Developing a complex endovascular fenestrated and branched aortic program


In 2008, the top priority in our division’s 5-year strategic plan was “to become an internationally recognized center of excellence for the endovascular treatment of complex aortic pathology extending from the aortic valve to the external iliac artery.” Five components were identified as “most critical” to achieve this strategic priority: (1) training at centers of excellence in complex endovascular repair; (2) industry partnership to improve access to developing technologies; (3) a fully integrated team approach with one leader involved in all steps of all cases; (4) prospective data collection; and (5) development and implementation of a physician-sponsored investigational device exemption for juxtarenal, pararenal, and thoracoabdominal aneurysms. We have now performed 49 repairs (16 commercially manufactured devices, 33 physician-modified devices) for 3 common iliac, 20 juxtarenal, 9 pararenal, and 17 thoracoabdominal aneurysms, using 142 fenestrations, branches, and scallops. All patients had complete 30-day follow-up for calculation of 30-day events. Kaplan-Meier analysis was used to calculate 1-year events. In 5 years, we developed a successful complex endovascular aortic program that uses fenestrated/branched repair techniques. A focused team strategic planning approach to program development is an effective way for vascular surgery divisions to gain experience and expertise with new complex technologies while ensuring acceptable patient outcomes. (J Vasc Surg 2015;61:826-31.)

Whenever new technologies are introduced, such as laparoscopic or endovascular catheter-based techniques, it is extremely challenging to create a state-of-the-art high-impact clinical program of national or international stature that successfully leverages the new technology. This challenge is in sharp contrast to the traditional evolution of open surgical procedures, such as a Whipple procedure or open thoracoabdominal aortic aneurysm repair, which involve incremental advances made during long periods. We are currently in the midst of a rapid evolution of technical advances in endovascular catheter-based treatments for aortic aneurysms. Appropriate use of these advances requires not only the acquisition of new techniques and surgical skills but also an understanding of new, rapidly changing endovascular graft design technologies. Thus, development of a state-of-the-art complex aortic endovascular program is a daunting challenge that requires a disciplined and strategic assessment of strengths, weaknesses, and opportunities. The time constant for development and implementation of such a program is inevitably long and requires a focused, persistent approach.

Among many potential options, our division made a collective decision to develop a strategic plan to organize our resources so that we could develop a high-impact program for the endovascular treatment of complex aortic pathology. The initial planning stages for our complex endovascular aortic pathology program began in 2008 and have continued to the present day. Since committing to this program, we have attempted to leverage strengths, to minimize weaknesses, and to seize opportunities to bring us closer to achieving a mutually agreed on goal: “to become an internationally recognized center of excellence for the endovascular treatment of complex aortic pathology extending from the aortic valve to the external iliac artery.”

The purpose of this study was twofold. First, we sought to identify key programmatic elements that are essential for successful implementation of a complex endovascular aortic pathology program. Second, we evaluated the outcomes achieved after our first 49 consecutive complex endovascular aortic pathology procedures.

METHODS
This study is a single-center retrospective review. All procedures were performed at one large academic hospital.
in a hybrid operating room with high-quality fixed radiology equipment with fusion overlay capabilities between November 2010 and May 2014. Any patient was included in the complex endovascular aortic pathology program if the intended endovascular repair necessitated one or more fenestrations or branches to achieve a durable endograft seal. The data of all patients were entered into a secure, prospectively maintained database by a research assistant. Institutional Review Board approval was obtained from the University of Massachusetts Medical School, and written informed consent was obtained for each patient.

Identification of key programmatic elements. The original action plan laying out the vision for the complex endovascular aortic pathology program was created in November 2008. This document was reviewed, and each action item included in the action plan was ranked by the study team according to the perceived importance of that specific action item (from “most critical” to “least critical”). Similarly, each faculty member who is a part of the complex endovascular aortic pathology team was surveyed for perspectives on most significant elements leading to the program’s success. These responses were then aggregated and compiled in order of ranking from most critical to least critical.

Procedure and outcomes. All repairs were planned on the basis of measurements obtained from high-resolution computed tomography angiography images on a three-dimensional workstation by standard centerline flow orthogonal techniques (TeraRecon, Foster City, Ca).5 For any patient’s anatomy for which a commercially manufactured fenestrated endograft (ie, Cook ZFEN; Cook Medical, Bloomington, Ind) or a trial device (ie, Cook Iliac Branch Device, Cook p-Branch; Cook Medical) was available to the study team, the appropriate commercially manufactured device option was selected. Otherwise, if a patient’s anatomy was not amenable to a commercially manufactured fenestrated or branched device, a physician-modified device was used.6-9

All patients included in the complex endovascular aortic pathology program were observed according to a standardized protocol that consists of postoperative computed tomography angiography at 1 month, 6 months, and yearly thereafter. In addition, all visceral arteries that are targeted by a fenestration or a branch are evaluated with duplex examination at 1 month, 6 months, and yearly thereafter. All patients, in the absence of a contraindication, are prescribed clopidogrel for 6 months and lifelong aspirin. The 30-day outcomes were calculated by standard counts and proportions. All 1 year outcomes were calculated by life-table analyses and the Kaplan-Meier time-to-event method.

RESULTS

Key programmatic elements. There were five programmatic elements that were ranked unanimously by all study team members as most critical for the successful development of a complex endovascular aortic pathology program. These programmatic elements included the following.

1. On-site training at established international centers of excellence in complex endovascular aortic intervention. Formal training for members of our study team was requested from three established centers of excellence, two in the United States (Cleveland Clinic, Cleveland, Ohio; and University of Washington, Seattle, Washington) and one in France (Lille University Hospital, Lille, France). All three centers permitted multiple training visits with an emphasis on complex aortic pathology case review, case planning and device ordering, and actual procedure conduct with direct observation in the operating room.

2. Industry partnership to improve access to developing technologies. Each device manufacturer involved in the development of complex endovascular aortic technologies was vetted to identify the company we believed to be best aligned with our vision for the future of endovascular aortic treatment.11 After identifying this company (Cook Medical, Bloomington, Ind), we attempted to establish a mutually beneficial relationship in which we could offer a thoughtful and meticulous approach to the development, testing, and implementation of evolving new technologies.

3. A fully integrated team approach with one leader involved in all steps of all cases. Given the complexity associated with fenestrated and branched endograft technology, the decision was made from the inception of the program to choose one team leader who would be involved in all steps of each case. The motivation for this decision was to ensure that the advanced skill set required for these types of procedures was maximized and not diluted among multiple team members. At the same time, we believed that it was critical to the success of the program to ensure buy-in from our entire division. As a result, the surgeon referring the patient into the program was included in all planning, procedural, and follow-up events and was the primary billing surgeon for the procedure.

4. Prospective data collection. Being able to demonstrate acceptable clinical outcomes is imperative to the success of any new program. As a result, we established a prospective database that was approved...
Table. Baseline characteristics of patients who underwent complex endovascular aneurysm repair between 2010 and 2014 (N = 49)

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. (%)</th>
</tr>
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<tbody>
<tr>
<td>Women</td>
<td>33 (67.3)</td>
</tr>
<tr>
<td>Mean age, years</td>
<td>73.5</td>
</tr>
<tr>
<td>Comorbidities</td>
<td></td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>29 (59.2)</td>
</tr>
<tr>
<td>Prior stroke</td>
<td>4 (8.2)</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease</td>
<td>15 (30.6)</td>
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<tr>
<td>Chronic renal dysfunction</td>
<td>13 (26.5)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>6 (12.2)</td>
</tr>
<tr>
<td>Cancer</td>
<td>7 (14.3)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>41 (84)</td>
</tr>
<tr>
<td>Tobacco (current)</td>
<td>12 (25)</td>
</tr>
<tr>
<td>Prior abdominal endovascular aneurysm repair</td>
<td>5 (10.2)</td>
</tr>
<tr>
<td>Prior thoracic endovascular aneurysm repair</td>
<td>2 (4.1)</td>
</tr>
<tr>
<td>First-degree relative with aortic aneurysm</td>
<td>5 (10.2)</td>
</tr>
<tr>
<td>Aneurysm extent</td>
<td></td>
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<tr>
<td>Common iliac artery aneurysm</td>
<td>3 (6.1)</td>
</tr>
<tr>
<td>Juxtarenal aortic aneurysm</td>
<td>20 (40.8)</td>
</tr>
<tr>
<td>Pararenal aortic aneurysm</td>
<td>9 (18.4)</td>
</tr>
<tr>
<td>Thoracoabdominal aortic aneurysm</td>
<td>17 (34.7)</td>
</tr>
<tr>
<td>Presentation</td>
<td></td>
</tr>
<tr>
<td>Elective intact aneurysm</td>
<td>41 (83.7)</td>
</tr>
<tr>
<td>Urgent symptomatic aneurysm</td>
<td>7 (14.3)</td>
</tr>
<tr>
<td>Ruptured aneurysm</td>
<td>1 (2.0)</td>
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</tbody>
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by our Institutional Review Board to evaluate our clinical outcomes at 6-month intervals.

5. Development and implementation of a physician-sponsored investigational device exemption (IDE) for the endovascular treatment of juxtarenal, pararenal, and thoracoabdominal aneurysms. Given the limited number of approved commercially available devices for the treatment of complex aortic pathology, we pursued a mechanism by which we could offer endovascular repair to patients with complex aortic pathology who were at high risk for open repair and were not candidates for a currently approved commercially available device. We engaged the U.S. Food and Drug Administration, which provided excellent guidance and advice on how to effectively move forward with an IDE application. With this guidance, we were able to successfully submit and to receive approval for implementation of the Complex Aortic Repair Using Physician Modified Endografts (CARPE) IDE study (IDE #G130210, ClinicalTrials.gov identifier: NCT02050113).

Cohort description. Between November 2010 and May 2014, we enrolled 49 patients into our complex endovascular aortic pathology program (1 in 2010, 7 in 2011, 14 in 2012, 22 in 2013, and 5 in 2014; Table). The average age of patients was 73.5 years, and 33 patients (67%) were women. Of known risk factors for aneurysm formation, 41 patients (84%) had a history of medically treated hypertension, 12 patients (25%) reported current tobacco use, and 5 patients (10%) reported a first-degree relative known to have an aortic aneurysm.

Aneurysm morphology and procedural characteristics. Of the 49 complex endovascular aortic pathology repairs, 16 were performed with commercially manufactured devices and 33 were performed with physician-modified devices. The aneurysm extent treated included 3 common iliac artery aneurysms, 20 juxtarenal aortic aneurysms, 9 pararenal aortic aneurysms, and 17 thoracoabdominal aneurysms (Fig 1). The average preoperative maximum aortic aneurysm diameter measured by centerline technique was 6.1 cm. The repairs incorporated 125 fenestrations and 17 scallops, of which 107 (75%) were bridged to a target vessel with a stent graft (Fig 2). Over time, the endograft design selected for complex endovascular repairs increased in complexity, with an average of 1.0, 2.3, 2.9, 3.1, and 3.4 fenestrations per repair in 2010, 2011, 2012, 2013, and 2014, respectively.

Outcomes. Technical success was achieved in 46 patients (94%) (failure to cannulate a renal artery in two patients and a type I endoleak in one patient). On evaluation of 30-day outcomes, 2 patients (4.1%) experienced progression of chronic renal insufficiency to require dialysis, 14 patients (29%) had a deterioration in renal function with a >30% decrease in glomerular filtration rate, 2 patients (4.1%) had a target renal artery that could not be cannulated and progressed to thrombosis, 7 patients (14.3%) experienced access vessel complications (2 brachial artery thromboses, 2 iliac artery ruptures, 1 lower extremity bypass thrombosis, 1 femoral artery thrombosis, 1 femoral artery pseudoaneurysm), 2 patients (4.1%) experienced a type I or type III endoleak, and 2 patients (4.1%) expired (one cardiac arrest of unknown etiology 2 days after being discharged to home on postoperative day 3 and one patient who required prolonged mechanical ventilation and was, in accordance with her family’s wishes, allowed to expire comfortably on postoperative day 9 after repair of a symptomatic type IV thoracoabdominal aneurysm). There were no instances of myocardial infarction, paraplegia, paralysis, or stroke (Fig 3). The average total length of stay was 3.7 days.

On evaluation of 1-year outcomes by life-table analysis, survival was 91.5%, type I or type III endoleak rate was 4.1%, and target vessel patency was 95.1% (two renal artery
vascular therapy for complex aortic pathology, the associated with the open surgical alternatives to endografts. However, given the high morbidity and mortality more dif

cicantly less than that of infrarenal aortic aneurysms, it is because the incidence of complex aortic pathology is signif-

cer and wire skill set, and a much slower rollout/regulatory approval of company-manufactured devices. Furthermore, the prerequisite advanced cath-

tery, requiring preservation of blood flow to involved branch arteries with fenestrations or branches, has been substantially slower and primarily limited to relatively few centers. There are a number of reasons for this limited adoption of complex EVAR that include but are not limited to restricted access to appropriate devices, a need for sophisticated preoperative and intraoperative imaging, the prerequisite advanced cath-

ter and wire skill set, and a much slower rollout/regulatory approval of company-manufactured devices. Furthermore, because the incidence of complex aortic pathology is signif-

cically less than that of infrarenal aortic aneurysms, it is more difficult to develop and to test these evolving technologies. However, given the high morbidity and mortality associated with the open surgical alternatives to endo-

ascular therapy for complex aortic pathology, the development and dissemination of these “next-generation” endovascular technologies remains a significant unmet need.

Using a strategic planning approach that involved all members of our division, we designed and implemented a complex endovascular aortic pathology program that enabled us to offer patients fenestrated and branched endo-

vascular aortic repairs with acceptable outcomes. Whereas every institution differs with regard to strengths, weaknesses, and opportunities, we believe that the five key programmatic elements highlighted in this study are critical to the successful implementation of a complex endovascular aortic pathology program in any environment. Regardless of location, training at centers of excellence in complex endovascular repair, industry partnership to improve access to developing technologies, leveraging of a fully integrated team approach with one leader involved in all steps of all cases, prospective data collection, and development and implementation of a physician-sponsored IDE for juxtarenal, pararenal, and thoracoabdominal aneurysms will help a program to successfully develop a complex endovascular aortic pathology program.

Obtaining institutional buy-in is essential to the success of any new innovative clinical program. At our institution, we presented the concept for this program to the most se-


nior leadership of both the hospital and the medical school to garner support for the program. In an attempt to maxi-

mize support, we have provided regular updates on the progress of the program to the hospital and medical school leadership with an emphasis on the clinical outcomes achieved, the growth in outside referrals to the program, and any presentations or publications regionally and nation-

ally about the program. The financial commitment necessary to support a complex endovascular aortic pathology program is not minor. Currently, the budget allotted for external au-


dits by a clinical research organization, imaging review by an imaging core laboratory, and outside independent event adjudication is approximately $30,000 per year. Further-

more, a full-time equivalent research coordinator manages the IDE. This effort has been funded entirely through a proj-

ect development grant and through support from our insti-

tution, with none of the funding arising from industry.

For a complex endovascular aortic pathology program like this one to have a lasting effect, it is important that the necessary skill set be disseminated to others in the divi-


don. With this conceptual framework in mind, since the inception of the program, we have involved two attending surgeons in every fenestrated or branched endovascular repair. Currently, all complex endovascular repairs are sched-

uled when the leader of the program is available to be involved in the case, but with time, it is our hope that we will have multiple faculty members able to play such a role.

There are obvious limitations to this study, and there are likely to be a number of intangible variables that have contributed to and hindered the development of our com-

plex endovascular aortic pathology program. Our experience


discussion

Since the first published description of endovascular aortic aneurysm repair (EVAR) in 1991, the transition from open infrarenal aortic aneurysm repair to EVAR has occurred quickly and broadly. In the United States, currently >80% of elective infrarenal aneurysm repairs are now performed by an endovascular approach. The adoption of similar endovascular techniques for complex aortic pathology, requiring preservation of blood flow to involved branch arteries with fenestrations or branches, has been substantially slower and primarily limited to relatively few centers. There are a number of reasons for this limited adoption of complex EVAR that include but are not limited to restricted access to appropriate devices, a need for sophisticated preoperative and intraoperative imaging, the prerequisite advanced cath-

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Fig 2. The total number of scallops, fenestrations, and branches used per procedure.

occlusions) (Fig 4). On follow-up imaging, one patient (2.0%) with a known type I endoleak experienced aneu-

rysm sac enlargement on 1-year imaging; he refused further intervention. To date, there have been no aneurysm rup-

tures, no aneurysm-related mortality events, and no modi-

fied endograft integrity issues.

Fig 3. Perioperative events in patients who underwent complex endovascular aneurysm repair between 2010 and 2014 (N = 49). GFR, Glomerular filtration rate; MI, myocardial infarction.
of 49 patients remains small, and because the program’s inception is recent, our patient follow-up duration is limited. Furthermore, this is an extremely heterogeneous group of patients including a wide spectrum of patients ranging from complex type II thoracoabdominal aneurysms requiring four visceral artery branches to relatively simple common iliac artery aneurysms requiring a single internal iliac branch. Also, a variety of different endovascular devices were used, including both company-manufactured custom devices and physician-modified devices. As mentioned before, whenever a patient’s anatomy is amenable to repair with a company-manufactured device and the patient is deemed stable to wait for the device to be manufactured, this option is chosen over a physician-modified device. Our division is currently involved in 19 industry-sponsored trials, seven of which involve aortic devices.

This heterogeneity is a major limitation and makes it impossible to compare our results with other published series. Furthermore, our cohort and event rate is presently too small for any meaningful comparative effectiveness evaluation to be made between company-manufactured devices and physician-modified devices. Nonetheless, we do believe that our outcomes are acceptable and justify further investigation through our ongoing IDE study. Finally, as mentioned before, for a division desiring to develop a complex endovascular aortic pathology program, there will almost certainly be local factors specific to the division, the hospital, and the region that will directly affect the success or failure of program development. The five most critical programmatic elements that we identified as being key at our center may be different at another center.

At this time, our 10 integrated vascular surgery residents are actively involved in all steps of planning and care for these complex patients. In addition, we have welcomed many referring physicians who have expressed interest to come to observe these complex repairs. However, we have not implemented a specific complex endovascular aortic training program.

CONCLUSIONS

We have not yet achieved our stated goal as articulated by our group in 2008, “to become an internationally recognized center of excellence for the endovascular treatment of complex aortic pathology extending from the aortic valve to the external iliac artery.” However, we do believe that we have made positive strides in this direction. We hope that our experience may help others to develop, to test, and to implement complex endovascular aortic repair strategies and thereby advance the field and bring these promising new technologies to a greater number of patients.

AUTHOR CONTRIBUTIONS

Conception and design: AS, LM
Analysis and interpretation: AS, DB, WR, JS, FA, LM
In this issue of the Journal of Vascular Surgery, Schanzer et al.1 from the University of Massachusetts, reported their experience with 49 patients treated by fenestrated and branched endografts for complex aortic aneurysms. Thirty-three patients had physician-modified endografts (PMEGs) based on the Cook Zenith fenestrated stent graft. Ann Vasc Surg 2010;24:980-4. They present their results and discuss the importance of the multidisciplinary approach and the need for training and education.


The authors are to be congratulated on their excellent results for an early experience, including 30-day mortality of 4% and technical success of 94%. At the 1-year follow-up, the rate of type I/III endoleak (4%) and primary target vessel patency (95%) were similar to those reported for manufactured devices, with no aneurysm rupture, conversion, or late aneurysm-related death. Long-term results of PMEGs are still not available, but these data support the importance of their use in high-risk patients who are not candidates for open repair or alternative techniques. PMEGs have a definitive role in centers that do not have access to manufactured devices and in patients who are not suitable for off-the-shelf endografts and need urgent or emergency repair.

Advanced endovascular aortic programs are the perfect example of integration between clinical practice, research, innovation, and education. Almost every successful program has been led by a vascular surgeon or specialist who pioneered the technique or spent additional time beyond the traditional training to learn the nuances of device planning, patient selection, and techniques of implantation. Even those who demonstrated exceptional endovascular skills and pioneered the technique (eg, Tim Chuter and Roy Greenberg) recognized early in their careers the importance of dedicated training. With only a few large fenestrated-branched programs and workshops available worldwide, this experience is not easy to get.

Another aspect emphasized in the article is the need for centers to concentrate their experience under a dedicated team. The learning curve is quite steep. Although most experienced operators can learn the basic steps with some 10 to 20 cases, mortality, morbidity, radiation dose, and contrast volume continue to improve well beyond the first 200 to 300 cases. Starting with less complex anatomy (eg, iliacs and pararenal) and then advancing to the thoracoabdominal aorta and arch is recommended. As demonstrated by Schanzer et al, the level of complexity gradually increased over the years.

These devices should be used under prospectively maintained industry-sponsored or physician-sponsored investigational device exemption protocols, which require a significant time investment from the investigator to acquire specialized skills and develop trusted relationships with industry, peers, and the U.S. Food and Drug Administration. Equally important is the financial burden that is needed to mature and maintain prospective clinical investigations. This has been possible with significant institutional support and collaborations with industry via device trial participation, consulting, and engineer partnerships.

REFERENCES