used the device in a post–open repair case of type A aortic dissection after bypassing the LCCA and LSA from the IA. The HGw was snared out from the right CCA after the endograft delivery system reached the aortic arch; tension on the HGw helped in orienting the branch toward the IA. A bridging covered stent was deployed for a successful outcome.

The commercially manufactured Valiant Mona LSA single-branch thoracic endograft system (Medtronic Vascular), which is designed to preserve LSA flow and is currently undergoing clinical evaluation, has an additional guidewire lumen that allows precannulation of a flexible cuff in the endograft. A guidewire advanced through this lumen is snared along the outer curve of the arch and exteriorized from the LBA to allow deployment of a mating branch stent-graft into the LSA from a femoral approach.[7] In both these techniques,[6,7] the precannulating guidewire is snared and exteriorized only after the endograft delivery system is close to the target arch branch; this reduces the problem of wire wrap but does not eliminate it. In our system, the snaring and exteriorization process is completed before insertion of the endograft delivery system into the patient and is performed using equipment better suited for the purpose (the initial guidewire exteriorized is not the one traversing

the fenestration). There is less technical difficulty, hardware clutter, and operator anxiety involved. Precannulation of 2 fenestrations is possible (as against one branch in the other systems); however, guidewire intertwining and wire wrap are likely to occur unless prevented by the maneuvers described above.

Our onsite fabricated fenestrated endograft system provides an alternative to the fairly limited range of options available for partial or total arch endovascular repair. Apart from the single-branch thoracic endografts described above, another option now available is the Cook inner-branched arch endograft.[8] This endograft has 2 internal side branches, each with an enlarged external orifice to assist cannulation. A curved introducer facilitates superior orientation of the endograft branches. The side branch–bearing midsection of the endograft is narrower than the ends and separates the side branch external orifices from the aortic wall. This facilitates branch cannulation and preserves perigraft flow. However, the midsection of the endograft does not contribute to debris entrapment or to proximal sealing (which is confined to the ascending aorta). Endograft deployment always has to start from zone 0, even if the patient's anatomy would allow a zone 1 or 2 start with a standard endograft. Another limitation is the need to revascularize the LSA surgically before endograft deployment in all cases. The early global experience with this device in 38 patients was published recently.[8] The technical success rate was 84.2%, 30-day mortality 13.2%, and cerebrovascular complications 15.8%; there were no aneurysm-related deaths.

Multiple centers in Japan have reported extensive experience with the use of custom-made arch endografts having large fenestrations that increase the margin of safety during deployment.[2,3] Precurved stainless steel endograft frames and J-shaped delivery sheaths ensure that the fenestrations are oriented superiorly when the endograft is deployed; the main advantage of this system is its relative simplicity. As the fenestrations are rectangular, larger than their target vessels, and may have stent struts going across them, they cannot be sealed by deploying covered stents within them; consequently, a >15- to 20-mm proximal sealing zone is required distal to the LCCA, and only pathology in the distal aortic arch and beyond can be treated. The LSA is usually simply occluded. Deployment of these endografts from zone 0 or 1 of the aorta increases their stability (which may compensate for their relatively low radial strength) and provides better sealing along the inner curve of the arch. In a recent study,[5] this technique was used in patients with a short sealing zone distal to the LCCA (mean length 11 mm, range 5–15); this resulted in a 32.4% type Ia endoleak rate at discharge and 16.2% aneurysm enlargement at follow-up.

In situ fenestration is another method of preserving blood flow into aortic arch branches covered by an endograft and is done in a retrograde manner using a laser, a long needle, or radiofrequency ablation.[9–11] If the IA or LCCA is covered by the endograft, maintenance of antegrade cerebral perfusion using temporary bypass is necessary during the fenestration process.[10] A recent study reported 60% technical success in 10 patients using radiofrequency ablation for in situ fenestration.[11]

The chimney graft is yet another competing endovascular technique that preserves flow into endograft-covered aortic arch branches. In a recent review[12] of 182 patients who underwent chimney graft deployment during arch endovascular repair, primary technical success was achieved in 98%, with a 5.3% stroke rate and a 13.6% type Ia endoleak rate. Chimney grafts are a good option for high-risk patients and in bailout situations. Though the short- and midterm results have been good, questions remain regarding durability and material interaction in the long term. The Multilayer Flow Modulator (Cardiatis, Isnes, Belgium), a bare, self-expanding, braided wire tube that induces gradual aneurysm thrombosis while preserving flow in the main vessel and side branches, is an off-the-shelf device that is easy to use. Experience with this device in the treatment of aortic arch aneurysms has been extremely limited.[13]

The performance of each of these endovascular techniques needs to be viewed against the backdrop of the well-established open surgical and hybrid techniques of aortic arch repair, which even today carry considerable mortality and stroke risk.[14,15]

Conclusion

Aortic arch endovascular repair using the precannulated fenestrated endograft system described in this report is feasible. The system has the potential to make arch repair simpler, more reliable, and safer. It enables utilization of longer and more proximal sealing zones and makes possible percutaneous total arch repair using unconstrained fenestrated endografts. Systematic clinical evaluation of the system is required before its status in comparison to alternative techniques can be ascertained.

Declaration of Conflicting Interests

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