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Evolving Techniques for Improving Outcomes in

Thoracic Aortic Disease

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Pitfalls in Pre-Case Planning for Thoracic Stent Grafting

What to consider to ensure clinical success.

BY W. ANTHONY LEE, MD

Accurate preoperative assessment is critical to the early and late success of thoracic endovascular aortic repair (TEVAR) (Figure 1). It can be said that 90% of the "battle" is won or lost before stepping into the operating room. Although repair of an uncomplicated mid-descending thoracic aneurysm is fairly straightforward, most thoracic pathologies lie close to the arch vessels proximally and/or the mesenteric vessels distally. Meticulous attention to detail and proficiency in advanced endovascular skills are required to safely complete these procedures and avoid the myriad of potential pitfalls that can lead to lethal complications.

Although experience with abdominal endografts is useful, TEVAR is sufficiently different due to the extreme tortuosity of the thoracic aorta that is not easily corrected with stiff wires, the greater hemodynamic forces in the arch, the remote location of the pathology, and the significantly increased risk of iatrogenic dissection and aortic injury that is not readily surgically accessible (Figure 2).

Even though the principles outlined in this article may be broadly applied to the repair of a variety of thoracic pathologies, certain problems, such as dissections and traumatic transections, require special considerations that are beyond the scope of the present discussion. It should be noted that the only currently approved indication for TEVAR is for degenerative aortic aneurysms with at least a 2-cm landing zone distal to the left common carotid artery and proximal to the celiac artery.

PITFALLS AND HOW TO AVOID THEM

Imaging

The importance of proper cross-sectional imaging cannot be overemphasized. Although this may be with either CT or MR imaging, the gold standard is CTA. The large volumetric data sets currently available with 32- and 64-multislice detector scanners can be rendered into a variety of 3D reconstruction formats and enable unprecedented morphologic and dimensional anatomic analysis. Two such postprocessing systems include the TeraRecon Aquarius Workstation (San Mateo, CA) and the M2S (West Lebanon, NH). Today, there is almost no role for invasive, conventional angiography. Use of multiplanar reformations and centerline measurements have become almost routine in the preoperative assessment and planning for TEVAR. Having said that, "garbage in, garbage out," and nothing can compensate for a poorly performed study. The ideal CTA should be acquired with ≤2-mm collimation, uniform arterial opacification, no venous contamination, and cover from the base of the neck to the femoral heads.

Device Selection

It is worth noting that, unlike endovascular abdominal aortic repairs, when sizing for thoracic repairs, the centerline measurements tend to underestimate the actual path that the device will take. If device lengths are matched exactly to the centerline analysis, the actual length of aortic coverage tends to be short by 3 to 5 cm. Therefore, the interventionist should always select a longer device if on the border between choosing one size shorter or longer and have extensions available.

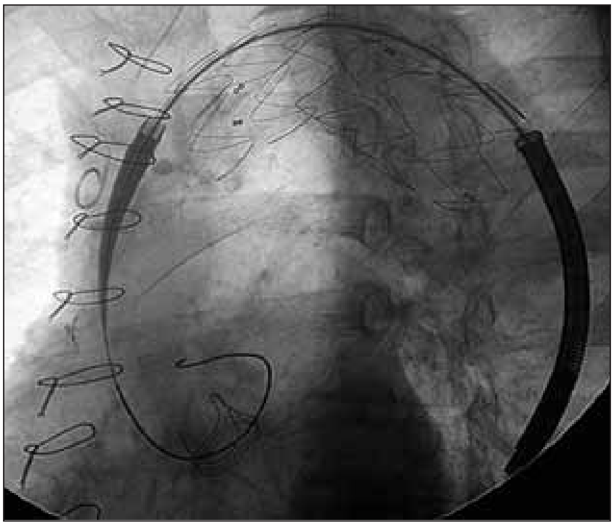

Figure 1. Medtronic Talent (Medtronic CardioVascular, Endovascular Innovations, Santa Rosa, CA) thoracic stent graft being deployed to repair a distal arch thoracic aneurysm.

Anesthetic Technique

Most patients with thoracic aortic disease have multiple cardiovascular comorbidities, and the procedures should be performed with anesthesia. The importance of maintaining an absolute sterile technique with proper airflow conditions of a formal operating room environment cannot be overstated to avoid a life-threatening graft infection. TEVAR should be performed under general or regional anesthesia. General anesthesia has clear benefits with its control of the airway, respiration, blood pressure, and patient movement. However, for cooperative patients, regional anesthesia is a viable option, especially for those with pulmonary insufficiency. Despite the obvious torsion, stretching, and movements of the thoracic aorta by the delivery catheter, and the wide hemodynamic fluctuations that can occur with transient proximal balloon occlusion, the patients do not seem to feel this. For hemodynamic monitoring, a radial arterial catheter should be routinely placed in the right wrist because left subclavian artery coverage is required in more than one third of cases to gain an adequate proximal landing zone.

Figure 2. Iatrogenic retrograde thoracic aortic dissection after TEVAR. The patient was asymptomatic, and the dissection was discovered on postoperative CTA. The dissection was electively repaired with ascending aortic and arch replacement with distal anastomosis directly onto the endograft (TAG).

Posterior Circulation Ischemia

For proximal aortic aneurysms, the anatomy of the vertebral arteries and the posterior cerebral circulation should be assessed. This study may be obtained at the same time as when the rest of the body is imaged using CTA. In 60% to 70% of cases, the left vertebral artery is dominant, and in approximately 2% to 3% of cases, one of the vertebral arteries terminates as the posterior inferior cerebellar artery without joining the basilar artery (Figure 3). In these situations, prophylactic revascularization is strongly recommended if coverage of the left subclavian artery is planned to prevent a potentially devastating posterior circulation ischemic stroke.[1] Patients with a previous left internal mammary coronary bypass graft should also undergo revascularization to avoid myocardial ischemia. Only very rarely is symptomatic upper-extremity ischemia an indication for subclavian artery bypass, which can be performed electively after the thoracic repair.

Stroke

Strokes remain one of the most devastating complications during TEVAR. In most case series, the incidence of clinically evident cerebrovascular accidents range from 4% to 5%. This risk seems to be increased in the subset of patients who require zone 2 coverage (extension to left common carotid artery). Although unsubstantiated, other anatomic factors that may play a role include the severity of atheromatous disease in the arch and calcifications of the origins of the great vessels. However, these are nonmodifiable factors that may be useful for preoperative risk stratification and in deciding whether to offer a repair, but if a patient presents with a life-threatening thoracic aortic problem, these factors would not by themselves be exclusionary. Last, operator technique plays a critical role in minimizing the risk of stroke during TEVAR. These include meticulous guidewire and catheter hygiene (frequent wiping of the wires, flushing of catheters, avoidance of bubbles during any injections), minimizing manipulation of the delivery system near the arch, and avoidance of balloon molding unless clinically indicated to achieve a seal.

Spinal Cord Ischemia

Placement of a prophylactic spinal drainage catheter is a controversial topic that is beyond the scope of this article. It should be noted, however, that in the absence of clearly proven risk factors, routine spinal drainage should be instituted except when there are obvious contraindications (such as coagulopathy and focal disease, such as a penetrating ulcer that requires <50% thoracic aortic coverage). The risk of serious iatro-

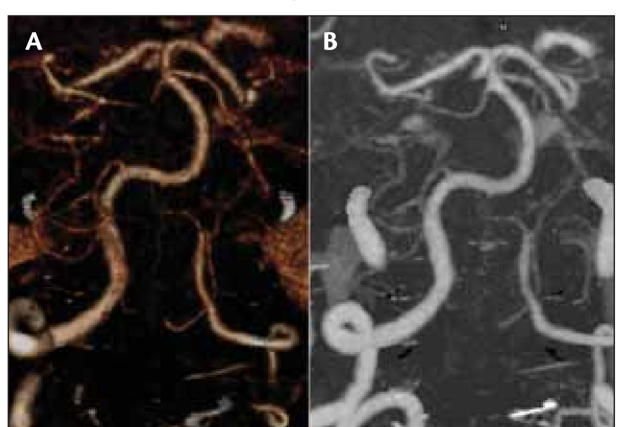

Figure 3. Posterior views of 3D reconstructions of the vertebrobasilar circulation. Surface shaded model (A), thin maximum-intensity projection (B). Note the dominant left vertebral artery and the diminutive right vertebral artery terminating before joining the basilar artery.

genic hemorrhagic complications from spinal catheter placement has ranged from 0% to 3%.[2] On the other hand, if expectant management is followed, patients should be monitored in an intensive care setting for at least 24 hours, with hourly lower-extremity motor-sensory examinations and a mechanism for immediate spinal drainage available around the clock.

Access

The beginning of any TEVAR procedure is to gain secure access to the aorta. The best side of entry for the endograft is selected based on preoperative evaluation of the access vessels. The currently commercially available TAG (Gore & Associates, Flagstaff, AZ) device requires introducer sheaths with outer diameters ranging from 23 F to 27 F, and two other thoracic endograft systems that are undergoing premarket approval process (TX2, Cook Medical, Bloomington, IN; Talent Thoracic, Medtronic Cardio-Vascular, Santa Rosa, CA) have similar profiles. There is a relatively higher proportion of women among patients who present with thoracic aortic pathologies compared to abdominal aneurysms.[3] This subset of patients has smaller iliofemoral vessels that are frequently involved with calcific occlusive disease. This combination results in approximately 15% of cases requiring an iliac conduit when the access vessels do not allow safe insertion of the delivery catheter.[4] This conduit is constructed through a lower-quadrant retroperitoneal approach with a 10-mm prosthetic tube graft anastomosed to the distal common iliac artery in an end-to-side manner (Figure 4). At the conclusion of the procedure, this conduit may be either (1) simply transected at its base, (2) left long and tucked underneath the inguinal ligament to be reaccessed in the future, or (3) converted as an iliofemoral bypass if the femoral pulse is weak. The threshold for performing an iliac conduit should be low. Iliac injuries, ranging from asymptomatic iliac dissection to life-threatening iliac ruptures, are the single most preventable life-threatening complications during endovascular aortic repair. Often, in the time it takes to perform all the adjunctive techniques, such as angioplasties and serial dilations to manage a compromised access vessel, an iliac conduit can be easily performed in most instances. It should be kept in mind that even if the delivery catheter or sheath were to be eventually advanced into the aorta, this represents only half the battle. A significant proportion of iliac injuries actually occur during retraction of the sheath after the device is deployed and can have a significant adverse impact on an otherwise successful thoracic repair.

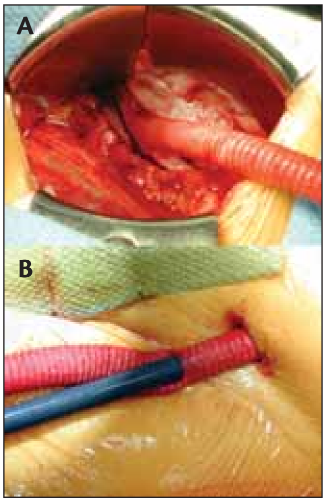

Figure 4. The iliac conduit. A Dacron tube graft is anastomosed to the distal common iliac artery and brought out through a separate incision at the level of the femoral artery (A). This is directly accessed using a standard Seldinger technique to introduce the delivery sheath (B).

Lesion Localization

Occasionally, the disease may not be easily seen on the aortogram if the aneurysm is lined with thrombus or if a penetrating ulcer is overlying the aortic lumen. In these situations, accuracy of the preoperative measurements in determining the location of the lesion relative to pertinent vessels or other radiographically visible structures is critical because accurate placement of the endograft is almost entirely dependent on them. Alternatively, adjunctive imaging techniques, such as intravascular ultrasound, may be helpful in localizing the lesion.

Aortic Arch

For accurate positioning of the endograft near the aortic arch, the origins of the great vessels must be clearly visualized. In cases of marginal proximal landing zone, critical millimeters of seal may be lost by improper localization of the left common carotid artery. Simple widening of the aortic arch using a left anterior oblique projection may not be

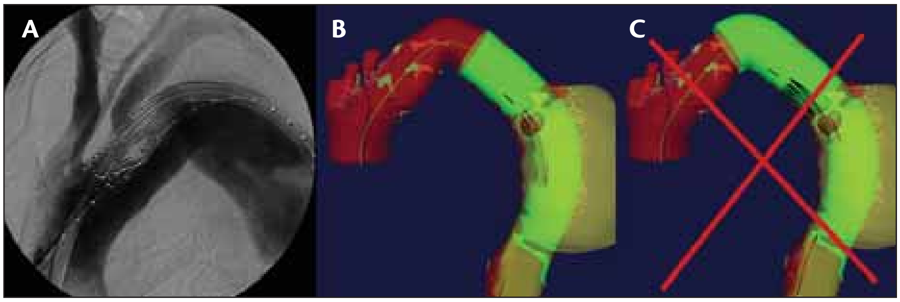

Figure 5. The concept of avoiding the apex of the arch in the deployment of a thoracic endograft. The endograft being deployed either in the proximal arch, even with the left subclavian artery being covered, or distal to the apex to land the device within a straight segment of the aorta (A, B). A suboptimal deployment at the apex of the arch (C).

sufficient to achieve maximum separation of the great vessels because of the complex and unpredictable distortions that are typically present in these aortas. Therefore, the 3D plane of the proximal delimiting artery relative to its adjacent vessels should be carefully assessed so that the optimal orthogonal projection of the image intensifier can be determined. As a matter of technique, the apex of the arch remains the Achilles' heel of TEVAR. All devices have a minimum radius of curvature below which the device fails to conform along the inner convexity of the arch. This malapposition can lead to type IA endoleaks and, rarely, device collapse.[5] Therefore, if there is an adequate length of nonaneurysmal proximal aorta, the endograft should be deployed sufficiently proximal to the apex of the arch, even if the left subclavian artery must be covered, or entirely distal ("downslope") to it so as to land the device in a parallel segment of the aorta (Figure 5).

Distal Thoracic Aorta

The distal limit of TEVAR is the celiac artery. It is not uncommon for the mesenteric vessels to originate at an anterolateral angle and a full 90º lateral projection, as is typically performed to visualize the mesenteric arteries, may not be optimal. Similar to optimal imaging of the arch vessel, the best orientation of the image intensifier can be determined on the axial images of the preoperative CT scan.

Aortic Coverage

The instructions for use for a particular device notwithstanding, 3 cm is the minimum length of proximal or distal neck that should be used if anatomically possible, and 5 cm should be the minimum device-to-device overlap length. The interventionist should always err on the side of covering more than less of the thoracic aorta. For proximal lesions near the arch, the centerline length may not be relevant in determining whether a seal is likely to be achieved. For example, in fusiform lesions, the limiting factor is the length of apposition along the lesser curve, and in saccular aneurysms or penetrating ulcers, with defects that may be situated anywhere along the circumference of the aortic lumen, the actual length of graft coverage from its most proximal extent to the start of the aortic defect is the relevant parameter.

Thoracoabdominal Tortuosity

Thoracic aortic aneurysms may present with at least three tandem segments of significant tortuosity—the abdominal aorta, the distal thoracic aorta, and the arch. Pushability is lost after passage of each successive segment due to the serial frictional resistance and the noncoaxial vector forces transmitted along the delivery catheter. Although, in theory, a stiffer guidewire may remedy this situation, even the stiffest wires available today (eg, Lunderquist, Cook Medical) are inadequate in certain cases, and the only option is to use a transbrachiofemoral wire (Figure 6).

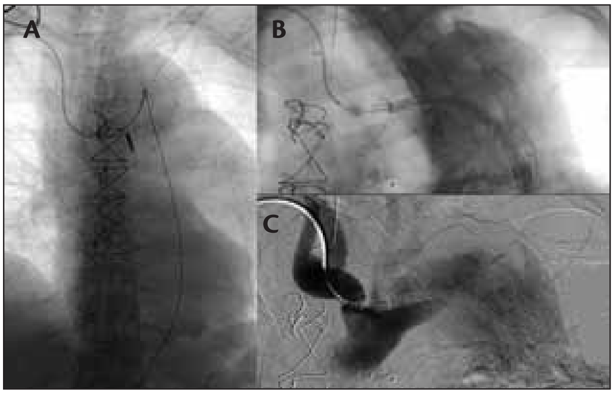

Figure 6. The transbrachiofemoral wire technique. A guidewire is introduced from the right brachial artery over a long guide catheter or sheath and snared from a femoral approach (A). The thoracic endograft is advanced over the guidewire applying firm tension at both ends (B). Having two points of fixation such as these provides a stronger rail than even the most stiff guidewire can provide. The long guide sheath (55 cm) can be used to inject contrast for control angiography during the deployment (C).

CONCLUSION

Safe performance of TEVAR requires skill sets learned from abdominal endovascular aortic repair and additional techniques that are unique to the treatment of the thoracic aorta due to its remote location, greater tortuosity, larger and stiffer delivery catheters, and the more severe hemodynamic conditions in which these devices must be deployed. However, meticulous attention to detail and careful preoperative planning can avert most technical pitfalls and result in a successful repair. ■

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Dynamic ECG-Gated CTA of the Thoracic Aorta

Insights into using 4D imaging when designing the next-generation thoracic endografts.

BY AARON M. FISCHMAN, MD, AND ROBERT A. LOOKSTEIN, MD

Surgical repair of thoracic aortic disease traditionally has been associated with high perioperative mortality and an extensive recovery period. Although long considered the gold standard, there are significant risks and morbidity associated with thoracic aortic surgery, including infection, pulmonary embolus, extended hospital course, and spinal cord ischemia.[1] Due to advances in endovascular devices and techniques, thoracic endovascular repair procedures (TEVAR) are becoming a promising alternative.[2] Endovascular repair has its own unique challenges—particularly device endoleaks, stent graft misplacement, subsequent migration and fracture, aortic perforation, and iliac artery trauma (Figures 1 and 2).[3]

Determining which patients are suitable candidates for endovascular therapy is critical to procedural success and to the reduction of postoperative complications.[4] TEVAR procedures have been shown to be associated with greater complications than endovascular abdominal aortic repair (EVAR).[5] Because of this increased risk, preoperative imaging of the thoracic aorta is of paramount importance in improving outcomes in these patients.

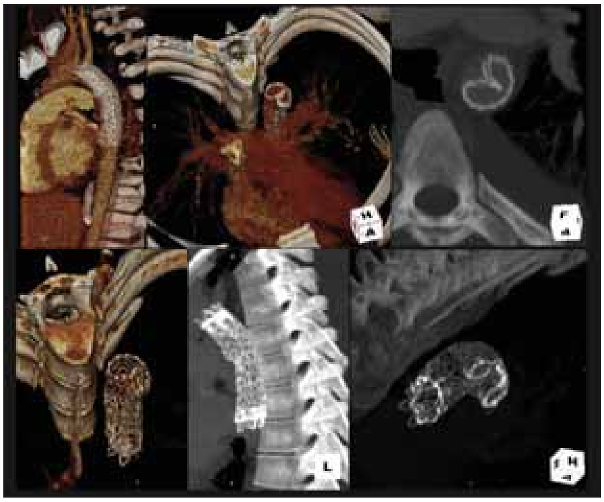
THE GOLD STANDARD?

Digital subtraction angiography remains the gold standard for arterial imaging, but CT is increasingly utilized as a noninvasive alternative. The use of CTA has dramatically facilitated device sizing[6] and can also predict problems such as migration and endoleaks when evaluating the proximal and distal seal zones of an endograft.[7]

Even with 3D reconstruction of these data sets, limitations still exist. In particular, the acquired data are not dynamic and only evaluate one point in the cardiac cycle. Currently, measurements for stent grafts are based on anatomic criteria using data from 2D/3D CTA, which has been criticized because it only provides a single temporal measurement and does not account for aortic wall dynamics and volume changes.[8] Due to its anatomical position, the thoracic aorta is particularly predisposed to have wall motion throughout the cardiac cycle.[9] The phase of the cardiac cycle in which aortic diameter is measured on traditional CTA is unknown. Utilizing nongated CTA for preoperative imaging results in inconsistent stent graft sizing.[4] ECG gating limits motion artifact and allows for optimal selection of the appropriate reconstruction interval.

4D IMAGING

Understanding the dynamic changes in aortic volume may offer improvements in patient selection and reduce postoperative complications. Understanding the dynamic changes in aortic volume may offer improvements in patient selection and reduce postoperative complications. Previous studies have provided insight regarding the dynamic changes in the aorta using techniques such as intravascular ultrasound and MRA.[10-12] 4D CTA, originally used to quantify wall motion and cardiac chamber changes such as ejection fraction, has more recently been praised for its high spatial resolution in comparison to other modalities and its



(Courtesy of Irina Oyfe.)

Figure 1. A 43-year-old man sustained blunt trauma to the descending thoracic aorta during a high-speed motor vehicle crash, which resulted in thoracic aortic disruption. He subsequently underwent TEVAR. The 3D and maximum-intensity projection images from 3-month follow-up CTA show collapse and infolding of the stent graft.

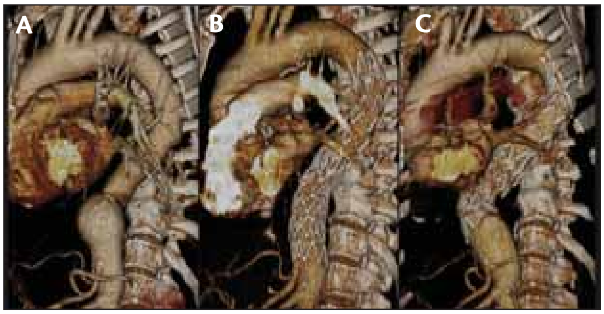


Figure 2. Thoracic stent graft migration due to aortic remodeling after TEVAR with the Relay investigational device (Bolton Medical, Inc., Sunrise, FL). Preoperative image (A). One-month postoperative image (B). Cranial stent migration of the distal device with kinking of the distal seal zone 1 year after initial placement (C).

feasibility in being able to measure diameter in cross section and area changes in a dynamic aorta.[8]

4D CTA: SINGLE-CENTER EXPERIENCE

Between March 2006 and January 2007, our imaging lab studied 40 patients (age range, 22-81 years) with a clinical diagnosis of acute aortic syndrome. These patients underwent ECG-gated 4D CTA of the thoracic aorta on a 64-slice Siemens Somatom Sensation 64 (Siemens Medical Solutions USA, Inc., Malvern, PA).

The entire aorta from the heart to the iliac bifurcation was imaged during a single breath hold phase of 20 seconds. The CTA protocol used a 1.2-mm collimation X 32 detector array, a pitch of .2, and radiation exposure parameters set at 140 kV and CTDI of 20.10 mGy. For each patient, intravascular nonionic contrast (100 mL, Isovue 370, Bracco Diagnostics, Princeton, NJ) followed by a 50-mL saline chaser bolus, was injected at a flow rate of 4 mL/s. The scan started with bolus-triggering software with a threshold of 80 HU over baseline, the ROI in the ascending aorta, and a rotation speed of 330 ms. ECG-triggered retrospective reconstructions were created at 10 equidistant time points (0% to 90%) over the R-R cardiac cycle. No medication was used to stabilize or decrease the patients' heart rates.

Data Analysis

The data sets (section thickness, 1.5 mm; increment, 1 mm) from each patient were loaded into a dedicated cardiovascular 3D/4D workstation (Aquarius WS, TeraRecon, Inc., San Mateo, CA) and postprocessed. The volume and length of the thoracic aorta for each patient, defined from the level of the aortic root to the ostium of the celiac artery, was measured during all 10 phases of the cardiac cycle. The TeraRecon workstation allows the user to select an angiographic volume (Figure 3).

Subsequently, the volumes of both the ascending aorta (defined from the aortic root to the origin of the left subclavian artery) and descending aorta (defined from the origin of the left subclavian artery to the celiac artery) were measured individually. Maximum and minimum volumes were obtained from data obtained at each point during the cardiac cycle. The absolute volume change was used to calculate a percentage change in each aorta. These data were compiled for the total thoracic aorta and both the ascending and descending portions.

Preliminary Findings

Volumetric and longitudinal changes were observed for every patient. All 40 patients demonstrated a rapid expansion during early diastole, and a gradual return to baseline during the remainder of diastole.

Volumetric changes during the cardiac cycle were observed for every patient (average, 18.7 mL; range, 6-61.1 mL). Every patient demonstrated a rapid volume increase of the thoracic aorta (mean, 7.4%; range, 1.6%-18.2%) during early diastole and a gradual return to baseline throughout the remainder of diastole. Figure 4 demonstrates the total blood volume of the thoracic aorta during each of the cardiac phases.

Similar findings were observed when the thoracic

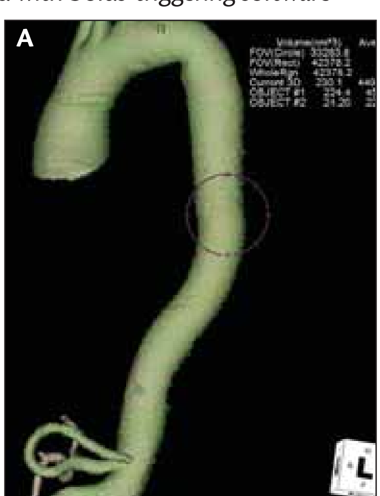


Figure 3. Volumetric analysis (A) and Centerline tool (B) on an Aquarius Workstation (TeraRecon, Inc.).

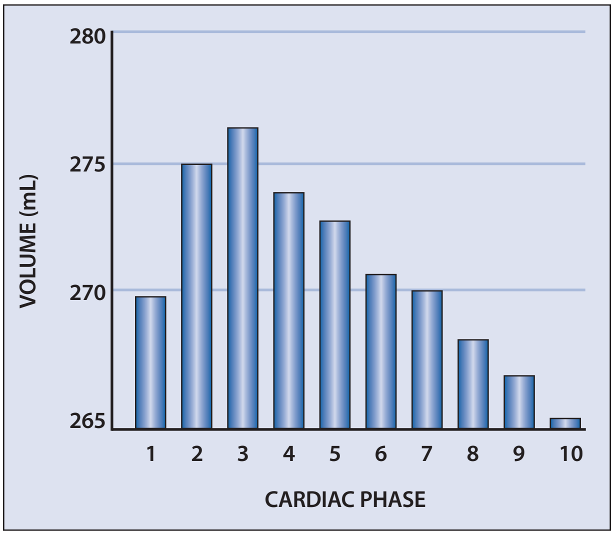


Figure 4. Total thoracic aorta blood volume during the cardiac cycle (average from 40 patients).

aorta was divided into ascending and descending portions (Figure 5). Volumetric changes during the cardiac cycle were observed for every patient with a rapid volume increase of 8.7% for both the ascending and descending portions. Longitudinal changes in the aortic length were also observed for each patient (average, 7.9%) (Figure 6).

THE PATH FROM 2D TO 4D

Conformational changes in the aortic wall are known to occur throughout the cardiac cycle due to cardiac pulsatility.[8,13] The thoracic aorta including the aortic root and great vessels experiences significant volumetric changes, particularly axial distention and longitudinal deformation. Previous studies related to determining normal thoracic aortic conformational changes and pulsatility have focused on changes in aortic diameter. Muhs et al utilized dynamic cine CTA to quantify changes in thoracic aortic diameter of up to 17.8% throughout the cardiac cycle.[8] Although aortic diameter is a crucial measurement for aortic stent graft placement, it is a 2D analysis in which diameter is only measured at specific points along the thoracic aorta.[8] Longitudinal and volumetric analysis provide a 3D perspective and greater coverage of the aorta. As we learn how to process and use the enormous amount of data acquired in ECG-gated data sets, we can bridge the gap into 4D imaging.

CAN WE PREDICT COMPLICATIONS?

Measuring volume provides a more accurate means of detecting early postoperative changes in aneurysms, and could be a potential method to predict device complications.[14] If the volume changes significantly during the cardiac cycle, there is a higher potential for graft migration and endoleaks due to suboptimal sizing at the proximal and distal seal zones.[15] Significant volumetric changes may require greater graft oversizing than the typical 10% to 15% that is standard practice by many interventionists.[16] Preoperative 4D evaluation of the aorta is a potential method to further decrease both cost and morbidity of this procedure.[17]

The preliminary results of this study indicate that there are volumetric and longitudinal changes of the thoracic aorta during the cardiac cycle. The rapid volume expansion occurred during early diastole, followed by a gradual return to baseline. The difference between the isolated portions and the total thoracic aorta indicates that there is asymmetric distribution of cardiac pulsatility resulting in varying aortic wall motion and volumetric changes.

WHERE WE ARE HEADED

There is great potential for future research using this technology. This study was performed initially to determine feasibility of this technique. As 3D/4D technology improves, work in this area will become easier. A 4D volu-

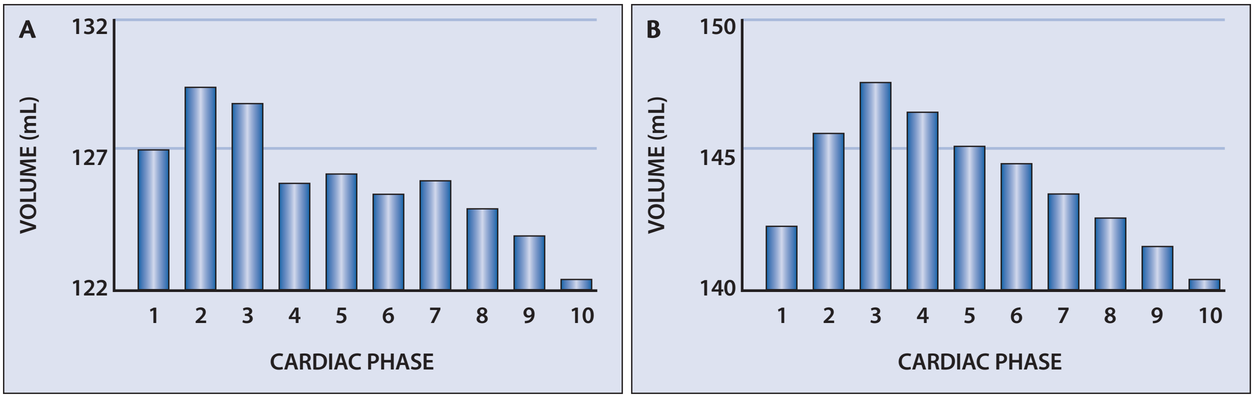


Figure 5. Ascending thoracic aorta blood volume during the cardiac cycle (average from 40 patients) (A). Descending thoracic aorta blood volume during the cardiac cycle (average from 40 patients) (B).

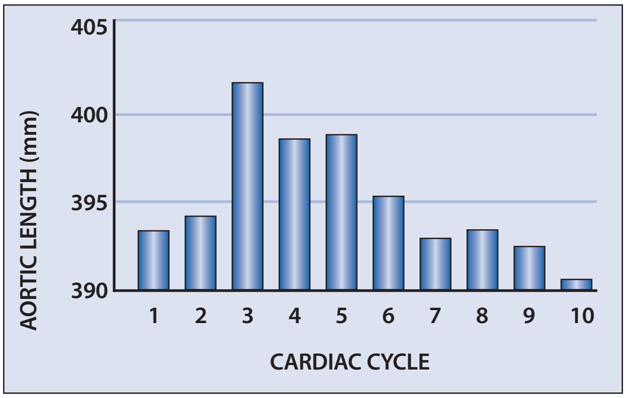


Figure 6. Thoracic aorta length during the cardiac cycle (average from 40 patients).

metric analysis can provide a stronger characterization of the relationship between aortic wall motion, compliance, and contractility. It has been shown that the wall stress of the thoracic aorta decreases linearly with age.[18] Healthy patients with more compliant aortas will likely demonstrate greater volume changes during the cardiac cycle. Although most aneurysmal aortas needing repair (open or endovascular) are diseased with large amounts of atherosclerotic plaque, great potential exists for providing this 4D evaluation in the preoperative evaluation of healthy younger patients with acute aortic injury, such as aortic transection and dissection. We believe this technique can have great impact on the care of patients with acute aortic injury because the aorta in these patients is subject to the greatest volumetric changes during the cardiac cycle.[19] Potential exists for providing a more durable endovascular repair for acute traumatic aortic injury for a larger number of patients in the near future.[20,21]

This technology may facilitate the development of devices that may be used in the ascending and transverse arch. The ability to quantify the forces on the arch vessels during the cardiac cycle may encourage the development of branch vessel technology. This technology may offer the ability to identify impending rupture by measuring compliance in aneurysmal aortas as a function of volumetric change. Last, this technology may become a novel technique for surveillance of chronic dissection by being able to record not only diameter changes, but compliance changes over time.

SUMMARY

ECG-gated 4D CTA offers a noninvasive modality to observe and perform volumetric analyses of the thoracic aorta, creating potential to improve endovascular device design and ultimately endovascular repair. By understanding how wall motion and compliance can be quantified in both normal and diseased aortas, significant advancements may be made in the endovascular treatment of thoracic aortic pathology. ■

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Pushing the Envelope With Complex TEVAR

Lessons learned, creative solutions, and new developments.

BY FRANK J. CRIADO, MD

Developments in thoracic endovascular aneurysm repair (TEVAR) have now gained their rightful place at the forefront of modern-day cardiovascular medicine. Advancements with thoracic endograft technologies and rapidly evolving new techniques have revolutionized the entire field of thoracic aortic surgery. One lesson that took time and considerable experience to learn was the necessary clear understanding that—unlike abdominal aortic aneurysm (AAA) endovascular procedures—TEVAR can be more complex and dangerous and, at times, extraordinarily difficult. An important reason for this difficulty is anatomy, and another is the wide variety of thoracic aortic pathologies being considered for endovascular treatment (Table 1).

Complex TEVAR is a term used to denote the performance of these procedures on patients who present with one or more anatomy- or disease-related factors leading to increased technical difficulty and to a higher risk for intra- and postoperative complications. Such factors and conditions are numerous; this article focuses on some of the most important considerations according to the author's 10-year TEVAR experience with more than 400 procedures.

TABLE 1. EXAMPLES OF THORACIC AORTIC LESIONS

• Aneurysms	• Ductus aneurysms
• Dissection	• Pseudoaneurysms
• Intramural hematoma	• Traumatic injuries
• Penetrating ulcers	• Embologenic plaques

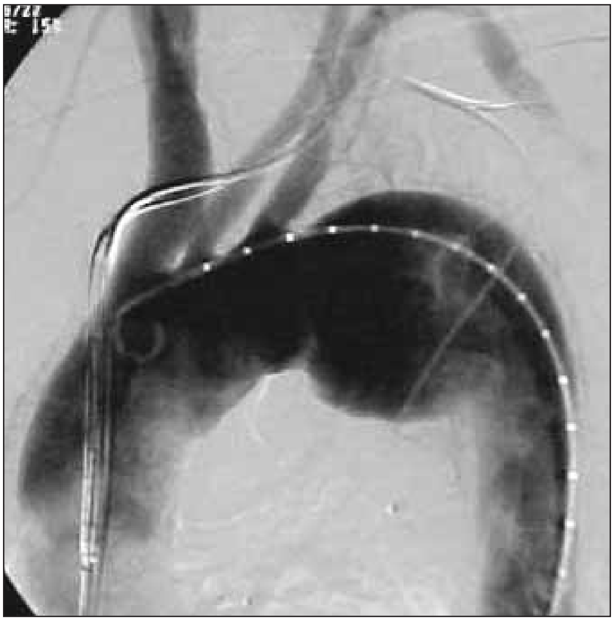

Figure 1. A large juxtasubclavian TAA.

CASE STUDIES

Complex TEVAR can perhaps be best described with two case examples.

Case 1

A 71-year-old man was referred for treatment of a large juxtasubclavian thoracic aortic aneurysm (TAA) measuring 8.5 cm in diameter (Figure 1). He had a history of severe aortoiliac occlusive disease and previous bilateral iliac artery stenting, creating a very difficult situation for endovascular access. Treatment of his TAA involved placing a single 11.5-cm-long Talent Thoracic Stent Graft (Medtronic CardioVascular, Endovascular Innovations, Santa Rosa, CA) with proximal bare springs that crossed the origin of the left subclavian artery (LSA) but did not exclude the vessel. It was immediately realized that proximal fixation length was not adequate, but access impediments precluded placement of a proximal extension cuff. Postoperatively, a type 1 endoleak was identified on CT (Figure 2). Transbrachial catheterization and coiling of the endoleak nidus proved feasible, resulting in complete thrombosis of the entire TAA sac. However, this outcome proved short-

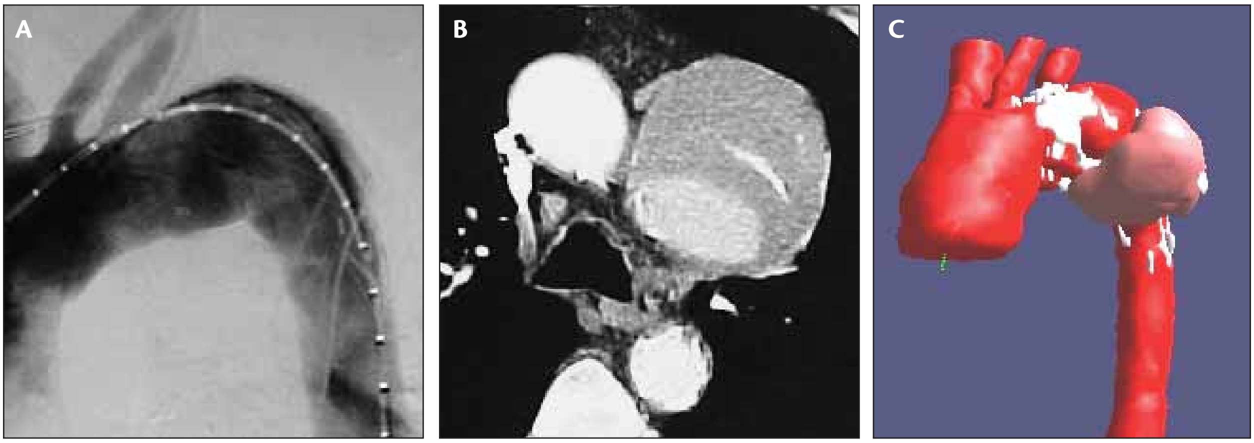

Figure 2. Angiographic result (A) and postoperative CT image (B) and three-dimensional reconstruction (C) confirming presence of a significant endoleak.

lived because the endoleak recurred 4 months later, with dramatic enlargement of the TAA sac and evidence of distal migration of the stent graft with diameter expansion of the neck just beyond the LSA origin. Definitive repair required preliminary transposition/bypass of the left common carotid artery (LCCA) with a crossover right-to-left carotid-carotid bypass and ligation of the proximal LCCA (Figure 3), followed 2 weeks later by placement of an access conduit attached to the distal descending thoracic aorta (Figure 4) via left thoracotomy that enabled delivery and deployment of an endograft cuff that extended the repair proximally to the origin of the innominate artery. Complete and secure exclusion of the TAA was finally obtained. The patient recovered and did well after the procedure but succumbed to lung cancer 2 years later.

Case 1 Commentary

Thoracic aneurysms adjacent to or in the aortic arch represent a challenge. The most common "mistake" relates to the operator's willingness to compromise to simplify the procedure. It is clear now that there can be no compromise at the time of obtaining a sufficient (2 cm) length of proximal neck for fixation and seal if an optimal and durable result is to be achieved, particularly in the region of the aortic arch knuckle.

Transposition/bypass of the LSA and/or the LCCA should have been considered from the outset. This patient's serious aortoiliac access issues complicated the TEVAR procedure enormously. Use of a descending thoracic aorta conduit is unusual, but it does represent one additional available option. Antegrade transcarotid or trans-subclavian access would not have worked because of the proximal location of the TAA.

Case 2

A relatively healthy 61-year-old woman was referred for treatment of a large ductus (saccular) TAA arising from the distal aortic arch. The lesion was directly across the origin of the LSA and a short distance

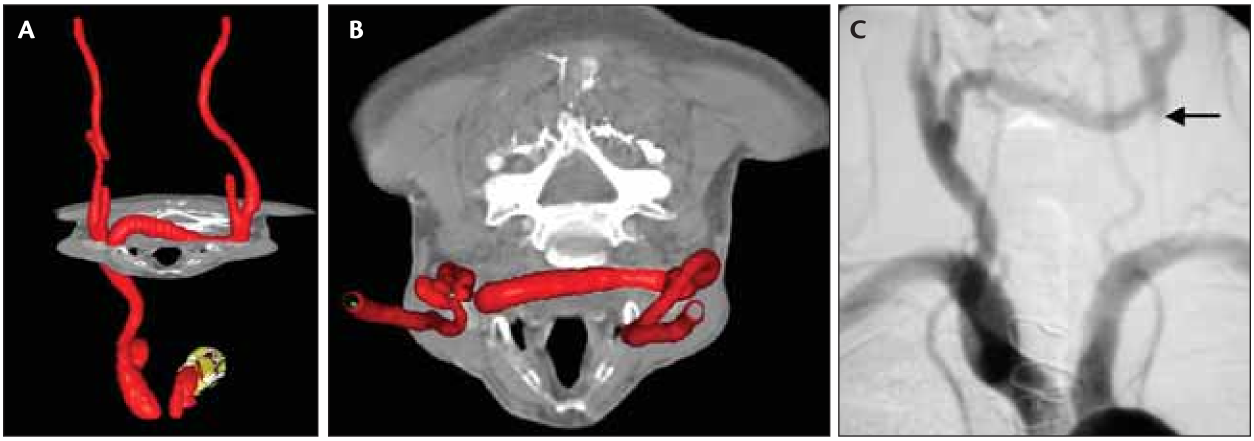

Figure 3. Crossover right-to-left carotid-carotid retropharyngeal bypass and ligation of LCCA just below anastomosis (arrow).

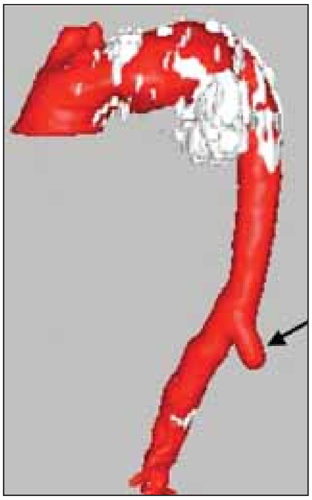

Figure 4. Stump (arrow) left behind after excision of access conduit (10-mm Dacron) that was anastomosed to the side of the distal descending thoracic aorta.

beyond the LCCA (Figure 5). The need for endograft coverage of these two vessels seemed likely, if not inevitable. The strategy consisted of preemptive percutaneous catheterization of the LCCA with retrograde advancement of a micropuncture wire into the ascending aorta, where it was initially parked (Figure 6). TEVAR involved deployment of a Talent Thoracic Stent Graft, resulting in near-complete exclusion of the vessel (Figure 7). Restoration of normal patency and antegrade flow into the LCCA required placement of an appropriately sized balloon-expandable stent across the origin of the artery and protruding (in its proximal one-third) into the lumen of the aortic arch, breaking the endograft seal in a focal area just behind the stent graft (Figure 8). Retrograde insertion (into the carotid artery) of a short 6-F introducer sheath was necessary for this procedure. The outcome was excellent, and the patient continues to do well 3 years after the intervention.

Case 2 Commentary

Arch branch preservation, not debranching, has been a major focus of ours recently. The technique originated as a troubleshooting effort on two patients who had unintentional coverage of the LCCA.[1] The technical requirements to perform retrograde stenting of the LCCA and LSA have proved relatively simple and versatile. They have also proved (so far) to be safe and durable. Although the potential to create an endoleak from loss of endograft apposition in the area occupied by the stent device is an obvious concern, we have not yet observed any such occurrence thus far. The advantages of these approaches over the more conventional cervical bypasses are significant because the patient is spared the need for preliminary or concomitant additional operations, and they allow the surgeon to resolve it all in one operative session. Patients with thick and very short aortic necks may not be good candidates for percutaneous retrograde stenting of the LCCA.

COMPLEX TEVAR

The most significant issues relate to access, anatomy, presence of aortic branches, the aortic arch, and certain treatment indications such as acute aortic dissection.

Access

Access is universally acknowledged to constitute the first crucial step in a TEVAR procedure and is potentially a significant impediment. Women comprise >30% of the thoracic patient population, contributing to the access challenges because of their small femoral and

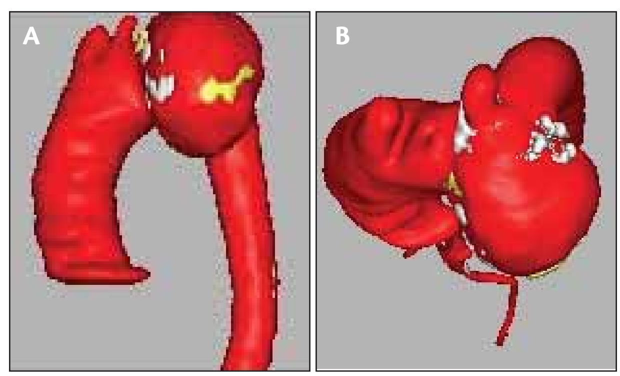

Figure 5. Large ductus arch TAA. Note the relationship with the LSA and the LCCA.

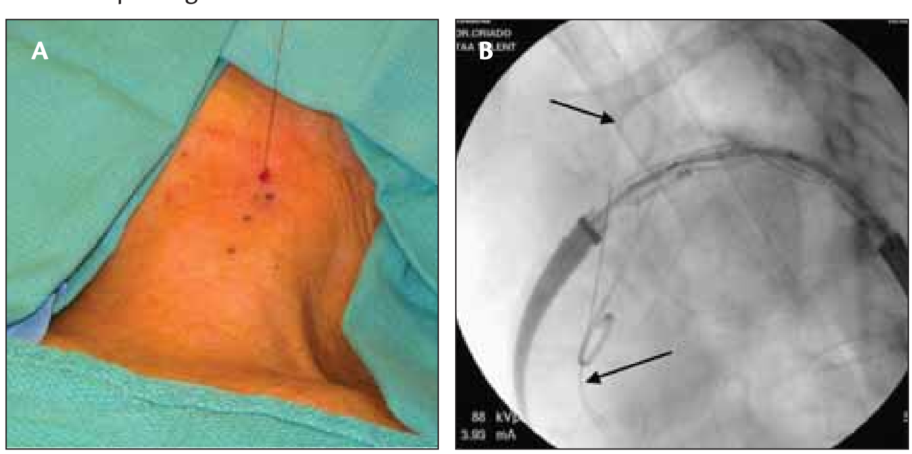

Figure 6. Retrograde percutaneous catheterization of the LCCA with micropuncture set and advancement of wire into the ascending aorta (arrows). Note also the presence of the diagnostic catheter coming from the left brachial artery sheath.

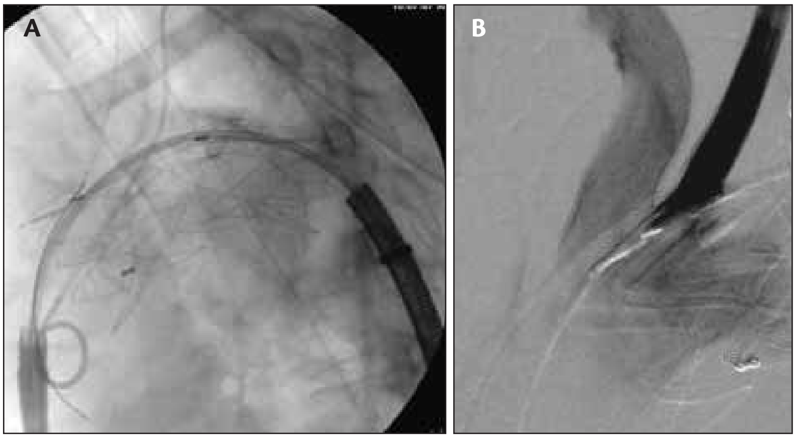

Figure 7. Coverage of the LCCA origin by the Talent Thoracic Stent Graft.

iliac arteries. Experience has taught us many important lessons and a few fundamental principles—particularly that probing the femoral-iliac arteries with Coons dilators (Cook Medical, Bloomington, IN) should be a routine procedure whenever the interventionist is in doubt about the adequacy of the access vessels. The dictum is, "The time to do it is when you think you might need one." Iliac conduits for endovascular access are important tools, with reported use in 15% to 30% of TEVAR procedures at the present time (Figure 9). Not surprisingly, technical considerations and attention to detail are paramount to achieve the results and to avoid complications and pitfalls.[2] Although it is a convenient disposal technique, partially excising the conduit at the end of the operation can leave a sizeable stump behind that may be later diagnosed as a pseudoaneurysm, leading to confusion and unnecessary concern (Figure 10). For that reason, an effort should be made to leave as small a stump as possible. At times, it is best to bring the graft down under the inguinal ligament and attach it to the common femoral artery as a permanently implanted iliofemoral bypass (Figure 11). Thoracic endograft introduction and delivery through a transcarotid approach is an unusual but potentially useful access option for patients with difficult aortoiliac arteries. The author has had an opportunity to perform this maneuver several times recently and has been impressed with the relative ease and adequacy of this technique. The right carotid artery would appear to be the best choice. The proximal common carotid artery tends to be a large and often normal artery that allows passage of a large sheath without difficulty. However, this approach is only workable for endovascular treatment of aortic lesions distal to the LSA.

AORTIC ANATOMY

This anatomy must be carefully assessed in every case, of course, because it can impose significant difficulty at the time of endovascular navigation and device delivery. Marked S-shaped angulations in the distal thoracic and proximal abdominal aorta can be particularly challenging.

The Aortic Arch and Its Branches

This area deserves our utmost attention. TEVAR implies dealing with the arch and branches in at least 30% of cases.[3] Creating an adequate proximal

TABLE 2. MANAGEMENT OPTIONS FOR AORTIC ARCH BRANCHES
• Simple coverage-exclusion (LSA)
• Cervical bypasses and transpositions (all)
• Retrograde stenting (LSA and LCCA)
• Retrograde endobranching (potentially all)
• Transthoracic ascending-aorta–based bypasses (all)

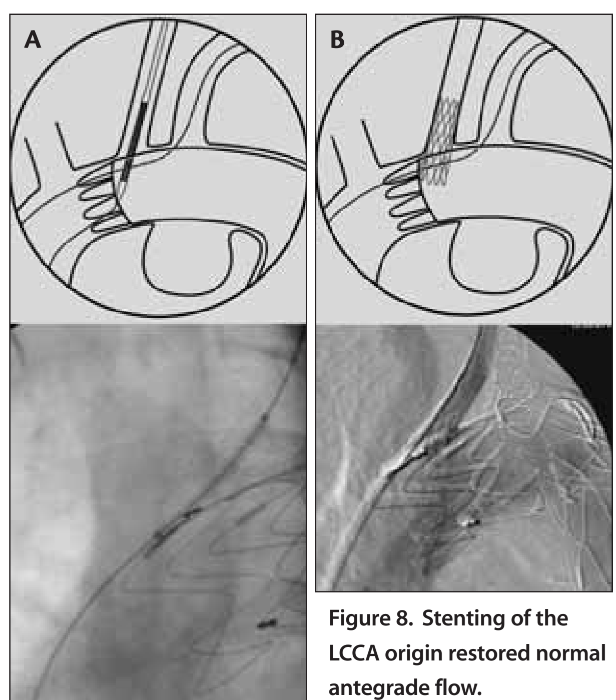

Figure 8. Stenting of the LCCA origin restored normal antegrade flow.

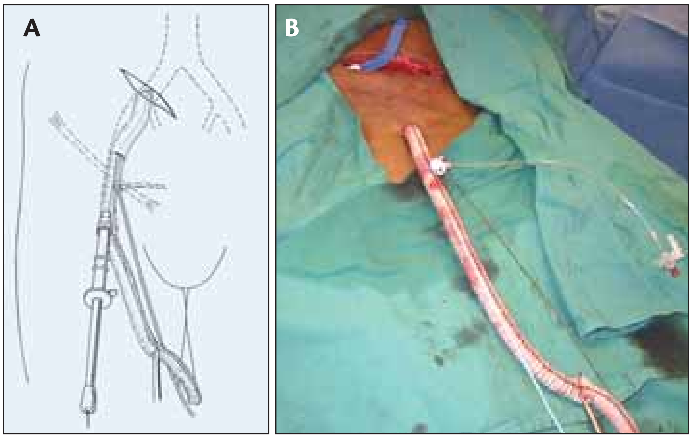

Figure 9. Common iliac conduit (10-mm-diameter Dacron graft) for endovascular access. Iliac exposure is retroperitoneal, exiting graft through a lower stab incision (just above inguinal ligament) to obtain a smoother entry angle.

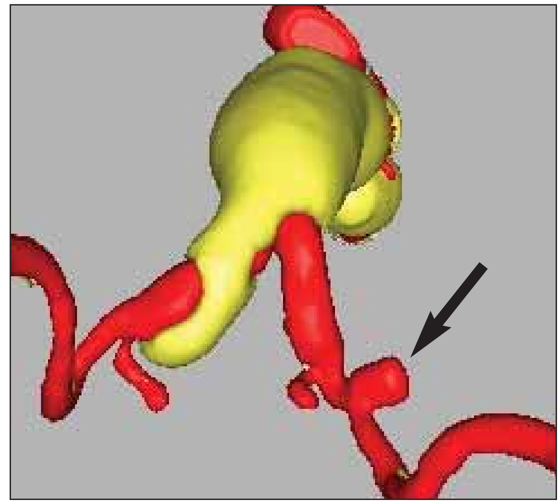

Figure 10. Pseudoaneurysm-like stump after excision of most of the access conduit (arrow).

fixation/seal zone (neck) of at least 2 cm in length often requires coverage of one or more branches. Various technical options exist with simple coverage-exclusion being well tolerated by perhaps the majority of patients when only the LSA is involved (Table 2). Debranching and extra-anatomic revascularization, on the other hand, have become increasingly popular methods to deal with these issues and expand applicability of endograft repair.[4] These cervical operations tend to be acceptably safe and quite effective. However, they do add a layer of complexity, take time, and may delay treatment of the aortic lesion. Also, well tolerated as they may be, these operations do carry risks of potential complications. With this in mind, the author sought to develop a different strategy focused on branch preservation instead of debranching.[1] Through the use of standard endovascular techniques and equipment, percutaneous retrograde catheterization can be easily performed to enable angioplasty and stenting of the origin of the LSA and/or the LCCA to restore normal patency and antegrade flow (Figure 12).

Figure 11. Conversion of the graft conduit into permanent iliofemoral bypass with distal anastomosis to the common femoral artery.

Technique Expansion

Expansion of such techniques is now being explored to achieve endobranching with the use of longer covered-stent chimney grafts.[5] These new concepts may have great potential, and they provide readily available

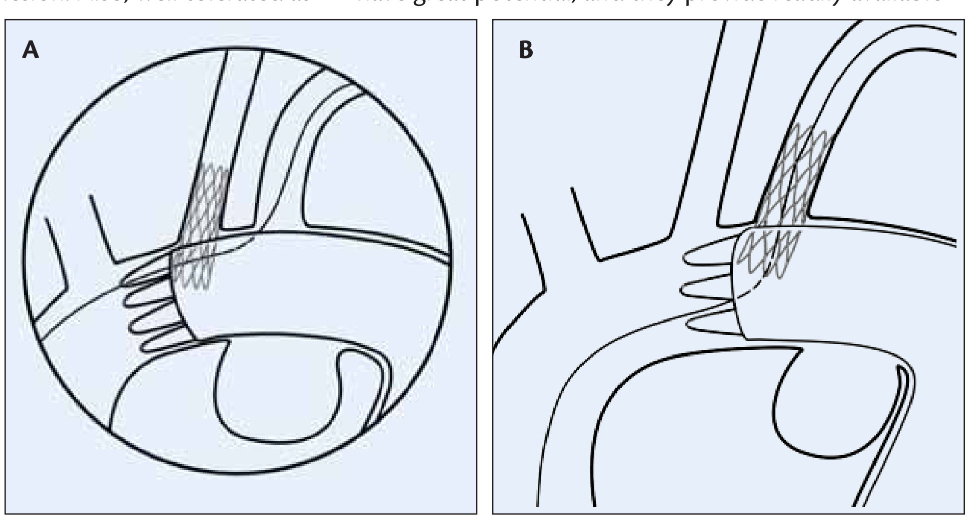

Figure 12. The retrograde stenting technique to preserve normal antegrade patency of the LCCA and the LSA.

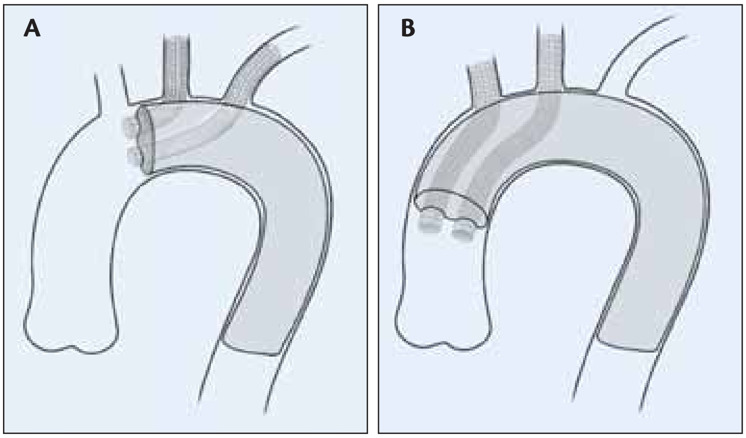

Figure 13. Chimney-graft endobranching techniques showing two different options.

tools for partial or even total endovascular arch repair—all done in one operative session and sparing the patient the need for multiple operations (Figure 13). However, many questions remain, including the potential for compression against the aortic wall by the thoracic endograft, the creation of endoleaks, and graft integrity issues resulting possibly from interaction between the two devices over time. Ultimately, truly branched endograft technologies may emerge as the ideal endovascular solutions for the arch and the visceral segment of the aorta. Unfortunately, these technologies are going to be complex and unlikely to become widely available for several years.

Total Transthoracic Debranching

This procedure is another technical option that can be used to enable complete endograft relining and repair of the entire arch. Through a median sternotomy approach, an ascending aorta-based bypass to the innominate artery and the LCCA can be relatively easily performed because it involves partial (side) clamping of the aorta only. Graft branching into the LSA may also be possible. For patients who cannot tolerate such an operation or patients who have anatomical impediments, a totally extrathoracic approach that involves the use of the right femoral artery as the inflow source can be considered (Figure 14).

Endograft Conformity at the Arch Knuckle

This is another important issue because sharp bends at the apex of the aortic arch represent an enormous challenge for currently available devices, which tend not to conform well to such geometries. Aortic wall malapposition along the lesser curve is particularly problematic, leading potentially to vessel injury and perforation, retrograde type A dissection, type 1 endoleak, and even endograft compression and collapse. Some devices are more prone to such problems than others. The surgeon must strive to avoid these potentially serious complications by not landing at or in the knuckle area. Instead, proximal fixation should take place just distal to the bend or (likely) more proximally within the transverse arch, which, of course, often implies that you must deal with one or more branches.

The Visceral Segment

This area is receiving increasing attention as the scope of TEVAR continues to grow. Endovascular treatment of juxtaceliac TAA and thoracoabdominal aortic aneurysm (TAAA) with involvement of one or more visceral and renal arteries is being reported more often at present. The most common complexity that operators are likely to encounter relates to TAA lesions that are in close proximity to the celiac artery origin (Figure 15). Deployment precision at the distal fixation site is paramount and perhaps a little more difficult to achieve when compared with the action at the proximal neck. Some TEVAR systems are certainly better than others in this regard (Figure 16). Endograft coverage of the celiac artery can be performed if necessary, and would appear to be well tolerated by the majority of patients. However, anecdotal

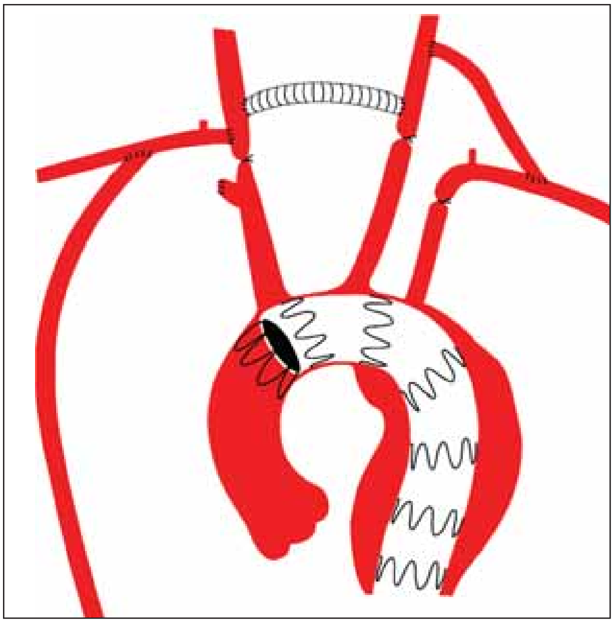

Figure 14. Femoral-based bypasses to achieve total extrathoracic debranching of the aortic arch.

reports of serious complications have brought into appropriate focus the potential dangers of such a maneuver, with no sure means today of predicting its safety in an additional case.

The risk of unintentional coverage of the superior mesenteric artery (SMA) is something the author finds more worrisome. Covering the SMA would be, of course, catastrophic, especially when excluding the celiac artery as well. It has become our routine to catheterize the SMA (from the femoral artery) in such cases and keep an indwelling catheter within the vessel while completing the TEVAR procedure (Figure 16). Having retrograde endovascular access to the SMA provides for a readily available pathway for balloon dilatation and stenting to restore patency quickly in the face of encroachment by the thoracic endograft.

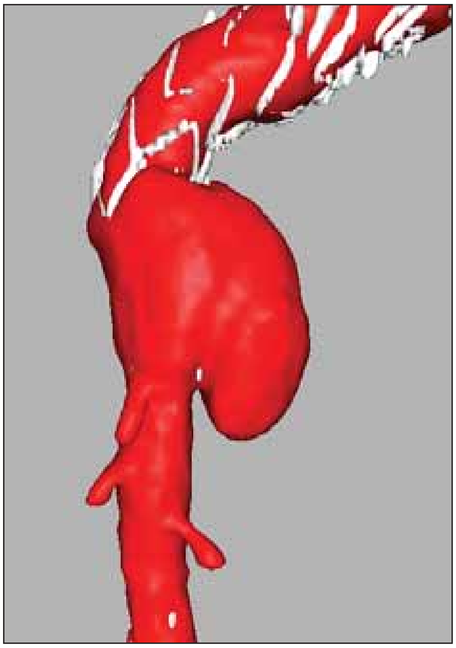

Figure 15. Aneurysm formation in the distal thoracic aorta in close proximity to visceral vessels.

Extra-Anatomic Intra-Abdominal Bypasses

Intra-abdominal bypass to two or more of the visceral-renal arteries (used with endovascular grafting in various hybrid combinations) can be formidable operations but are generally considered to represent less of a physiologic insult than direct surgical thoracoabdominal repair with prolonged aortic clamping (Figure 17). This may be especially true for older patients with significant medical comorbidities and a large TAA. Mario Lachat, MD, of Switzerland[6] has made a significant contribution to the field with his VORTEC (Viabahn Open Rebranching Technique) strategy that promises to simplify (or obviate) the performance of some of the most difficult anastomoses, particularly those to the renal arteries that tend to be the most challenging aspect of such operations (Figure 18).

TEVAR for Type B Aortic Dissection

TEVAR for type B aortic dissection is, almost by definition, complex and high risk both in the settings of acute and chronic dissections. Acute dissection challenges are multiple, often leading to higher-than-usual risks of serious complications, including aortic perforation and rupture, retrograde type A dissection, and issues related to the anatomical complexities derived from the presence of a long and spiraling false lumen that needs to be carefully identified and separated from the true lumen. Experience and refined endovascular skills are para-

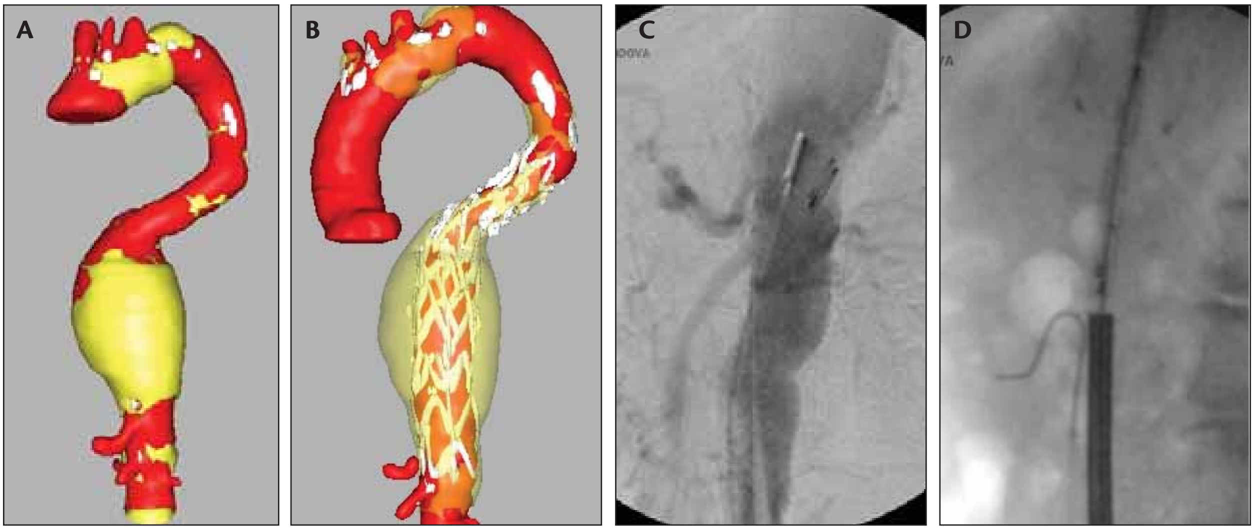

Figure 16. Juxtaceliac aneurysm (A) treated with the Talent Thoracic Stent Graft landing precisely just above the origin of the celiac artery (B). Retrograde (transfemoral) catheterization of the SMA performed to provide access pathway for vessel stenting in case of unintentional coverage by endograft (C, D).

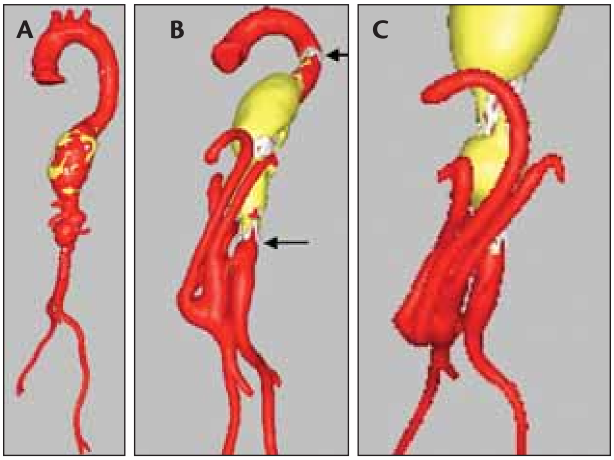

Figure 17. Complex TAAA (A) treated with extensive endograft aortic coverage (B, arrows) after preliminary right iliac artery-based extra-anatomic bypasses to all visceral and renal arteries—the *Octopus Operation* (C).

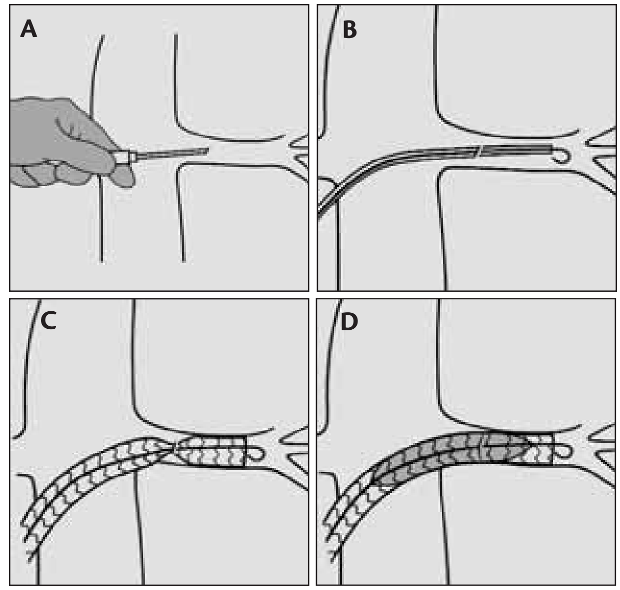

Figure 18. Lachat's technique involves minimal exposure of anterior surface of the target (renal) artery, followed by needle puncture with passage of a guidewire, and over-the-wire introduction/deployment of a Viabahn covered stent device.

mount at the time of planning and execution. However, unlike most other pathologies, acute dissections can and often go on to heal and resolve after endovascular repair. Chronic dissections, when considered for treatment (often because of the development of a large dissecting aneurysm), represent a real challenge because of the extent of the dissection process and the very complex anatomy at various levels. Preservation or restoration of normal aortic branch flow is a frequent concern.

CONCLUSION

We can all recognize in 2007 that TEVAR developments are of enormous significance in the field of endovascular therapy and for the whole of cardiovascular medicine. Although only one thoracic endograft is currently approved by the FDA, at least two more are on the verge of being approved and commercially released, likely in 2008. Stating that TEVAR practices are about to "explode" may not be an exaggeration. However, amid all the excitement and well-justified optimism about these therapies, surgeons and others interested in developing a thoracic endovascular practice must gain a clear understanding of present and future challenges. Unlike EVAR, thoracic procedures can be extraordinarily difficult and dangerous. Impeccable planning and execution are paramount to achieve success with TEVAR and require the most refined, seasoned endovascular skills. ■

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Coverage of the Left Subclavian Artery During TEVAR

How to predict and prevent neurological complications.

BY RACHEL CLOUGH, MRCS (ENG); EITAN HELDENBERG, MD; MOHAMAD HAMADY, FRCR; AND NICK CHESHIRE, MD, FRCS

Thoracic endovascular aortic repair has become a viable option for treating multiple aortic pathologies. Large series document mortality and morbidity rates that are substantially lower than those of comparable open repair.[1-4]

Adequate proximal and distal landing zones are fundamental to successful endovascular repair, and inability to achieve these can predispose to type I and type II endoleak. Traditional series, such as by Dake et al, and more recent series (Riesenman et al, Stanley et al, Saito et al) have suggested that to achieve satisfactory proximal fixation, the landing zone must include at least 20 mm of healthy aortic tissue.[5-8] With advancements in endovascular devices and user expertise, the indications for thoracic stenting have grown, and the proximal landing zone has advanced to the distal and, in some cases, the proximal, aortic arch. It can be quickly realized that a landing zone within this position will necessitate coverage of one or more of the aortic arch vessels. This article focuses on the coverage of the left subclavian artery and the neurological complications that may occur as a consequence of this.

Anatomical studies, such as that of Biglioli et al, reveal the importance of the left subclavian artery in the perfusion, via the left vertebral artery, of both the spinal cord and the brain (Figure 1).[9] Isolated coverage of the left subclavian artery in the presence of normal arterial anatomy may not necessarily precipitate neurological sequelae due to the presence of collateral networks both within the brain via the circle of Willis and within the spinal cord via the contributions of the intercostal, Adamkiewicz, and lumbar arteries to the anterior spinal artery.

Early series, such as those of Hauseggar et al, Burks et al, and Görich et al, published in 2000-2001, were among the first to extend the landing zone to within the proximal aortic arch.[10-12] In their combined series of more than 30 thoracic stent grafts, there was no incidence of neurological complications. At our institution, in our initial series of 14 in which endovascular repair necessitated coverage of the left subclavian artery, we reported a single embolic intracranial event with full resolution of symptoms and no occurrence of spinal cord injury or vertebrobasilar insufficiency. Further centers from across Europe revealed similarly encouraging results.[13-17]

More recently, large, multicenter series have emerged. The combined series of Thompson et al (containing our experience with the Valiant Thoracic Stent Graft [Medtronic CardioVascular, Endovascular Innovations, Santa Rosa, CA]), Fattori et al, Leurs et al, and Makaroun et al, consists of more than 1,000 patients

Figure 1. Extensive collateral network.

and reveals stroke rates of 2.3% to 3.9% and rates of spinal cord injury of 1.7% to 3.3% (Figure 2).[18-21] There was little or no mention of the subclavian steal phenomenon.

STROKE

The etiology of intracranial injury is likely multifactorial. Fattori et al and Thompson et al both showed a significant association between the coverage of the left subclavian artery and the incidence of stroke.[18,19] Feezor et al reiterate this finding and, in addition, illustrate that of the nine strokes that occurred in their series, five occurred in the posterior circulation in individuals who had not undergone a previous revascularization procedure.[22]

Other series, such as that of Reece et al, suggest that stent and wire manipulation within the arch may be an important factor, illustrated by three embolic intracranial events within the distribution of the anterior intracranial circulation in their series.[23] Thompson et al and Makaroun et al both showed a clustering of strokes in individuals with a high proximal atherothrombotic load, a finding that adds weight to the conclusions of Reece et al.

Feezor et al found that 56% of individuals with a stroke during thoracic stent grafting had documented intraoperative hypotension with a systolic blood pressure of <80 mm Hg.[22]

SPINAL CORD INJURY

Our current series of more than 70 visceral hybrid repairs serves to illustrate the successful management of long-segment aortic disease and, in addition, the ever-present risk of spinal cord ischemia.

The registry series of Thompson et al, Fattori et al, and Leurs et al revealed an association between the length of the aortic segment coverage and the rate of spinal cord injury. In addition, in the four cases of spinal ischemia described by Makaroun et al, two patients had undergone previous aortobifemoral repairs.[21] The published series to date declare no specific association between coverage of the left subclavian artery and the incidence of spinal cord ischemia, but this artery's contribution to the anterior spinal artery and thus the collateral spinal network cannot be disputed.

PREVENTION OF NEUROLOGICAL INJURY

Pre-emptive revascularization of the left subclavian artery often follows careful preoperative evaluation of both the local and intracranial anatomy using one or a combination of CTA, MRA, DSA, or Duplex. Indications for revascularization include an aberrant or dominant left vertebral artery, a hypoplastic right vertebral artery, a deficient circle of Willis, and current use of the left internal mammary artery as a coronary artery bypass graft.[22,23]

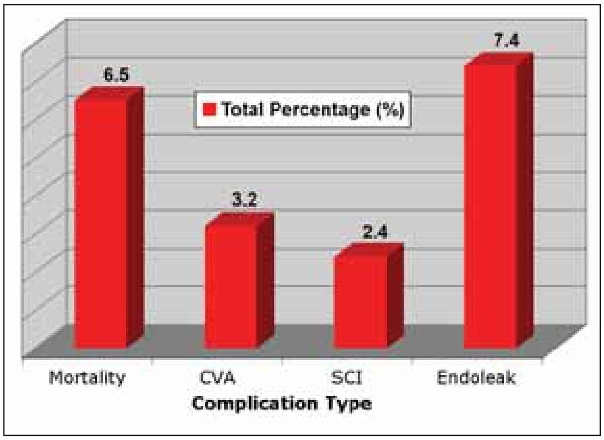

Figure 2. Combined registry data by complication type.

Revascularization may take the form of either a left common carotid artery to left subclavian artery bypass or left subclavian artery to left common carotid artery transposition. The latter is frequently described in the literature with good results. Bypass becomes a more attractive option if the left vertebral artery takes early origin from the left subclavian artery or when the left internal mammary artery is incorporated into a coronary bypass grafting procedure. Technically more challenging, bypass requires division of the anterior scalene muscle and identification of the left subclavian artery more distally. Compared to proximal covered stents, a proximal bare stent configuration may allow precise deployment and help to fix the graft in the case of a short neck (<2 cm) without compromising flow through the left subclavian artery.

In addition to revascularization, flow to the left subclavian artery may be maintained via the use of bare metal stents for proximal fixation. These devices allow secure proximal fixation with coverage of the vessel, and their use in this location is currently evolving.

Systematic review of the two procedures reveals similar rates of mortality and morbidity between the two techniques with recognized complications including nerve injury, stroke, lymphatic damage, and hematoma formation.[24]

Methods for preventing spinal cord injury during endovascular thoracic aortic repair focus on maintaining an adequate arterial perfusion pressure with an appreciation of its relationship to the cerebrospinal fluid (CSF) pressure; the length of aortic coverage cannot be easily manipulated. Weigang et al institute neurophysiologic monitoring and CSF pressure monitoring for all elective cases.[25] They have shown that with an increase in CSF pressure, there is also a change in the evoked potentials and that institution of CSF drainage at this point can prevent spinal cord injury.

CONCLUSION

Our current series of more than 200 thoracic endografts serves to illustrate both the success of this therapeutic intervention and the growing evidence that coverage of the left subclavian artery is associated with a higher incidence of neurological injury. Furthermore, we have seen that coverage of the left subclavian artery without its ligation may precipitate complex type Ia/type II endoleak within the proximal region of the graft.

The concept of total endovascular repair is evolving, and the literature reveals promising early reports of the use of branch and fenestrated grafts within this anatomical location.[8,26-28]

With relation to coverage of the left subclavian artery and the incidence of neurological injury, it is clear that there is an association, but whether this relationship is causal or purely a function of more extensive disease remains to be elucidated. ■

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Endovascular Treatment of Aortic Dissections

Provision of evidence through trial data.

BY MATT THOMPSON, MD, FRCS; DAVID SAYER, MB BS; IAN LOFTUS, MD, FRCS; AND ROB MORGAN, FRCR

Endovascular techniques have been enthusiastically applied to the thoracic aorta during the last decade, and in many diseases, endovascular surgery has gained preference over conventional open procedures. This change in clinical practice has been driven by patient and physician preference, the belief that modern technology can improve medical practice, the evolution of most surgical procedures to encompass minimally invasive alternatives, commercial drivers, and clinical outcome data. Interestingly, endovascular repair of the thoracic aorta has become an established treatment modality with a relatively poor evidence base, because there have been none of the traditional randomized trials that often accompany the introduction of new therapies.

There are good explanations for the lack of randomized data when the clinical outcomes for pathologies with established indications for treatment are compared between endovascular procedures and open thoracic surgery.[1] Case series and registry data would appear to show that the endovascular procedures offer significantly lower mortality, morbidity, and paraplegia rates when compared to open thoracic repair of thoracic aneurysms or acute dissections.[2] The IRAD registry, an independent registry of patients with dissections, has provided some data regarding the long-term results of acute type B dissections.[3] The lack of randomized trials does, however, pose a problem for endovascular techniques because much of the evidence base is composed of small retrospective series and registries that do not offer sufficient detail to facilitate the subgroup analysis that is mandatory to refine indications for treatment. This situation is not helped by the stringent inclusion and exclusion criteria of trials that are designed for regulatory purposes because they often do not reflect the types of lesions encountered in day-to-day clinical practice.

As a result of the problems encountered with the quality and quantity of the published literature, it has become difficult to determine the outcome of endovascular repair for differing indications within the thoracic aorta. These challenges are of particular relevance to thoracic aortic dissections due to their differing presentations, differing indications for treatment, and varying outcomes, which often reflect the initial presentation. Progress in treating thoracic dissections can only be made by improving the evidence base. Many clinicians have suggested that this process should be facilitated by the endovascular industry providing "not-for-profit" support of clinical trials and registries.[4] This article briefly reviews the current issues regarding endovascular therapy of type B aortic dissections and outlines some of the current trials in this area. The indications for treatment discussed represent the criteria used at the St. George's Vascular Institute in our routine clinical practice.

INDICATIONS FOR TREATMENT AND AREAS OF UNCERTAINTY

Acute Dissections

There appears to be a general consensus that patients with acute type B dissection have robust indications for endovascular therapy if they present with complications (ie, rupture, end organ ischemia), unremitting pain, or persistent hypertension. A number of series have reported reasonable short-term outcomes in these cohorts, although long-term results are less well documented, as is the morphologic fate of the false lumen over the longer term.[5] Several technical details of acute dissection therapy remain unresolved, such as the length of thoracic aorta that should be covered, whether bare-metal stents have a role to play in stimulating remodeling and reducing paraplegia by limiting the number of intercostals occluded,[6] whether there are any specific outcomes that could be related to graft design (eg, retrograde type A dissection and proximal fixation methodology), and defining whether endografts should have differing designs in dissections as compared to aneurysms.

In recent years, several investigators have suggested that asymptomatic acute type B dissections might benefit from endovascular repair in preventing acute and long-term complications.[7] The rationale for this proposition revolves around the outcome for patients with asymptomatic dissection. Several historical studies have suggested that aortic-related death was high in this group of patients and that mortality (from acute complications or late aortic rupture) might be reduced by endovascular repair. It might be argued that newer data have revealed a low rate of complications in patients with stable, uncomplicated type B dissections[8,9] and that the key issue in this group of patients will be to define a subgroup that exhibits a high complication rate that might benefit from aortic repair in the acute phase.[10] Careful morphologic studies and long-term follow-up will be required to define these groups, but some useful data have recently been published, which identify some simply applied criteria that predict rapid aortic expansion.

Chronic Dissections

Indications for repair of chronic dissections have usually been limited to the onset of complications and an aortic diameter exceeding 5.5 cm to 6 cm. Again, there was enthusiasm for attempting endovascular repair of asymptomatic chronic type B dissections to prevent long-term complications that was addressed in the INSTEAD trial.[7] The early results of this study did not demonstrate any difference in medically treated and endovascularly treated patients, but long-term outcomes have not yet been released.

The literature surrounding the results of endovascular repair for chronic dissections is particularly poor. Many studies combine acute and chronic dissections, and the long-term fate of the aorta in chronic dissections treated endovascularly remains undefined. There have been anecdotal reports that the false lumen below the stent may continue to expand after treatment and that the rate of repeated intervention is high.[11] This is an area that requires careful documentation to facilitate effective therapy. Again, procedural details require refinement because there is still uncertainty regarding the extent of aorta that should be covered, whether covering the entry tear is sufficient or if all re-entry tears should be treated, and whether aortic remodeling can be predicted by the morphology of the lesion.

CURRENT TRIALS

Clearly, there are a number of significant issues concerning the natural history and treatment of type B aortic dissection that require resolution by carefully planned and executed clinical trials. A number of trials are sponsored by industry partners; we describe a selection of these trials.

VIRTUE

The VIRTUE study is a prospective single-arm clinical registry designed to evaluate the Valiant Thoracic Stent Graft (Medtronic CardioVascular, Endovascular Innovations, Santa Rosa, CA) in the treatment of acute, subacute, and chronic type B dissections. The study is sponsored by Medtronic, and the Principal Investigator is Professor Matt Thompson. The study plans to recruit 100 patients with type B dissection, treated with the Valiant Thoracic Stent Graft from 18 European centers. The primary endpoint is procedure-, device-, or disease-related mortality at 12 months, but more importantly, patients will be evaluated by serial imaging up to 36 months after the procedure; the results of CT imaging will be evaluated by a core lab. This study will provide reliable data regarding the morphology of the aorta after endovascular treatment, and in particular, may help to define the results of endovascular therapy in subacute and chronic cases. Similar registry data are being acquired by both Bolton Medical (Sunrise, FL) and LeMaitre Vascular, Inc. (Burlington, MA).

ADSORB

The ADSORB study is a randomized trial of patients with acute uncomplicated type B dissection, and the Principal Investigator is Professor J. Brunkwall. The study will recruit 270 patients from 30 European sites and randomize them to endovascular repair using the TAG prosthesis (Gore & Associates, Flagstaff, AZ) or best medical therapy. Primary endpoints are focused on aortic morphology after treatment, and secondary endpoints include dissection and all-cause mortality; imaging will be interpreted by a core lab. In the light of recent data defining the outcome of uncomplicated dissection, randomizing this subgroup of patients might be considered controversial to some. However, like many randomized trials, the acquisition of data regarding the natural history of medically treated disease will be invaluable and will help to define subgroups of patients with uncomplicated dissection who will benefit from treatment.

Zenith Dissection Endovascular System

The Zenith dissection system (Cook Medical, Bloomington, IN) combines a covered proximal endograft (TX2) with an uncovered, open mesh distal component (TZD). The Zenith system is proposed to facilitate remodeling of the aorta with effective closure of the entry site without coverage of a long length of aorta. The system has a number of potential advantages and is attractive in concept. A trial of 40 patients at six European and Australian sites is planned to evaluate the effectiveness of the system in treating acute type B aortic dissection. Endpoints for this study include survival at 30 days, as well as clinical utility, incidence and rate of adverse events, mortality, and factors related to morbidity at 12 months.

CONCLUSIONS

Endovascular treatment of thoracic dissections is a challenging field that requires a steady stream of robust data in order to evolve. The studies we have described will provide good quality data on the natural history of type B dissections and their response to treatment at differing time periods. Acquisition of such data is important and should be encouraged. ■

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Traumatic Thoracic Aortic Transection

Early outcomes favor endovascular repair over open repair.

BY GALE L. TANG, MD, AND MARK K. ESKANDARI, MD

Traumatic thoracic aortic transection (TTAT), also known as blunt aortic injury, from deceleration injuries, such as motor vehicle collisions or falls, is the second most common cause of death from blunt trauma.[1] Patients surviving transport to the hospital usually have a contained rupture or pseudoaneurysm of the descending thoracic aorta at the isthmus just distal to the takeoff of the left subclavian artery. They frequently have multiple associated injuries complicating the management of their aortic injury. Although aortography previously was the gold standard for diagnosis of TTAT, it has recently been challenged by CT angiography (Figure 1A). Strict blood pressure and heart rate control significantly decrease the risk of rupture of the pseudoaneurysm and fatal exsanguinations, allowing stabilization of other injuries.[2] However, when concomitant head or spinal injuries are present, this strategy may result in suboptimal neurologic outcomes. In addition, a small portion of patients experience ruptures while awaiting stabilization before definitive repair.

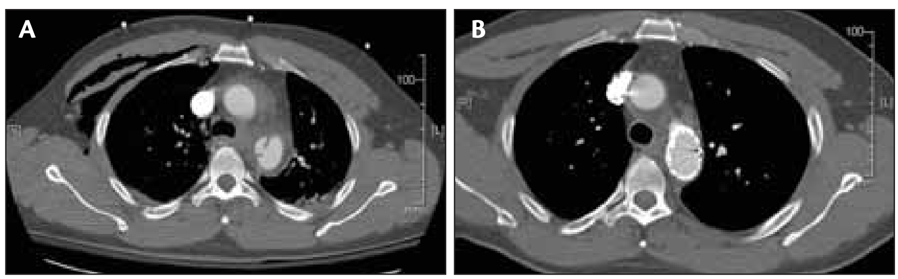

Figure 1. A CT scan with intravenous contrast. Preprocedural image shows a blunt aortic injury with associated mediastinal and periaortic hematoma, as well as a right chest wall contusion (A). Postprocedural image shows endovascular repair with the endograft in place, sealing the injured segment of the descending thoracic aorta (B).

OPEN REPAIR

Successful open surgical repair of traumatic injury was first reported in 1959 by Passaro and Pace.[3] Open surgical repair is carried out through a left thoracotomy with single-lung ventilation and aortic cross-clamping, followed by primary repair or placement of an interposition graft. Patients with associated significant pulmonary contusions or acute lung injury may not be able to tolerate single-lung ventilation. Aortic cross-clamp time is directly related to spinal cord ischemia and the development of the potentially devastating complication of paraplegia. Mortality rates range from 5% to 28% after open repair, with paraplegia rates secondary to spinal cord ischemia between 0% and 14%.[4,5] Several adjuncts for spinal protection have been described, including use of the Gott shunt, left heart bypass, and total cardiopulmonary bypass. These adjuncts trade spinal cord protection for the need for low-dose or high-dose systemic heparinization, which may be contraindicated in patients with multiple injuries. Procedure-specific complications include recurrent laryngeal nerve palsy, phrenic nerve palsy, and cardiac tamponade.

ENDOVASCULAR REPAIR

The availability of thoracic endografting technology has resulted in a dramatic shift in the standard of care for the treatment of TTAT. After the first report by Dake et al in 1997,[6] trauma centers in the US and worldwide have moved away from open repair in favor of endovascular stent graft placement. Endovascular repair (TEVAR) is significantly less invasive for the trauma patient. Advantages of endovascular stent graft placement include avoidance of thoracotomy, single-lung ventilation, and aortic cross-clamp time. It can be performed without systemic heparinization and has been done entirely percutaneously.[7] If necessary, it may be performed under local or regional anesthesia. When reported, operation time and estimated blood loss are less for endovascular repair than for open repair.

Operators should have technical expertise in thoracic stent grafting, as well as experience with large-bore (16 F to 24 F) vascular access, and the ability to manage vascular access complications, especially iliac rupture, which may lead to rapid blood loss. A combined operating room angiosuite with anesthetic support is likely the safest environment for the patient. Although a variety of devices kept "on the shelf" facilitate emergent repair of this injury, frequently, patients may be temporized with strict blood pressure and heart rate control until appropriate devices are available for endovascular repair.

A wide variety of devices have been used for this purpose, including custom (homemade) devices, proximal abdominal aortic extension cuffs, and thoracic stent grafts. Recommended device oversizing is 10% to 15% larger than the native aorta. The approach is usually femoral but may require iliac or aortic exposure for conduit placement, especially in young patients with small iliac arteries (6.2 mm for 16-F sheath to 9.2 mm for 24-F sheath). Aortic or iliac exposure may also be favored if the patient requires an exploratory laparotomy for other injuries. Secondary access for diagnostic angiography may be gained from the opposite groin or from the brachial artery. A variety of techniques have been described for improved accuracy of deployment, including apnea, adenosine arrest, and controlled hypotension, although with the current commercially available devices, none of these strategies is likely necessary.[8] Procedure-specific complications include need for open conversion, endoleak, access complications (thrombosis, dissection, avulsion, or rupture), contrast nephropathy, and graft collapse, as reported with the Gore TAG endoprosthesis (Gore & Associates, Flagstaff, AZ).

TABLE 1. 30-DAY OUTCOMES AFTER TEVAR AND OPEN REPAIR

	TEVAR (n)	Open Repair (n)	*P* Value
Mean age	41.3 (355)	38.9 (278)	<.1
Mean ISS	39.8 (245)	36 (207)	<.1
Mortality	28/7.6% (370)	50/15.2% (329)	.0076
Paraplegia	0/0% (370)	18/5.5% (329)	<.0001
Stroke	3/.81% (370)	15/5.1% (294)	.0028
Technical success	96.5% (370)	98.5% (329)	.58
Procedure-specific complications	44 (370)	50 (294)	.030

Presented at: SVS Annual Meeting; June 7-10, 2007; Baltimore, Maryland.

PUBLISHED RESULTS

Multiple small case series have been published demonstrating the safety and efficacy of stent grafts for TTAT. Several nonrandomized comparisons between open and endovascular repair have also been published.[6,9,10] Much of the published literature originates from Europe where more devices are available. A meta-analysis performed by our group of the last 5 years (2001-2006) showed improved early outcomes for stroke, paraplegia, and death after endovascular repair when compared with open repair (Figure 1B).[10] These results were presented at the 61st Annual Society for Vascular Surgery meeting in June 2007 and are summarized in Table 1. All the published reports are retrospective and nonrandomized, with mean injury severity scores and ages of the patients similar between groups, thus suggesting that outcome comparisons between the groups are valid.

Although mortality rates were cut in half by TEVAR (7.6% vs 15.2%), they were still higher than those seen for thoracic stent grafting for descending thoracic aortic aneurysms,[11] reflecting the patients' serious associated injuries. Stroke rates were also significantly less after TEVAR than for open repair, or for thoracic stent grafting for descending thoracic aortic aneurysms. This probably reflects the decreased incidence of significant atherosclerotic arch disease in the younger trauma patient population.

Most strikingly, the paraplegia risk is lower than after open repair. Just one case of paraplegia has been reported thus far out of more than 400 published cases.[9,10,12,13] The paraplegia risk may be lessened because only a short segment of aorta is covered, there is no cross-clamp time, and the location of the injury is away from the significant intercostal arteries. The single case of paraplegia and two cases of transient paraparesis, all of whom had the origin of the left subclavian artery covered, however, indicate that patients are still at risk for this complication after stent graft repair. Because there is no possibility of intercostal artery reimplantation during stent graft repair, adjunctive measures, such as elevation of mean arterial pressure and placement of a lumbar drain to increase the spinal perfusion pressure, are indicated in patients who develop paraparesis or paraplegia after endovascular repair.

The origin of the left subclavian artery is covered in approximately 30% of cases.[10] This is well tolerated in most patients, with only a small percentage developing symptomatic claudication or upper-extremity ischemia, which can usually be addressed at a later time after other injuries have resolved. Left subclavian artery coverage, however, may be associated with an increased stroke risk. In addition, the vertebral artery is a collateral pathway for spinal cord perfusion via the anterior spinal artery. Therefore, pre-emptive left carotid-subclavian artery transposition or bypass may be indicated in patients who are stable enough to tolerate an additional procedure and who have a dominant left vertebral artery, previous infrarenal abdominal aortic repair, and/or occluded hypogastric arteries, putting them at increased risk for posterior circulation hypoperfusion or for spinal cord ischemia. In patients who have a left internal mammary artery-based coronary bypass graft, a left carotid-subclavian artery bypass with proximal subclavian artery ligation or embolization is preferred over left carotid-subclavian artery transposition to preserve flow through the coronary bypass graft.

TECHNICAL LIMITATIONS

In general, patients with TTAT tend to be young and, therefore, frequently have small aortic diameters (16 to 20 mm) and a tighter aortic arch curvature than patients with degenerative thoracic aortic aneurysms. This, coupled with excessive device oversizing, can lead to the serious complication of poor lesser curve wall apposition and stent graft collapse, as reported with the Gore TAG.[13] Additional problems may be encountered when using proximal abdominal aortic extension cuffs that are available in smaller diameters. The relatively short lengths of these devices may require multiple cuffs (2 to 4 mm) to cover the lesion adequately, predisposing the risk of a type III endoleak. Moreover, the short delivery system of abdominal aortic cuffs may not reach the proximal thoracic aorta in tall patients when using a routine femoral approach. Lastly, younger trauma patients may have small iliac and brachial arteries, as well as the propensity to develop intense vasospasm that may lead to access site complications. Currently, in the US, TEVAR represents an off-label usage of commercially available devices. Development of lower-profile delivery systems and smaller-diameter devices for this application will likely improve the safety and efficacy of endovascular repair.

Long-term outcomes are clearly a concern in a patient population that has notoriously poor follow-up. Because the endograft is usually being placed in a surrounding healthy aorta, early and midterm results have tended to show minimal migration and healing of the pseudoaneurysm. However, young patients have decades of life expectancy within which their aorta may enlarge over time, which may ultimately result in loss of fixation. In addition, material fatigue, such as stent fractures and fabric fatigue, as well as component separation, worsen over time. Lastly, it is not yet clear whether thoracic stent grafts are more or less prone to long-term infectious complications than interposition grafts. Fortunately, these problems will likely arise years after the original trauma when they may be addressed in a more elective and controlled fashion without the confounding influence of associated injuries. Patients need to be made aware of the necessity of life long follow-up, and operators have a responsibility to keep track of patients receiving TEVAR.

CONCLUSIONS

TEVAR has significant early advantages over open repair in terms of death, stroke, and paraplegia rates. None of the currently available devices are designed for this specific application, suggesting that as devices continue to evolve, perioperative morbidity for TEVAR should improve over time. Long-term follow-up data will be critical for assessing the overall durability of this procedure, which will in turn determine whether it should supplant open surgery as first-line therapy for blunt thoracic aortic injuries. ■

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Establishing an Acute Aortic Treatment Center

Rapid patient transportation, diagnosis, and introduction of therapy by a dedicated multidisciplinary team can reduce the significant mortality of acute aortic syndromes.

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There is increasing recognition of the need for expeditious care in a variety of life-threatening illnesses. Whereas rapidly getting a patient to an emergency room has long been associated with management of the critically ill trauma patient ("scoop and run," "the golden hour"), there has been less emphasis on moving patients rapidly through the hospital after they arrive on site. It is the combination of increasingly efficient transportation to the hospital coupled with rapid diagnosis and emergent introduction of therapy that is currently being widely embraced. Door-to-balloon times are now broadly documented, reported, and recognized as a quality marker for management of acute myocardial infarction. Likewise, early treatment of stroke has resulted in development of stroke centers where stroke recognition and early intervention are hallmarks of excellence. In our institution, acute stroke therapy and speed of recanalization for acute myocardial infarction have broken down administrative, processing, and physician barriers so that we can focus on reducing morbidity by streamlining transportation, diagnosis, and initiation of appropriate therapy. It is against this backdrop that we believe it is timely to focus these resources on rapid treatment of patients with acute aortic syndromes.

RATIONALE

Acute aortic syndromes consist of aortic dissection, aortic rupture, intramural hematoma, penetrating ulcers, and acute aortic occlusion, all of which can be immediately life-threatening and mandate a highly skilled, multidisciplinary team of physicians and resources for optimal outcomes.

These emergencies are immediately life threatening, with mortality rising with increasing time after the acute episode. This is particularly the case with one of the most common aortic emergencies—Stanford type A (DeBakey I and II) aortic dissection. With this diagnosis, the mortality rate increases at a rate of 1% per hour. In fact, type A dissection is more fatal than acute myocardial infarction if not treated emergently.

We have established a new type of critical care center at the Methodist Hospital in Houston, Texas: the acute aortic treatment center (AATC). The focus of this center is rapid transportation, diagnosis, and introduction of therapy for patients with acute aortic syndromes. The center will also focus on patient and physician education regarding acute aortic syndromes. This education process is imperative for rapid delivery of patients to the center.

The keys to successful treatment of acute aortic disease, therefore, include early diagnosis, rapid institution of medical therapy, endovascular or surgical intervention, high-quality cardiovascular anesthesia, selective customized cardiovascular intensive care unit (CVICU) care, and outcomes tracking.

WHY SHOULD A HOSPITAL DEVELOP AN AATC?

The concept of an AATC is relatively new, focusing on acute aortic emergencies and creating a differentiated market strategy. A successful AATC will position the institution for upcoming acute aortic clinical trials. There is then the potential to generate interesting outcomes and human-interest stories for public relations and state-of-the-art research opportunities, as well as the potential to differentiate from other competing hospitals with a strong market position in thoracic aortic disease.

AATC development is primarily an organizational issue, with minimal capital outlay required. Most tertiary hospitals already have the necessary components (Table 1), such as state-of-the-art imaging suites in an operating room environment where both open- and catheter-based therapy can be performed in the presence of a cardiovascular anesthesiologist, which is the ideal scenario for acute aortic care. An AATC leverages the hospital's existing rapid-response services infrastructure, creating shorter door-to-balloon times for acute myocardial infarction and rapid intervention at the stroke center.

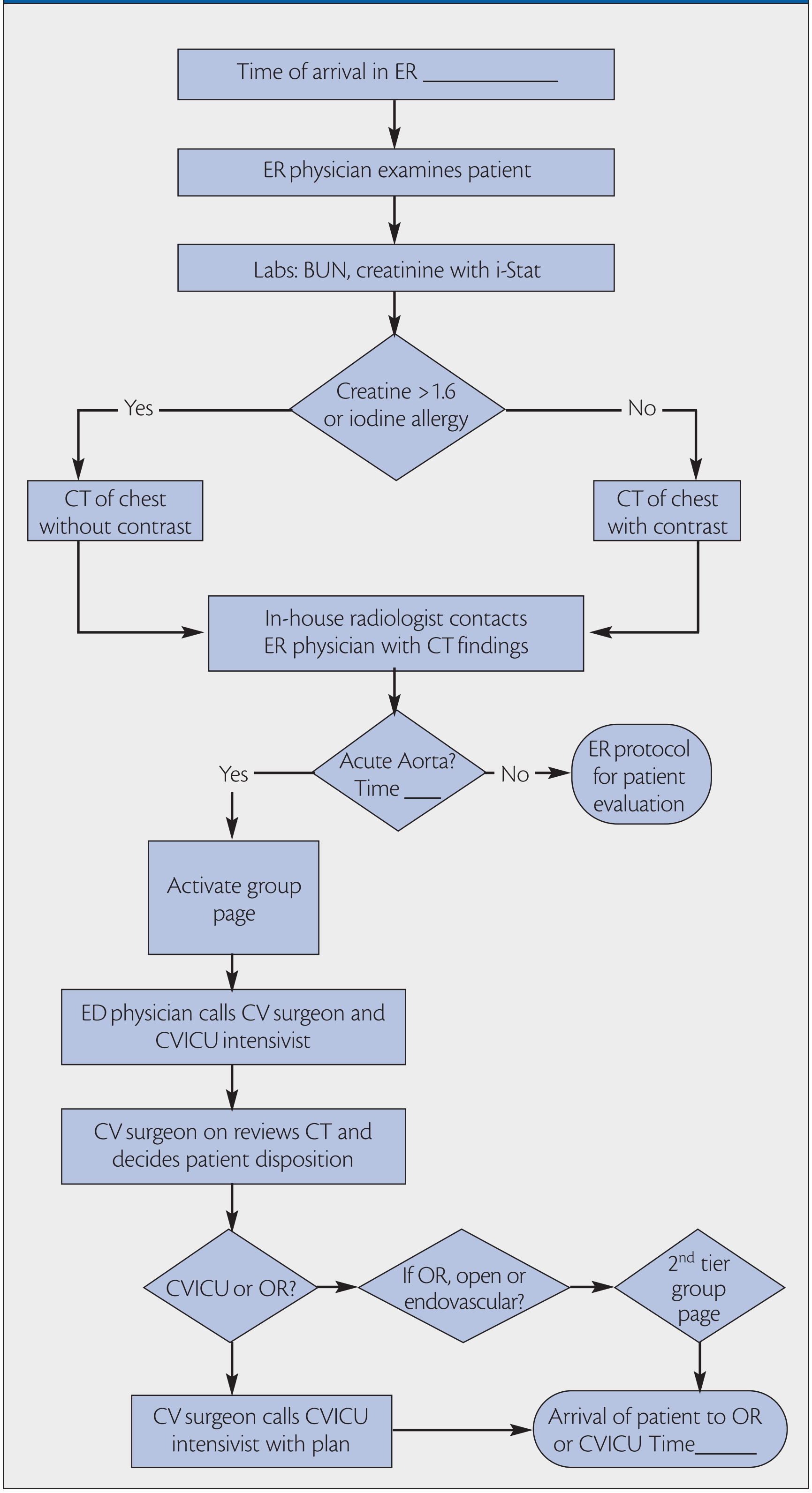
KEY PHYSICIAN RESOURCES

There are five essential physician positions that must be in place to effectively operate an AATC: (1) an emergency room physician to function as a point person in the emergency room and act as an interface with EMT services; (2) the Medical Director of the CVICU, who would coordinate care for emergent stabilization; (3) a CT radiologist to provide emergent interpretation of CT imaging; (4) an on-call surgeon, servicing the AACT, who will triage based on CT images; and (5) cardiac and vascular surgeons who work in close collaboration and are part of the same department of cardiovascular surgery. This group comprises the primary reviewing and triaging team.

IMPLEMENTING CLINICAL PATHWAYS AND PROTOCOLS

In addition to the dedicated AATC physician team, several other elements must be put in place. A clinical pathway from diagnosis through emergent

FIGURE 1. FROM DIAGNOSIS OF ACUTE AORTIC SYNDROME TO MEDICAL OR SURGICAL TREATMENT IN ≤60 MINUTES



transportation to the AATC, including resuscitation protocols for EMTs, must be designed and implemented. There must also be a defined clinical pathway from the emergency room through the scanner to the ICU or operating room. The abbreviated patient flow sheet and clinical pathways are included in Figure 1 and later in this article. Specific protocols should be in place for the management of each of the following clinical presentations:

- Type A dissection (eg, immediate operating room intervention)
- Type B dissection (eg, medical management)
- Malperfusion syndromes
- Intramural hematoma
- Ruptured thoracic aorta
- Ruptured abdominal aortic aneurysms; for this disease state, the only advancement to reduce mortality rates is endovascular repair, in which the AATC have significant experience
- Symptomatic thoracic aneurysms
- Symptomatic abdominal aneurysms
- Penetrating ulcers
- Thoracic aortic injury
- Shaggy aortic syndrome

A PACS or home-based electronic access system should also be available for the triaging surgeon.

ACUTE AORTIC TREATMENT: CLINICAL PATHWAYS

An AATC should establish two pathways for patient throughput. On Pathway A, patients will be transported to an emergency room with established diagnosis of acute aortic syndrome. Pathway B includes patients in the emergency room who are suspected of having an acute aortic syndrome.

Pathway A

The patient is transported to the AATC, and CT imaging from an outside institution is immediately uploaded to PACS, if available. There is an in-house radiologist on call who reads the CT and immediately contacts responsible emergency room physician with the findings. The treatment continues according to Pathway B, line 6.

Pathway B

1. The emergency room physician examines patient.
2. If acute aortic syndrome is suspected, labs will be collected and analyzed with i-Stat (turnaround time, 10 minutes).
3. If the patient's creatinine is ≤1.6, a CT of the chest, abdomen, and pelvis with contrast is promptly obtained.
4. If the patient's creatinine is >1.6 or he has an iodine or contrast allergy, a CT of the chest without contrast is obtained. This scan is reviewed and discussed, and the decision is made whether to repeat scan with contrast.
5. The in-house radiologist on call reads the CT and immediately contacts the responsible emergency room physician with findings.
6. If acute aortic syndrome is suspected or confirmed, a group page will be sent to the following personnel:
   - -CV surgeon on call
   - -CVICU
   - -Operating room supervisor
   - -Nursing supervisor
   - -Security
7. The emergency room physician calls the CV surgeon directly.
8. The CV surgeon reviews CT scans on site or via Web-based viewing.
9. The CV surgeon determines patient disposition: If the patient had noncontrast CT, the surgeon will make a decision about risk/benefit ratio of proceeding with contrast because it may be necessary for diagnosis/decision making.
10. The CV surgeon decides if open surgical intervention (such as for type A dissection), endovascular repair (which is appropriate ruptures of thoracic and abdominal aneurysms and dissection with malperfusion syndromes), hybrid procedures, or medical management (such as for type B dissection) will be needed.
    - -Cardiac anesthesiologist is paged.
    - -If an endovascular route is taken, the radiology tech is paged.
11. The CV surgeon calls CVICU intensivist with treatment plan.
12. The emergency room physician calls CVICU intensivist.
13. The patient is transported expeditiously to the appropriate destination, and treatment is initiated.

CHALLENGES

One of the most significant obstacles to establishing a successful AATC is to increase awareness of its existence in outlying emergency rooms. However, these referral centers, as well as local EMTs and the community as a whole, must also be educated on how to identify the symptoms and risk factors of acute aortic syndromes. These include patients with known untreated aortic aneurysms; history of treated aortic aneurysms; severe chest, abdominal, or back pain; "tearing"-type chest pain; or a pulsatile abdominal mass.

TABLE 1. COMPONENTS OF A SUCCESSFUL AATC AND PROGRAM
• Rapid identification and transport system
• Education of emergency medical technicians and local area emergency rooms on recognition of acute aortic syndromes
• Emergency room group with extensive experience in diagnosis and resuscitation of patients with acute aortic emergencies
• On-site 64-slice CT scanner in emergency room for immediate, fast imaging to permit emergent case triage
• Dedicated cardiovascular operating rooms and hybrid suites
• Goal of emergency room to treatment initiation time of <1 hour
• Highly experienced cardiovascular surgeons
• Highly experienced endovascular surgeons
• Surgeons working in close collaboration as a team of physicians for triaging cases and in surgical procedures
• History of integrating endovascular and open approaches
• Highly experienced, board-certified cardiovascular anesthesiologists
• Comprehensive operating room to CVICU care, with 24-hour in-house intensivist care
• Availability of new technologies for endovascular therapy of acute aortic syndromes
• Outcomes database

The AATC will likely also have to establish and coordinate the rapid transport mechanisms with appropriate reimbursement, and then, as previously indicated, educate the ambulance service staff regarding identification of acute aortic syndromes. A key element of the education for transport services regards the concept of permissive hypotension for ruptured aneurysms.

A public awareness campaign should be designed with the goal of driving patient requests for transportation to the AATC should they feel symptoms. A dedicated, AATC-specific Web site helps to build community awareness of the facility's program. Patient-oriented information about aortic disease and treatment options should be displayed prominently.

Drs. Michael E. DeBakey, Stanley Crawford, and Denton Cooley first tackled what was formerly a prohibitive surgical disease and developed contemporary surgical techniques to treat the thoracic and abdominal aorta. Dr. DeBakey was the first to classify aortic dissection, a classification that bears his name to this day. Due to the legacy of these physicians and a long history of innovation in treating aortic disease, The Methodist Hospital in Houston is particularly well suited for development of this new concept. ■

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