Establishing a protocol for endovascular treatment of ruptured abdominal aortic aneurysms: Outcomes of a prospective analysis

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Purpose: In our transition from elective abdominal aortic aneurysm (AAA) to emergent ruptured AAA (r-AAA) repair with endovascular techniques, we recognized that the availability of endovascularly trained staff in the operating rooms and emergency departments, and adequate equipment were the limiting factors. To this end, we established a multidisciplinary protocol that facilitates endovascular repair (EVAR) of r-AAA.

Methods: In January 2002, we instituted a multidisciplinary approach that included the vascular surgeons, emergency department physicians, anesthesiologists, operating room staff, radiology technicians, and availability of a variety of stent-grafts to expedite EVAR of r-AAAs. Five patients with symptomatic, not ruptured AAAs suitable for EVAR underwent simulation of patients presenting to the emergency department with r-AAAs. Emergency department physicians alerted the on-call vascular surgery team (vascular surgeon, vascular resident or fellow) and the operating room staff, emergently performed an abdominal computed tomography (CT) scan in only hemodynamically stable patients with systolic blood pressures >80 mm Hg, and transported the patient to the operating room. The vascular surgeon informed the operating room staff to set up for EVAR and open surgical repair in an operating room equipped with interventional capabilities. The operating room setup was rehearsed with the anesthesiologists, operating room staff, and radiology technicians who were knowledgeable of the sequence of steps involved. Since then, 40 patients have undergone emergent EVAR for r-AAAs with general anesthesia.

Results: No complications developed in any of the symptomatic (simulation) patients, and 40 (95%) of 42 patients with r-AAAs had a successful EVAR with Excluder (n = 27, 68%), AneuRx (n = 9, 23%), or the Zenith (n = 4, 10%) stent-grafts. The mean age was 73 years (range, 54 to 88 years), and pre-existing comorbidities included coronary artery disease in 26 (65%), hypertension in 23 (58%), chronic obstructive pulmonary disease in 7 (18%), renal insufficiency not on dialysis in two (5%), and diabetes in nine (23%). Fourteen (38%) patients were diagnosed with r-AAAs at another hospital and subsequently were transferred to us, and 26 (62%) presented directly to the emergency department at our institution. At the initial presentation, 30 patients (75%) were hemodynamically stable and either had a CT scan at an outside hospital or in the emergency department, and 10 (25%) hemodynamically unstable patients with systolic blood pressures <80 mm Hg were rushed to the operating room for EVAR without a preoperative CT scan. The mean time from the presumptive diagnosis of a r-AAA in the emergency department to the operating room for EVAR was 20 minutes (range, 10 to 35 minutes), and the mean operative time from skin incision to closure was 80 minutes (range, 35 to 125 minutes). Seven patients (18%) needed supraceliac aortic occlusion balloon, and six (15%) needed aortouniliac stent-grafts. The mean blood loss was 455 mL (range, 115 to 1100 mL). Two patients each (5%) developed myocardial infarction, renal failure, and ischemic colitis, seven (18%) developed abdominal compartment syndrome, and seven (18%) died. Over a mean follow-up of 17 months, three patients with endovascular r-AAA repair required four secondary procedures.

Conclusions: The early results show that emergent endovascular treatment of hemodynamically stable and unstable patients is associated with a limited mortality of 18% once a standardized protocol is established. There is an increased recognition of emerging complications with an endovascular approach, and a synchrony of disciplines must be developed to initiate a successful program for endovascular treatment of r-AAAs. (J Vasc Surg 2006;44:1-8.)

Elective endovascular aneurysm repair (EVAR) has become an established means of treating abdominal aortic aneurysms (AAAs) and has been shown to reduce morbidity and mortality compared with open surgical repair, particularly in patients at high risk for open surgery.1-4 Open surgical repair remains the gold standard for treating a
ruptured AAA (r-AAA), although it is associated with a high morbidity and mortality ranging from 35% to 80%.\textsuperscript{5–7} Recently, several centers have reported on the feasibility and efficacy of EVAR for treating r-AAA; however, ambiguity remains among the vascular surgeons about the wide acceptance of an endovascular approach for treating r-AAA.

There are several reasons for our failure to adopt the endovascular means for treating r-AAA: unavailability of preoperative computed tomography (CT) in patients with r-AAA, unavailability of a dedicated operating room and ancillary staff equipped to perform emergent EVAR at all times, unavailability of off-the-shelf stent-grafts, and the lack of data from multicenter randomized trials. We too recognized the limitations of this technology in treating patients with r-AAA in that it was not necessarily the stent-graft design, but rather our inability to coordinate a seamless transition for these patients from the emergency department to the operating room to undergo endovascular repair. After our first successful attempt of endovascular r-AAA repair, it was all too obvious that a strict protocol was needed to streamline the patient through-put from the emergency department to an operating room that was fully equipped with trained interventional surgeons, anesthesiologists, and staff (nurses and interventional radiology technicians) to expeditiously perform EVAR in emergent settings.

We therefore established a protocol that trained these health care providers who would be involved in treating patients with r-AAA by simulating these emergent circumstances on patients with symptomatic AAAs. Once a standardized protocol was established for treating r-AAA, we used endovascular means as our primary modality for treating patients with aneurysm rupture.

MATERIAL AND METHODS

In 2002, we established a multidisciplinary approach for treating patients with r-AAA. This included vascular surgeons, emergency department physicians, anesthesiologists, operating room staff, radiology technicians, the availability of a variety of stent-graft sizes and types, and an operating room that was adequately equipped to perform endovascular procedures with an OEC-9800 (GE OEC Medical Systems, Salt Lake City, Utah) mobile fluoroscopic unit. Initially, we established treatment algorithms for r-AAA and rehearsed modus operandi with all the emergency department physicians, designated operating room staff that would participate in EVAR, anesthesiologists, and the radiology technicians. In doing so, we accomplished getting them interested in understanding the implications of emergent diagnosis and treatment in this setting. Because a patient with a r-AAA can present at any time, we rehearsed the procedure with staff who worked through the morning, evening, and night shifts.

Five patients with symptomatic but not r-AAA who were deemed suitable for endovascular repair underwent a simulation of patients presenting to the emergency department with r-AAA. The simulation included an expeditious patient evaluation by the emergency department physician who alerted the on-call vascular surgeon and the operating room (Fig). While in the emergency department, each simulation patient had an expeditious CT scan and was then transported to the operating room equipped with fluoroscopic equipment. The operating room staff was set up for endovascular and open surgical AAA repair. The procedures were well rehearsed with the anesthesiologists, the operating room staff, and the radiology technicians that were knowledgeable of the sequence of steps involved.

All procedures were performed in the operating room with general anesthesia via bilateral femoral cutdown. The stent-grafts used were currently approved by United States Food and Drug Administration (FDA) and available off the shelf. Although initially only the AneuRx (Medtronic AVE, Santa Rosa, Calif) was available as off the shelf for emergent use, two other stent-grafts, the Excluder (W. L. Gore & Associates, Flagstaff, Ariz) and Zenith (Cook, Inc, Bloomington, Ind), later gained FDA approval and were available for treating patients with r-AAA. The selection of particular stent-grafts was up to the discretion of the surgeon and determined primarily by the anatomic limitations of patient’s aortoiliac morphology.

After a femoral artery cutdown, ipsilateral access was obtained into the descending thoracic aorta using a floppy guidewire and a guiding catheter. The floppy guidewire was exchanged for a super-stiff wire that was used to place a large sheath (12F to 22F) in the ipsilateral femoral artery. A 33-mm or 40-mm compliant Equalizer occlusion balloon catheter (Boston Scientific/Medi-Tech, Natick, Mass) was advanced over the super-stiff wire up to the supraceliac abdominal aorta under fluoroscopic guidance and was not inflated. Access was then obtained from the contralateral femoral cutdown, and an arteriogram was done to better define the aortoiliac morphology. Unless anatomically prohibitive, the femoral artery contralateral to the site of aortic occlusion balloon was used for the stent-graft main body. The patients received intravenous heparin (50 U/kg), the aortic occlusion balloon was exchanged for a marker flush catheter, and an aortogram was done to better define the aortic neck morphology. The remainder of the EVAR was conducted in routine fashion.

It was only after five patients with symptomatic AAAs underwent simulation of patients presenting with r-AAA that we routinely adopted the endovascular approach for treating r-AAA at our institution. There were a few differences in the treatment algorithm of nonsimulation patients that presented with r-AAA. The only exclusion criterion was a preoperative CT scan indicating an aneurysm clearly unsuitable for endovascular repair. We accepted an aortic neck length >5 mm, and inability to gain access from the femoral arteries was never a limiting factor. The stent-grafts were oversized 15% to 20% based on the maximum aortic neck diameters.

When the infrarenal aortic neck for endovascular repair was sized, the location of measurements varied depending on the type of stent-graft used. Aortic neck sizing for the Excluder stent-graft was done from inner wall to inner wall,
as recommended by the guidelines of the pivotal phase II trials. For the AneuRx and Zenith, the aortic neck measurements were done from outer wall to outer wall.

Other limitations were that of the on-call surgeon’s bias and unease in performing EVAR in emergent settings and the lack of available endovascularly trained staff at hospitals other than Albany Medical Center where this study was conducted. A preoperative CT scan, when unavailable from referring institutions, was only obtained in hemodynamically stable patients. Unstable patients with systolic blood pressures <80 mm Hg who could not safely undergo a preoperative CT scan were taken directly to the operating room. We routinely used the technique of hypotensive hemostasis in all patients with r-AAAs by limiting resuscitation and maintaining a detectable blood pressure to limit the potential for ongoing hemorrhage.

We used brachial artery access for placement the supraceliac aortic occlusion balloon catheter in the initial two cases; subsequently, we have routinely used the femoral approach for placement of aortic occlusion balloon, as needed.

Earlier in our experience, patients received systemic heparinization during EVAR for r-AAAs, but we no longer anticoagulate patients during these procedures. We found an increased activated partial thromboplastin time to be a significant risk factor for the development of abdominal compartment syndrome in these patients.

In patients with hemodynamic instability or anatomic limitations that precluded expeditious exclusion of the r-AAA, modular bifurcated stent grafts were converted to aortouniiliac (AUI) devices by deploying aortic cuffs (AneuRx, Excluder, or Zenith AUI converter) across the stent-graft flow-divider. The contralateral iliac artery was interrupted by open ligation, endoluminal occlusion, or placement of a covered stent from the internal iliac artery into the external iliac artery, and femorofemoral bypass was performed.

Perioperative data were prospectively collected in a vascular surgery registry to analyze the outcomes of patients undergoing endovascular repair for r-AAAs

RESULTS

In all five patients with symptomatic AAAs who underwent simulation of r-AAA, endovascular repair was uneventful. The mean procedure time was 80 minutes (range, 35 to 125 minutes), the mean blood loss was 260 mL
Table I. Demographics of patients with a ruptured abdominal aortic aneurysm

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N = 40 (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>29 (73)</td>
</tr>
<tr>
<td>Mean age, years (range)</td>
<td>74 (54–88)</td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>26 (65)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>23 (58)</td>
</tr>
<tr>
<td>COPD</td>
<td>7 (18)</td>
</tr>
<tr>
<td>Renal insufficiency</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>9 (23)</td>
</tr>
</tbody>
</table>

*COPD, Chronic obstructive pulmonary disease.
*Data presented are numbers (%) or means (ranges).

(range, 150 to 400 mL), and the average length of hospital stay was 1.4 days (range, 1 to 2 days). None of the patients had complications of myocardial infarction, renal insufficiency, respiratory failure, wound infections, stent-graft migration, or limb thrombosis. One patient with persistent type II endoleak 6 months after EVAR underwent successful translumbar coil embolization of the aneurysm sac.

Since 2002, 85 patients presented to our institution with r-AAA’s and underwent endovascular (n = 40, 47%) or open surgical repair (n = 45, 53%). Overall, EVAR was attempted in 42 patients, and two patients (4.8%) in our earlier experience were converted to open surgical repair because of technical difficulties encountered during the procedure that precluded expeditious r-AAA exclusion.

During the emergent open surgical conversion, a compliant aortic occlusion balloon catheter was left at the level of the supraceliac aorta and was ready for aortic occlusion, if needed. Forty patients with r-AAA’s underwent EVAR with the AneuRx (n = 9, 23%), Excluder (n = 27, 68%), or the Zenith (n = 4, 10%) stent-grafts. The mean age was 73 years (range, 54 to 88 years), and pre-existing comorbidities included coronary artery disease in 26 (65%), hypertension in 23 (58%), chronic obstructive pulmonary disease in seven (18%), renal insufficiency not on dialysis in two (5%), and diabetes in nine (23%) (Table I).

Fourteen patients (38%) were diagnosed with r-AAA’s at another hospital and were transferred to us, and 26 (62%) presented directly to the emergency department at our institution. At the initial presentation, 30 patients (75%) were hemodynamically stable and either had a CT scan at an outside hospital or in our emergency department, and 10 (25%) hemodynamically unstable patients were rushed to the operating room for EVAR without a preoperative CT scan. The mean time from the presumptive diagnosis of a r-AAA in the emergency department to the operating room for EVAR was 20 minutes (range, 10 to 35 minutes), and the mean operative time from skin incision to closure was 80 minutes (range, 35 to 125 minutes).

During the procedure, supraceliac aortic occlusion balloon was required in seven patients (18%): one from the brachial approach, and the remainder from the femoral approach. In six patients (15%), modular bifurcated stent-grafts were converted to AUI devices due to ongoing hemodynamic instability and inability to expeditiously cannulate the contralateral gate. The mean external blood loss was 455 mL (range, 150 to 1100 mL) (Table II).

The overall mortality rate was 18% (7 of 40). One patient died ≤1 hour of the procedure due to myocardial infarction, and the rest of the deaths were secondary to multisystem organ dysfunction. In two patients (5%) each, morbidities included myocardial infarction, renal failure requiring dialysis, respiratory failure requiring tracheotomy, and ischemic colitis requiring colon resection and colostomy; and seven patients (18%) had abdominal compartment syndrome (ACS) (Table III). Although the overall mean hospital length of stay was 15 days, it was much higher for patients who developed ACS (mean, 34 days; range, 8 to 83 days) than for patients who did not develop ACS (mean, 9 days; range, 2 to 26 days) (Table III).

Over a mean follow-up of 17 months, three patients with endovascular r-AAA repair required four secondary procedures. One patient with an angulated aortic neck presented with stent-graft migration from the proximal fixation site at the 6-month follow-up and underwent successful placement of an aortic cuff. The second patient refused to attend follow-up after the initial endovascular r-AAA repair, but presented at 16 months with a recurrent r-AAA secondary to stent-graft migration from the proximal fixation site. He underwent a successful endovascular repair of the recurrent r-AAA with placement of an aortic

Table II. Procedural characteristics of patients with a ruptured abdominal aortic aneurysm

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N = 40 (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient hemodynamically stable</td>
<td>30 (75)</td>
</tr>
<tr>
<td>Patient hemodynamically unstable</td>
<td>10 (25)</td>
</tr>
<tr>
<td>Preoperative CT available</td>
<td>30 (75)</td>
</tr>
<tr>
<td>Need for aortic occlusion balloon</td>
<td>7 (18)</td>
</tr>
<tr>
<td>Stent-graft conversion to AUI device</td>
<td>6 (15)</td>
</tr>
<tr>
<td>Mean operative time, minutes (range)</td>
<td>80 (35–125)</td>
</tr>
<tr>
<td>Mean blood loss in mL (range)</td>
<td>455 (150–1100)</td>
</tr>
</tbody>
</table>

CT, Computed tomography; AUI, aortouniiliac.
*Data presented are numbers (%) or means (ranges).

Table III. Morbidity and mortality after endovascular ruptured abdominal aortic aneurysm

<table>
<thead>
<tr>
<th>Event</th>
<th>N = 40 (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myocardial infarction</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Respiratory failure</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Renal failure, dialysis</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Ischemic colitis</td>
<td>2 (5)</td>
</tr>
<tr>
<td>ACS</td>
<td>7 (18)</td>
</tr>
<tr>
<td>Mean hospital LOS (days)</td>
<td>9 (2–26)</td>
</tr>
<tr>
<td>Without ACS (range)</td>
<td>34 (8–83)</td>
</tr>
<tr>
<td>Mortality</td>
<td>3/33 (9)</td>
</tr>
<tr>
<td>With ACS</td>
<td>4/7 (57)</td>
</tr>
<tr>
<td>Overall mortality</td>
<td>7 (18)</td>
</tr>
</tbody>
</table>

ACS, Abdominal compartment syndrome; LOS, length of stay.
*Data presented are numbers (%) or means (ranges).
cuff at the proximal infrarenal aortic neck. The third patient presented at 6 months with a type II endoleak and an increase in AAA sac diameter and underwent translumbar aneurysm sac coil embolization. He presented at 9 months with stent-graft migration from the proximal fixation site at the aortic neck that required placement of a proximal aortic cuff. At the 12-month follow-up, he had a persistent type II endoleak and a further increase in the maximum aneurysm sac diameter from 8.5 cm to 11 cm. He subsequently had a successful elective conversion to open surgical repair and stent-graft explant.

Since 2002, we have also treated 45 patients with r-AAAs via open surgical approach, with a mortality of 51%. These patients did have a selection bias in that they either presented at an outside hospital that was not adequately equipped for endovascular procedures due to lack of equipment and endovascularly trained staff, or the on-call surgeon was reluctant to pursue endovascular treatment for r-AAAs. Only three (6.7%) of the 45 patients with pararenal aortic aneurysms had aortoiliac morphology that was prohibitive for endovascular r-AAA repair. Since 2002, the overall mortality of patients undergoing open surgical and endovascular r-AAA repair was 35% (30 of 85).

**DISCUSSION**

The mortality rate of open surgical repair for r-AAAs remains notably high, from 32% to 70%. Although endovascular r-AAA repair remains experimental, it is evolving and offers the potential for improved outcomes in patients that otherwise have a high morbidity and mortality. In our experience, a multidisciplinary approach that involves the vascular surgeon, emergency department physicians, anesthesiologists, operating room staff, radiology technicians, the availability of a variety of available off-the-shelf stent-grafts, and an operating room that is adequately equipped to perform endovascular procedures is crucial in obtaining better outcomes. After establishing a protocol for endovascular treatment of r-AAAs, we were able to expedite the recognition and treatment of patients with r-AAAs, resulting in a survival rate of 82% when patients were treated by endovascular means, which is markedly improved compared with the historical data of open surgical repair for AAA rupture.

This study is unique in that 25% of the patients with r-AAAs were hemodynamically unstable and did not have a preoperative CT scan to evaluate their aortoiliac morphology before endovascular repair, and all patients were treated with commercially available off-the-shelf stent-grafts with a standardized endovascular approach. Despite the technique, treatment of r-AAAs can be arduous and requires a synchrony of events for optimum patient outcomes. With the changing paradigm and the evolution of EVAR for treating r-AAAs, a coordinated multidisciplinary approach is increasingly crucial. Although we have had a substantial experience with elective endovascular AAA repair, our first attempt of endovascular r-AAA repair was disheartening as we realized our deficiencies in treating patients under emergent circumstances. Although the patient survived, there was a lack of coordinated effort among the emergency department staff, operating room staff, anesthesiologists, radiology technicians, and the vascular surgeon.

We therefore established a standardized approach to the endovascular procedure and obtained an adequate inventory of commercially available stent-grafts, catheters, wires, balloons, sheaths, and fluoroscopic equipment in the operating room. Although we were able to acquire a substantial inventory of stent-grafts in that we have had the availability of all sizes that the Excluder, AneuRx, and Zenith offered, we do not think a large inventory is necessary for treating patients with r-AAAs. We recommend that surgeons and interventionists should be comfortable performing endovascular aneurysm repair under elective circumstances and have an inventory of standard equipment (wires, catheters, sheaths, balloons, particularly large, compliant aortic occlusion balloons, and fluoroscopic equipment) before attempting endovascular repair of r-AAAs. Surgeons and interventionists who are involved in establishing an endovascular program for treating r-AAAs should choose the stent-grafts they are most comfortable using and should get the sizes to match the largest aortic neck diameter and the shortest aneurysm length, and a variety of iliac extensions. We recommend the following stent-graft inventory: for the Excluder, a 28.5 mm × 140 mm and a 24 mm × 140 mm; for the AneuRx, a 28 mm × 135 mm and a 24 mm × 135 mm; and for the Zenith, a 32 mm × 77 mm, and a 28 mm × 77 mm.

Once adequate equipment was acquired, we rehearsed the procedure with all health care providers who were involved in treating patients with r-AAAs, and established a uniform triage protocol (Fig). The emergency department physician would alert the vascular surgery team, the operating room staff, and the radiology technician, and obtain a CT in hemodynamically stable patients with systolic blood pressure >80 mm Hg. All other patients were directly transferred to the operating room that was ready and equipped to perform both endovascular and open surgical procedures. As long as the patients maintained a measurable blood pressure, the technique of hypotensive hemostasis was used in all patients, limiting resuscitation to maintain a detectable blood pressure to help minimize ongoing hemorrhage. These standardizations led to an acceptable transfer time (mean, 20 minutes) of patients from the emergency department to the operating room.

Lloyd et al recently published their data on a time-to-death study in patients with r-AAAs who did not undergo any treatment. Their findings indicate that 88% (49 of 56) died >2 hours after admission with the diagnosis of a r-AAA. The median time interval from the onset of symptoms to admission to the hospital was 2.5 hours, and the interval between hospital admission with the diagnosis of r-AAA and death was 10.5 hours. Their data also suggest that most patients with r-AAAs have time to undergo an expeditious CT scan before repair.

The decision to use a particular stent-graft type and size was determined by the patient’s aortoiliac morphology. In
25% of patients that were hemodynamically unstable and did not have a preoperative CT scan, the device selection was based on intraoperative angiographic findings; we have routinely oversized the stent-graft generously when sizing is based solely on intraoperative arteriographic findings. We recognize that stent-graft sizing based only on arteriographic findings can sometimes be misleading. Our goal in endovascular r-AAA repair has been to exclude the aneurysm at presentation and get the patient though the initial high-risk period, even at the cost of an elective secondary procedure or conversion to open surgical repair once the patient is hemodynamically stable.

Although we did not use intravascular ultrasound guidance, one can speculate on its usefulness in identifying proximal and distal stent graft landing sites in patients without a preoperative CT scan.

In patients with a difficult anatomy, hybrid stent-grafts were used by combining pieces from different manufacturers (Excluder, AneuRx, and Zenith). In a recent analysis comparing morphologic features of intact and ruptured aortic aneurysms, our findings after evaluating 39 CT scans of patients with a r-AAA indicate that most (85%) were suitable for endovascular repair if the inclusion criteria were modified to include aortic neck length of ≥10 mm and neck diameter of 30 mm. Hinchliffe et al have also analyzed morphologic features of r-AAA. Their findings suggest that only 43% of patients are amenable to endovascular ruptured aneurysm repair. Their inclusion criteria were strict, however, and similar to that of pivotal EVAR trials: aortic neck length ≥15 mm, neck diameter ≥30 mm, and iliac artery diameter ≤22 mm.

Since the primary objective of treating r-AAA is to increase patient survival, we believe that the use of a modified anatomic inclusion criteria for EVAR in these patients is justified as long as the patients undergo vigilant follow-up and evaluations for the possible complications of stent-graft failure. With this approach, we have been successful in 95% of patients (40 of 42) who underwent an attempted EVAR for rupture. At a mean follow-up of 17 months, the incidence of secondary interventions in 33 survivors was only 12% (4 procedures in 3 patients), and elective open surgical conversion was 3% (1 patient).

None of the three patients who required secondary procedures had any significant morbidity or mortality. All had undergone EVAR with the AneuRx stent-graft, and migration from the proximal fixation at the infrarenal aortic neck was the primary cause of stent-graft failure. A detailed evaluation of the infrarenal aortic neck anatomy in this cohort indicated that the aortic neck angulation (infrarenal aortic neck of the AAA) was approximately 60° in two patients and 45° in the third patient. None of these patients had an aortic neck diameter >26 mm or an aortic neck length <15 mm. As one might expect, migration from the proximal fixation sites in two of these patients could have been attributed to the significant aortic neck angulation. The number of patients is too small to make any drastic changes on our approach to patients with angulated aortic necks; however, we often place a Palmaz (5010) stent at the juxtarenal aorta when the stent-graft fails to accommodate the angulated aortic neck.

In the setting of hemodynamic instability or anatomic limitations that precluded expeditious exclusion of the r-AAA, temporary use of aortic occlusion balloon was required in seven patients (18%). Like others, we also have used the brachial approach for placement of the aortic occlusion balloon; however, we prefer to use the femoral approach and have found this to have several advantages:

1. It allows the anesthesia team to have access to both upper extremities for arterial and venous access.
2. Patients who require the aortic occlusion balloon are often hypotensive, and percutaneous brachial access can be difficult in these patients and more time consuming than femoral cutdown.
3. The currently available aortic occlusion balloons require at least a 12F sheath, which requires a brachial artery cutdown and repair, and stiff wires and catheters across the aortic arch without prior imaging under emergent circumstances might lead to other arterial injuries, or embolization causing a stroke, or both.

Although distal migration of the aortic occlusion balloon by the blood flow can occur when the femoral approach is used, this can be easily overcome by placing the balloon through a long 12F sheath (≥55-cm length). Once the tip of the sheath is placed in the distal thoracic aorta, just below the level of aortic occlusion balloon, it can be used to support the occlusion balloon and prevent distal migration. Once the stent-graft is adequately positioned at the aortic neck, the occlusion balloon is deflated and withdrawn with the sheath into the aortic aneurysm sac (while maintaining wire access), and the stent-graft is deployed.

The modular bifurcated stent-grafts were converted to AUI devices in six patients (15%), and all patients with the AUI devices also had a femorofemoral bypass and contralateral common iliac artery interruption via ligation and coil embolization in four, or endovascular external-to-internal iliac bypass with a covered stent in two. In our experience, there was a selection bias in that most patients who underwent conversion of bifurcated stent-grafts into AUI devices were hemodynamically unstable and required aggressive resuscitation. One can speculate that perhaps ongoing retroperitoneal hemorrhage in these patients could have contributed to ACS in 67% of patients (4 of 6) with AUI devices.

One can also speculate whether the primary use of AUI devices for these patients might lead to less blood loss and decreased morbidity and mortality. The use of AUI stent-grafts was first reported by the Montefiore group with the use of a surgeon-made Montefiore Endovascular Grafting System (MEGS), which included a large balloon-expandable stent (Palmaz 4910) sutured to a thin-wall expandable polytetrafluoroethylene graft, in conjunction with contralateral common iliac artery interruption and a femorofemoral bypass. In their experience of 30 patients with r-AAA who underwent endovascular repair, preferably with the MEGS since it was readily available and off the shelf, the incidence of ACS was 3% (1 of 30), and the overall mortality was 11%.
In our experience of endovascular r-AAA repair, the incidence of ACS was much higher at 18% (7 of 40) than previous reports. One might expect a higher incidence of ACS, because our protocol did not exclude hemodynamically unstable patients with r-AAA from undergoing EVAR. The resulting overall mortality was 18% (7 of 40); however, patients without ACS experienced far less mortality at 9% (3 of 38) compared with 57% (4 of 7) in those with ACS.

Our findings are supported by several other recent articles on the endovascular treatment of r-AAA.14–22 Although these studies have smaller numbers and do not include establishment of a standardized protocol based on a simulation of patients presenting to the emergency department with r-AAA, they support our findings of a limited morbidity and mortality in patients undergoing endovascular r-AAA repair. This study is a prospective analysis of outcomes based on a protocol for endovascular treatment of r-AAA; however, it has several limitations: patients were not randomized to endovascular vs open surgical repair, preoperative CT scans were not available in all patients to establish suitability for endovascular repair, and the on-call surgeon’s bias and unease in performing EVAR in emergent settings.

CONCLUSION

Endovascular repair of r-AAA is evolving and offers the potential for improved outcomes, particularly in patients who otherwise have a high mortality of open surgical repair. Most patients with r-AAA can be treated with currently available bifurcated modular stent-grafts, and AUI devices are required in only 15%. We recommend that a standardized protocol for endovascular treatment of r-AAA should be established that includes a multidisciplinary approach and collaborative efforts of the emergency department staff, operating room staff, and the vascular surgeons, and the availability of adequate equipment including off-the-shelf stent-grafts. The resulting treatment algorithm can minimize delays and even lead to treatment of hemodynamically unstable patients with r-AAA.

Furthermore, the anatomic inclusion criteria for EVAR should be modified to accept patients who would under elective circumstances be considered to have an unfavorable anatomy. Preoperative CT is not an absolute necessity. As long as adequate proximal and distal sealing can be obtained initially, the endovascular procedure can be a bridge to stabilize the patient who might need open surgical conversion at a later time. The initial results of endovascular r-AAA repair are promising and warrant further randomized controlled investigations, not only with currently available devices but also with newer-generation stent-grafts that are tailored for treating hemodynamically stable and unstable patients.

AUTHOR CONTRIBUTIONS

Conception and design: MM, RCD, PBK, KJO, PSKP, BBC, SPR, DMS
Analysis and interpretation: MM, JBT, RCD, PBK, KJO, PSKP, BBC, SPR, DMS, YS
Data collection: MM, JBT, RCD, PBK, KJO, PSKP, BBC, SPR, DMS, YS
Writing the article: MM, JBT, RCD

Critical revision of the article: MM, RCD, PBK, KJO, PSKP, BBC, SPR, DMS, YS
Final approval of the article: MM, JBT, RCD, PBK, KJO, PSKP, BBC, SPR, DMS, YS
Statistical analysis: Not applicable
Obtained funding: Not applicable
Overall responsibility: MM

REFERENCES

INVITED COMMENTARY

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At Montefiore, we performed our first endovascular aneurysm repair (EVAR) for ruptured abdominal aortic aneurysm (r-AAA) in 1994, and since then, we have pushed this technology in an attempt to apply it to as many patients as possible. Use of aortic occlusion balloons, permissive hypotension, preferential use of percutaneous delivery, and local anesthesia led to the increased penetration of this technology. Such efforts led to improved outcome at Montefiore, but this could not be reproduced readily elsewhere. One reason is that the early pioneers, including ourselves, failed to publish and describe the logistic details and its importance for performing EVAR for r-AAA.

What good is a gifted endovascular surgeon who doesn’t have the appropriate catheters and stents? What good is a high quality C-arm, if the patient is lying on a table that is not compatible with fluoroscopy? What good is a well-executed EVAR accomplished in 60 minutes if the intensivist/anesthesiologist has already infused 10,000 mL of crystalloid? (Ruptured AAA reflex). Indeed, “the devils are in the details.”

Dr Mehta and the group are congratulated for this fine study in which improved survival after EVAR and open repair for r-AAA was achieved after developing a hospital-wide protocol, rehearsing it, and building a multidisciplinary team. They have ironed out the details, which are of paramount importance under this urgent setting. I recommend all the physicians who currently treat r-AAA to read this practical paper. It may be beneficial to post the algorithm (Fig 1) in the emergency department and the operating room.

I agree with Dr Mehta that EVAR is the treatment of choice in most cases of r-AAA; however, we should not forget that a poorly prepared and ill-executed EVAR for r-AAA is worse than a well-executed open repair. The fact that the mortality rate after open repair is 70% to 80% does not give one a blank check to do anything, including EVAR.

REFERENCE