Patient-specific total endovascular aortic arch repair using custom fenestration of an off-the-shelf thoracic endovascular aortic repair aortic-stent

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Physician-modified fenestrated stent-graft for thoracic endovascular aortic repair (TEVAR) has economic advantages and can be used in acute situations for aortic dissection and aneurysm involving aortic arch.[1] However, accurate alignment of fenestrations and branch arteries of the aortic arch is challenging, especially for multi-fenestration.[2] Once misaligned, complications such as branch occlusion or cerebral ischemia will occur. Details about how to align fenestrations with branch arteries of the aortic arch in TEVAR with physician-modified triple fenestrated stent-graft are elaborated in this article.

A 64-year-old female with chronic type A aortic dissection that involves the segment from the aortic arch to both common iliac arteries was treated with TEVAR with physician-modified triple fenestrated stent-graft. All branches were perfused by the true lumen, including innominate artery (IA), left common carotid artery (LCCA), left subclavian artery, celiac artery, superior mesenteric artery, and both renal arteries. The main entry tear was distal to the ostium of IA.

Precise fenestration depends on precise pre-operative measurement. Endosize workstation (Therenva SAS, Rennes, France) with the function of centerline of flow, three-dimensional reconstruction, and multi-planar reconstruction was used. Computed tomography angiography (CTA) with a slice of 1 mm thickness or thinner was used to measure anatomical and morphological features of the aortic arch and its branch arteries. Factors measured including diameter of the proximal and distal landing zone, optimal projection angle of the X-ray, length of the aortic arch at the greater curvature, diameter of each branch artery, distance between each ostium of branch arteries at the greater curvature, and the position of each ostium of branch arteries in expression of clock direction.

A 36 mm × 200 mm valiant thoracic stent-graft (Medtronic Vascular, Santa Rosa, CA, USA) was selected for modification since it could be partially released and easily re-sheathed. The proximal landing zone was located in the middle 1/3 of the ascending aorta, of which the diameter was 36 mm and not involved by the dissection.

Several pieces of the stent-graft were deployed on the operating table according to the pre-operative design. Normally, additional one or two pieces distal to the fenestration are unsheathed to ensure the smoothness of the fabric around the fenestration. With fenestrations ready, one assistant tied the released part of the stent-graft with 10# wire and compressed the stent, then another assistant rotated the handle to push the sheath forward. During this process, position of the white point of the front grip must be fixed to lock the direction. The operator compressed the unsheathed part piece by piece into the sheath.

A right femoral cut down was performed to establish the access for catheters and stent-graft. Left anterior oblique 52° was ideal for separating the branches of the aortic arch. Before stent implantation, the operating table was locked and the screen marker indicating the contour of the aortic arch and target vessels were labeled on the digital substraction angiography monitor. In this case, diameter of the aorta at distal landing zone was 28 mm, which is far smaller than 36 mm, thus a 28 to 150-mm Valiant stent-graft (Medtronic Vascular) was deployed in advance as restrictive and extensive stent-graft for the distal part,

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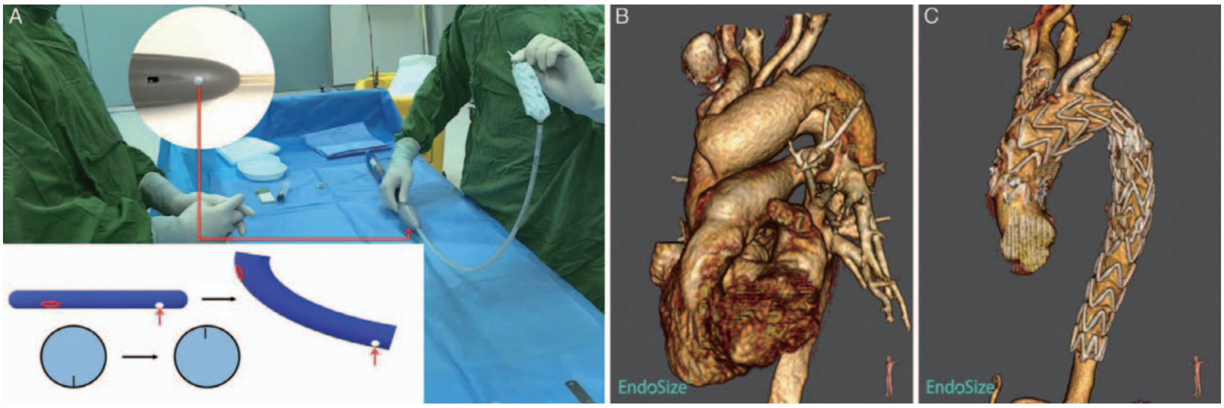

Figure 1: (A) Lu's direction-turnover technique. During the advancement of the delivery system, the white point of the front grip was kept in the 6 o'clock direction [QSIImage] (red arrow), the fenestrations which were coaxial with the white point mark on the front grip would turn over to 12 o'clock when marching through the greater curvature side of the aortic arch. (B) Pre-operative CTA showed the aortic dissection involving the aortic arch. (C) Post-operative CTA showed that the stent-graft was stable and all branched arteries were patent after 3-year follow-up. CTA: Computed tomography angiography.

covering 4 to 5 cm of the proximal stent-graft. The delivery system of the fenestrated stent-graft was then advanced through the stiff guidewire from the right femoral access. During the advancement of the delivery system, the white point of the front grip must be firmly kept perpendicular to the ground, which indicated 6 o'clock direction, by holding the front grip tightly without any rotation. The fenestrations would automatically turn over to 12 o'clock direction (the direction of ostia of all branch arteries) when marching through the aortic arch to the ascending aorta, which was defined as Lu's direction-turnover technique [Figure 1A]. The axial position was identified by the screen marker and the pieces of the stent. Starting from the bare part of the stent-graft, the end point of the third piece was the distal end of the fenestration for IA, which was aligned with the distal contour of IA. The operator could deploy the stent-graft with one fenestration properly aligned with the target artery, and the rest fenestrations would be inaccurate alignment with target arteries. After deploying the stent-graft, another angiography would be performed to ensure patency of all branch arteries and complete exclusion of the false lumen. In order to maintain the patency of the branched arteries, the LCCA was catheterized through the second fenestration into the stent-graft. After that, an 8-mm balloon was used to correct and dilate the second fenestration. Then, an 8 to 50-mm Viabahn covered stent (Gore, Flagstaff, AZ, USA) was deployed into the second fenestration. The same method was applied to the third fenestration, using an 8 to 60-mm Fluency covered stent (C.R. BARD, Murray Hill, NJ, USA) without balloon. Finally, a 16–13–80-mm Endurant Leg extension (Medtronic Vascular) stent-graft was inserted and deployed into the first fenestration, with the distal end in IA.

Final angiography was performed to confirm complete exclusion of the false lumen, patency of all branch arteries, and proper positioning of the stent-graft without any sign of endoleak. Antiplatelet therapy was applied during the follow-up period. CTA at 3 years showed complete thrombosis and shrinkage of the false lumen, patent branch arteries, and stable stent-grafts [Figure 1C] [Supplementary Video, http://links.lww.com/CM9/A503].

When performing fenestrations, spanning across the stent wire should be avoided, otherwise endoleak or compression of the bridging stent-graft could occur. Either scalpel or electrotome is optimal for making fenestrations. If the edge of the fenestration is rough, hemstick suture will be needed. Guide wire loops or radiopaque marks could indicate the position of the fenestrations (eg, "8").[3]

No rotation is allowed when resheathing the fenestrated stent-graft. A few rules to follow during the process of resheath are listed below: (1) Do not shorten the distance between any pieces; (2) Do not rotate any piece; (3) Do not move the stent-graft forward with the cover sheath; (4) Do not release the tip-capture device.

A small fenestration with bridging stent-graft implanted could prevent stent-graft migration and reduce the risk of branch artery stenosis or occlusion and endoleak.[4,5] The guide wire should be advanced inside the fenestrated stent-graft and crossed the fenestration into the target branch artery. The diameter of the bridging stent-graft should be equal to or slightly larger than that of the fenestration, and about 1 cm insertion of the bridging stent-graft into the aorta is advocated.[4,5] Post-expansion is required when there is sign of stenosis or occlusion within the bridging stent-graft.

Accurate alignment between branch arteries and fenestrations can be achieved by pre-operative precise measurement, accurate fenestration design, Lu's direction-turnover technique, and application of bridging stent-grafts.

This technique has strict requirements on the stent-graft for modification. Partially-released and easily-resheathed are two essential functions embedded by the stent-graft used for *in vitro* fenestration, which excludes many products in the first place. Besides, performing fenestration is a demanding job. There remains a significant learning curve to achieve proficiency in this technique.

Conflicts of interest

None.

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