Is Renal Branch Occlusion the Achilles Heel of Endovascular TAAA Repair?

A look at the causes of and possible solutions to this lingering complication.

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There is no shortage of candidates for the title "Achilles heel of endovascular thoracoabdominal aortic aneurysm (TAAA) repair." For all of its advantages, endovascular TAAA repair has many potential failure modes. However, the more common complications (eg, type II endoleak) tend to be relatively benign, whereas those that are more life-threatening or disabling (eg, paraplegia) tend to be rare.[1,2] Only renal branch failure (thrombosis, fracture, or dislocation) is late occurring, difficult to predict, difficult to treat, potentially life-threatening, and seen in as many as 20% of patients, depending on the length of follow-up and the exact method of branch construction.[1-6]

Although early reports[2] suggested that most cases of renal branch occlusion occurred within 6 months of repair, later studies (with longer follow-up) have shown a steady accumulation of new cases long after stent graft implantation.[3,5] As other barriers to the widespread application of endovascular TAAA repair diminish, the rising rate of renal branch failure after this procedure could become a limiting factor. It is still difficult to advocate endovascular TAAA repair in patients who are healthy enough to undergo open repair, and the prospect of long survival after endovascular repair might paradoxically raise the risk of late-occurring renal branch failure.

TYPES OF BRANCHED STENT GRAFTS

All of the currently available modular systems for endovascular TAAA repair combine an aortic stent graft with multiple (usually four) covered stents. The site of branch attachment is either a wire-reinforced hole in the wall of the stent graft (fenestration) or a short axially oriented branch (cuff).

As a rule, fenestration-based branches are created from balloon-expandable covered stents. Cuff-based branches are more variable: some are created from self-expanding covered stents, and some are created from balloon-expandable covered stents. Regardless of type, covered stents are often lined with self-expanding stents to minimize infolding and kinking, smooth the transition from the stiff stented portion of the renal artery to the flexible unstented portion, and stabilize branch attachment by providing a site for arterial ingrowth. Commonly used covered stents include iCast (Maquet; balloon expandable), Jostent (Abbott Vascular; balloon expandable), Viabahn (Gore & Associates; self-expanding), and Fluency (Bard Peripheral Vascular, Inc.; self-expanding). Commonly used uncovered stents include Zilver (Cook Medical) and Wallstent (Boston Scientific Corporation).

Some investigators prefer fenestrations,[5-8] some cuffs,[1-4] and some a mixture of the two.[9,10] The resulting heterogeneity of stent graft design both helps and hinders the study of renal branch failure. Differences in the rate and form of renal branch failure between branch types and locations may suggest possibly various risk factors, but statistically meaningful analysis is complicated by low event rates and the need to stratify results by different stent graft constructs. Analysis is also hindered by unclear naming conventions, most of which reflect the evolutionary origins of the field. Some studies[6] fail to distinguish between simple fenestrations (anchored by uncovered stents) and fenestration-based branches; others[5] use terms like "branched stent graft" (meaning a stent graft with cuff-based branches) and "fenestrated stent grafts" (meaning a stent graft with fenestration-based branches).

MECHANICAL DIFFERENCES BETWEEN GRAFT TYPES

The basic methods of fenestrated stent graft implantation were developed in the late 1990s and were reported in 2001.[11] This approach employed constraining ties to maintain a state of partially expanded stent graft, a bridging catheter to help guide the fenestration to the arterial orifice, and a bridging stent to keep the fenestration anchored. The substitution of a balloon-expandable covered stent for the original uncovered bridging stent changed a fenestration into a branch. Whereas the uncovered stent of a simple fenestration relies on direct apposition between the stent graft and the aorta for sealing, the covered stent of a fenestration-based branch has an impervious wall, which means it can bridge a gap between the stent graft and aorta, thereby providing inflow to branches that originate from a pararenal or thoracoabdominal aneurysm.[12] For a fenestration-based branch to work without leakage (type I endoleak), there must be hemostatic connections between the fenestration and the covered stent proximally, as well as between the covered stent and the lumen of the target artery distally.

A stable hemostatic connection between a covered stent and the wire-reinforced rim of a typical fenestration requires near-perfect transaxial orientation of the branch relative to the long axis of the stent graft, which in turn requires near-perfect alignment between the fenestration and the target artery orifice. Only the so-called pivoting fenestration[13] has enough tolerance for nonperpendicular branch orientation to accommodate renal/fenestration misalignment. The stability of the fenestration-to-branch connection also depends on the high local forces generated where the nitinol-reinforced margin of the fenestration contacts the outer surface of an unyielding balloon-expandable stent (self-expanding stents do not provide the necessary force required in this scenario). Because balloon-expandable stents take the shape of the balloon (and balloons straighten forcibly on inflation), fenestration-based branches tend to be both straight and stiff.

Cuff-based branches were originally designed and specifically used for treating TAAAs.[14] Although they come in a variety of forms (helical or straight, external or internal), all have a substantially axial alignment (they point up or down along the stent graft) and all provide a cylindrical (not merely circular) implantation site on the stent graft for overlap with the covered stent.[15] The intrinsic stability of an intercomponent overlap allows for the use of relatively compliant self-expanding covered stents. The axial orientation allows covered stents to pass obliquely up or (more often) down the aorta at a variable angle for a variable distance before turning into the target artery orifice.[16] Self-expanding stents may be more flexible than balloon-expandable stents, but they are still more stiff than the typical native renal artery.

RENAL BRANCH OCCLUSION AFTER ENDOVASCULAR TAAA REPAIR

Based on the experience at University of California, San Francisco,[3] approximately 10% of cuff-based renal branches occlude, which translates to a per-person rate of approximately 20%. For cuff-based branches, the risk factors for occlusion include sex (men), aneurysm extent (not Crawford type II aneurysms), a history of myocardial infarction, and renal artery length. Notably absent from this list are aortic diameter (< 30 mm at the level of the renal orifices), renal artery diameter, renal artery angle, and branch angle. In the majority of cases, each branch combined a Fluency covered stent with a slightly oversized vascular Wallstent. The stiffness of the resulting branch was an intentional design feature, the goal being to stabilize the multibranched construct and help prevent both migration and component separation.

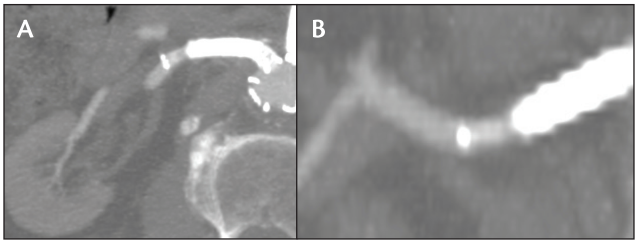

Figure 1. Follow-up CT angiography demonstrating how a relatively stiff Fluency stent creates angulation of the distal renal artery despite the presence of a slightly less stiff Zilver stent (A). Incipient hyperplasia and stenosis are seen just distal to the Fluency stent (B).

In this experience, most cases of renal branch occlusion go unheralded by observable changes in luminal diameter, probably because the causative lesion is located just distal to the end of the branch where markers on the Fluency stent create a starburst effect on follow-up CT (Figure 1). It is even possible to miss established branch occlusion because the downstream artery may be patent through adrenal collaterals and flow may be sufficient to maintain the size of the affected kidney, especially when the contrast bolus is poorly timed. Under these circumstances, the potential for preservation of viable renal function is sufficient to justify an attempt at aspiration thrombectomy, transcatheter thrombolysis, and stent implantation.

Compared to cuff-based branches, fenestration-based branches appear to be less likely to occlude but more likely to fail in other ways, such as fracture and disconnection.[5,6] All in all, fenestration-based branches have a failure rate of approximately 10%, which is basically the same rate of failure seen in cuff-based renal branches. Kaplan-Meier and exponential decay curves show rates of branch failure and reintervention as high as 20% at 5 years.

RENAL ARTERY ANATOMY AND MOVEMENT BEFORE AND AFTER ENDOVASCULAR TAAA REPAIR

The proximal renal arteries rarely originate at right angles to the aorta. Most are caudally oriented, especially on the left.[16-18] The presence of an aneurysm changes the renal artery orientation by altering the position of the pararenal aorta. Crawford type IV aneurysms lengthen the infrarenal aorta and push the renal orifices up, causing the renal arteries to be more caudally oriented. Crawford type II and III aneurysms lengthen the suprarenal aorta and push the renal orifices down, causing the renal arteries to be more cranially oriented.

The renal arteries are seldom straight, especially proximally, although they may appear so on anteroposterior angiography. In the absence of heavy calcification, the proximal 2 cm of the renal artery is often mobile, bending up and down, back and forth, to accommodate the effect of diaphragm descent on the position of the kidneys.[18]

After endovascular TAAA repair, the proximal 1 to 3 cm of each renal artery is occupied by a covered stent. The effect on renal anatomy depends on the length, stiffness, and orientation of the stent, which varies according to operator preferences. Most fenestration-based branches are inserted from below (transfemoral), and their presence rotates the proximal renal artery into a more cranially oriented position.[6] Most cuff-based branches are inserted from above, and their presence rotates the proximal renal artery into a more caudally oriented position. Fenestration-based branches are all balloon-expandable, which means that they are stiff and straight. Cuff-based branches are usually self-expanding, which means that they are less stiff than fenestration-based branches, but still more stiff than unstented renal arteries.

With both branch types, the stented portion of the renal artery goes from curved, flexible, and mobile to straight, stiff, and immobile. However, the stented portion of the flow lumen with its robust impermeable lining is not the portion most at risk for compression, kinking, hyperplastic ingrowth, or anything else that might constrict the lumen. The greatest risk is where the stiff branch meets the flexible renal artery, creating an abrupt mechanical discontinuity. Postimplantation CT scans show this to be the site of acute angulation (Figure 1). Because endovascular TAAA repair does nothing to arrest the kidneys' respiratory motion, the renal artery continues to bend with every breath, and due to the presence of the stiff branch, bending is isolated to the distal end of the branch, which becomes a discrete hinge point.

Thus, we hypothesize that acute angulation and repetitive microtrauma at the distal end of a stiff renal branch cause hyperplasia, leading to stenosis and eventual occlusion.

THE FUTURE

If this hypothesis is correct, the use of a flexible covered stent should help reduce the stiffness mismatch between the stented and unstented portions of the renal artery, thereby reducing angulation and repetitive microtrauma. With this in mind, we at the University of California, San Francisco have switched from Fluency to Viabahn covered stents. The early results of this change were marred by cuff-induced infolding of the Viabahn, which went unrecognized because completion angiography was performed with the tip of the catheter well into the branch. Currently, we routinely line the Viabahn with a Zilver stent, dilate the entire branch to iron out irregularities, and perform completion angiography using a 5-F sheath placed just inside the proximal end of the branch.

None of the renal branches inserted since we made this change (a little over 2 years ago) have occluded. This is not to say that we believe the Viabahn device to be the ideal covered stent for this application. For example, neither of the available lengths (5 and 10 cm) are ideal. The 5-cm version is too short to allow for a 2-cm overlap proximally, a 2-cm overlap distally, and the usual central gap (of 2 cm or more) between the cuff and the target artery. The 10-cm version, on the other hand, protrudes too far into the renal artery and the trunk of the stent graft and can curve through the aneurysm sac between widely spaced attachment points. The latter is a concern because the central segment of the Viabahn covered stent can shorten, lengthen, or bend in an uncontrolled way that, in theory, deprives both the branch and the stent graft of stability. In practice, we have never seen stent graft migration or branch dislocation, perhaps because the celiac and superior mesenteric branches still consist of a (relatively stiff) Fluency/Wallstent combination.

Again, if the previously stated hypothesis is correct, fenestration-based branches would also benefit from a higher degree of flexibility—the limiting factor being the intrinsic rigidity of the balloon-expandable stent. One possible solution involves the combination of a PTFE graft with multiple short balloon-expandable stents. Nothing of the sort currently exists, at least not in sizes compatible with renal use.

CONCLUSION

There is no denying that renal branch thrombosis is the most common failure mode in the endovascular repair of TAAA, but I would argue that this is a product of the current technology, not the technique itself. If this is true, the rate of branch occlusion may be amenable to changes in device design. Although this observation applies to both fenestration-based branched and cuff-based branches, the underlying problems and solutions may be different. In the case of cuff-based branches, the most important cause is mechanical discontinuity between the stiff branch and the flexible native artery, and the most important change would be an increase in the flexibility of the branch. Ideally, this change would occur with the development of covered stents specifically designed for this purpose. In the meantime, we have opted to use the most flexible self-expanding covered stent available (Viabahn), and medium-term results suggest that we may be moving in the right direction. If so, we may have reached the point at which endovascular repair of TAAA really has no Achilles heel, and the technique may be ready to assume the role of first-line treatment. ■

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1. Chuter TA, Rapp JH, Hiramoto JS, et al. Endovascular treatment of thoracoabdominal aortic aneurysms. J Vasc Surg. 2008;47:6-16.
2. Reilly LM, Rapp JH, Grenon SM, et al. Efficacy and durability of endovascular thoracoabdominal aortic aneurysm repair using the caudally directed cuff technique. J Vasc Surg. 2012;56:53-64.
3. Premprabha D, Sobel J, Pua C, et al. Visceral branch occlusion following aneurysm repair using multibranched thoracoabdominal stent grafts. J Endovasc Ther. 2014;21:783-790.
4. Bisdas T, Donas KP, Bosiers MJ, et al. Custom-made versus off-the-shelf multibranched endografts for endovascular repair of thoracoabdominal aortic aneurysms. J Vasc Surg. 2014;60:1186-1195.
5. Mastracci TM, Greenberg RK, Eagleton MJ, Hernandez AV. Durability of branches in branched and fenestrated endografts. J Vasc Surg. 2013;57:926-933.
6. Martin-Gonzalez T, Pincon C, Maurel B, et al. Renal outcomes following fenestrated and branched endografting [published online ahead of print May 25, 2015]. Eur J Vasc Endovasc Surg.
7. Conway BD, Greenberg RK, Mastracci TM, et al. Renal artery implantation angles in thoracoabdominal aneurysms and their implications in the era of branched endografts. J Endovasc Ther. 2010;17:380-387.
8. Greenberg RK, Lyle R. Endovascular repair of thoracoabdominal aneurysms. Circulation. 2008;117:2288-2296.
9. Haulon S, D'Elia P, O'Brien N, et al. Endovascular repair of thoracoabdominal aortic aneurysms. Eur J Vasc Endovasc Surg. 2010;39:171-178.
10. Verhoeven EL, Tielliu IF, Ferreira M, et al. Thoracoabdominal aortic aneurysm branched repair. J Cardiovasc Surg. 2010;51:149-155.
11. Anderson JL, Berce M, Hartley D. Endoluminal aortic grafting with renal and superior mesenteric artery incorporation by graft fenestration. J Endovasc Ther. 2001;8:3-15.
12. Anderson JL, Adam DJ, Berce M, Hartley DE. Repair of thoracoabdominal aortic aneurysms with fenestrated and branched endovascular stent grafts. J Vasc Surg. 2005;42:600-607.
13. Kitagawa A, Greenberg R, Eagleton MJ, Mastracci TM. Zeith p-branch standard fenestrated endovascular graft for juxtarenal abdominal aortic aneurysms. J Vasc Surg. 2013;58:291-301.
14. Chuter TA, Gordon RL, Reilly LM, et al. An endovascular system for thoracoabdominal aortic aneurysm repair. J Endovasc Ther. 2001;8:25-33.
15. Chuter TA, Greenberg RK. Standardized off-the-shelf components for multibranched endovascular repair of thoracoabdominal aortic aneurysms. Perspect Vasc Surg Endovasc Ther. 2011;23:195-201.
16. Park KH, Hiramoto JS, Reilly LM, et al. Variation in the shape and length of the branches of a thoracoabdominal aortic stent graft: implications for the role of standard off-the-shelf components. J Vasc Surg. 2010;51:572-576.
17. Mazzaccaro D, Malacrida G, Nano G. Variability of origin of splanchnic and renal vessels from the thoracoabdominal aorta. Eur J Vasc Endovasc Surg. 2015;49:33-38.
18. Draney MT, Zarins CK, Taylor CA. Three-dimensional analysis of renal artery bending motion during respiration. J Endovasc Ther. 2005;12:380-386.