The impact of hemodynamic status on outcomes of endovascular abdominal aortic aneurysm repair for rupture

Manish Mehta, MD, MPH, Philip S. K. Paty, MD, John Byrne, MCh, FRCSI(Gen), Sean P. Roddy, MD, John B. Taggert, MD, Yaron Sternbach, MD, Kathleen J. Ozsvath, MD, and R. Clement Darling III, MD, Albany, NY

Objective: To date, there are no published reports comparing hemodynamically (Hd)-stable and Hd-unstable patients with ruptured abdominal aortic aneurysms (r-AAAs) undergoing endovascular aneurysm repair (EVAR). This study evaluates outcomes of EVAR for r-AAA based on patient’s Hd status

Methods: From 2002 to 2011, 136 patients with r-AAAs underwent EVAR and were categorized into two groups based on systolic blood pressure (SBP) measurements before EVAR: 92 (68%) Hd-stable (SBP ≥80 mm Hg) and 44 (32%) Hd-unstable (SBP <80 mm Hg for ≥10 minutes). All data were prospectively entered in a database and retrospectively analyzed. Outcomes included 30-day mortality, postoperative complications, the need for secondary reinterventions, and midterm mortality. The effect of potential predictors on 30-day mortality was assessed by χ² and logistic regression.

Results: Of the 136 r-AAA patients with EVAR, the Hd-stable and Hd-unstable groups had similar comorbidities (coronary artery disease, 63% vs 59%; hypertension, 72% vs 75%; chronic obstructive pulmonary disease, 21% vs 26%; and chronic renal insufficiency, 18% vs 18%), mean AAA maximum diameter (6.6 vs 6.4 cm), need for on-the-table conversion to open surgical repair (3% vs 7%), and incidences of nonfatal complications (43% vs 38%) and secondary interventions (23% vs 25%). Preoperative computed tomography scan was available in significantly fewer Hd-unstable patients (64% vs 100%; P < .05). Compared with Hd-stable patients, the Hd-unstable patients had a significantly higher intraoperative need for aortic occlusion balloon (40% vs 6%; P < .05), mean estimated blood loss (744 vs 363 mL; P < .01), incidence of developing abdominal compartment syndrome (ACS; 29% vs 4%; P < .01), and death (33% vs 18%; P < .05). ACS was a significant predictor of death; death in all r-EVAR with ACS was significantly higher compared with all r-EVAR without ACS (10 of 17 [59%] vs 22 of 119 [18%]; P < .01).

Conclusions: EVAR for r-AAA is feasible in Hd-stable and Hd-unstable patients, with a comparable incidence of conversion to open surgical repair, nonfatal complications, and secondary interventions. Hd-stable patients have reduced mortality at 30 days, whereas Hd-unstable patients require intraoperative aortic occlusion balloon more frequently, and have an increased risk for developing ACS and death. (J Vasc Surg 2013;57:1255-60.)

The evolution of endovascular aneurysm repair (EVAR) has led to improvements in our ability to treat elective and ruptured abdominal aortic aneurysms (r-AAAs). However, even today, one of the biggest limitations in widespread acceptance of an EVAR-first approach for all patients with r-AAAs is our limited understanding in managing hemodynamically (Hd) unstable r-AAA patients by endovascular means and the lack of data on outcomes of Hd-stable vs Hd-unstable patients with r-AAAs undergoing EVAR. This prospective nonrandomized study was based on an EVAR-first approach for all r-AAA patients and evaluates outcomes based on patient’s Hd status.

METHODS

In 2002, we established a protocol-oriented approach for treating patients with r-AAAs. In the emergency room, Hd-stable patients undergo expeditious computed tomography (CT) scan and are subsequently transferred to the operating room (OR), and Hd-unstable patients are directly transferred to the OR without a preoperative CT scan for an endovascular-first approach and conversion to open surgical repair (OSR) as needed. As long as the patients maintain a measurable blood pressure, the techniques of hypotensive hemostasis by limiting the resuscitation to maintain a detectable blood pressure can help minimize ongoing hemorrhage. Earlier in our experience
in Hd-unstable patients, we sometimes made the decision for ruptured EVAR (r-EVAR) without the availability of a preoperative CT scan. In such instances, aortic neck measurements were performed on the basis of intraoperative angiography only. In cases of juxtarenal r-AAAs, the decision for conversion to OSR vs one or both renal artery coverage was at the discretion of the vascular surgeon.

All procedures were performed in the OR with general, regional, or local anesthesia via a femoral cutdown or a percutaneous approach. The stent grafts used were currently approved by the U.S. Food and Drug Administration and available off the shelf and included the Excluder (W. L. Gore & Associates, Flagstaff, Ariz), Zenith (Cook Inc, Bloomington, Ind), and AneuRx and Talent (Medtronic AVE, Santa Rosa, Calif). Patient selection for EVAR vs OSR, as well as the selection of particular stent grafts, was at the discretion of the surgeon and determined primarily by the anatomic limitations of the patient’s aortoiliac morphology. The stent grafts were oversized 20% to 30% relative to angiographic aortic neck measurements.

All patients without a preoperative CT scan had a post-EVAR CT scan that confirmed r-AAA. Our algorithm for management of r-AAAs by EVAR has been detailed previously. Patient selection for EVAR or OSR depended on the surgeon’s discretion and experience. During r-EVAR, stent grafts were chosen on the basis of the availability and the patient’s aortoiliac morphology. With experience, particularly during the past 5 years, most vascular surgeons in our group have the ability and are comfortable with r-EVAR, resulting in less bias toward OSR in Hd-stable as well as Hd-unstable patients, and improvements in our ability to treat patients with increasing complexity of aortoiliac morphology. In this data set we accepted the real-world scenario clinical bias that vascular surgeons face when evaluating r-AAA patients for r-EVAR vs OSR. Patients who underwent OSR were not included in this analysis.

The r-EVAR procedure. The patients are placed supine and are prepared and draped. Femoral access (surgical cutdown or percutaneous) is obtained using a needle, floppy guidewire, and a guiding catheter. The floppy guidewire is exchanged for a super-stiff wire that can be used to place a large sheath (12F-14F, 30-45 cm length) in the ipsilateral femoral artery, and the sheath is advanced to the juxtarenal abdominal aorta so it is ready to be used to deliver and support the aortic occlusion balloon (AOB), if needed. Access is subsequently obtained from contralateral femoral artery (cutdown or percutaneous) in similar fashion and a marker flush-catheter advanced to the juxtarenal aorta for an arteriogram.

Our standard approach has been to perform r-EVAR under general anesthesia with femoral artery cutdown. We have reserved the percutaneous approach for EVAR of r-AAA in select Hd-unstable patients who can cooperate with the anesthesiologist and the vascular surgeon/interventionists. In these patients, we prefer percutaneous femoral artery access without a closure device, advance an appropriately sized sheath 18F-22F as needed, and carry out the r-EVAR. At the completion of the endovascular procedure, the femoral sheaths are removed via the femoral artery cutdown and direct femoral artery repair.

The placement of the stent graft main body is planned based on the aortoiliac morphology that is best suited for r-EVAR. Unless prohibitive, in Hd-stable patients, the AOB is removed from the initial ipsilateral side after the initial arteriogram and the stent graft main body advanced under fluoroscopic guidance, which limits the number of catheter exchanges. In Hd-unstable patients who require inflation of the AOB, the marker flush-catheter is exchanged for the stent graft main body, which is delivered up to the renal arteries. An arteriogram is done via the sheath that is used to support the AOB, the tip of the stent graft main body is aligned with the lowermost renal artery, the AOB is subsequently deflated and withdrawn back with the delivery sheath into the AAA, and the stent graft main body is deployed. The remainder of the EVAR procedure is performed similar to as in elective circumstances.

In patients with Hd instability or anatomic limitations that precluded expeditious exclusion of the r-AAA, modular bifurcated stent grafts were converted to aortouniliac (AUI) devices by deploying aortic cuffs (AneuRx, Excluder, or Zenith Renu AUI converter) or a second aortic stent graft main body 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.

Patient Hd status was categorized according to vital signs any time before the r-EVAR; patients with systolic blood pressure (SBP) measurements of $<80$ mm Hg for $>10$ minutes in duration were categorized as Hd-unstable, and all other patients (SBP $>80$ mm Hg) were considered Hd-stable for this analysis. The diagnosis of abdominal compartment syndrome (ACS) was made on the basis of bladder pressures $>35$ mm Hg with severe abdominal distention, or cardiovascular collapse, or both. All data were prospectively collected, and statistical analysis was performed using $\chi^2$ and life-table methods.

RESULTS

In our single-center experience, from 2002 to 2011, 283 patients presented with r-AAAs, of which 136 underwent r-EVAR and were categorized into two groups by their perioperative Hd status: 92 (68%) were considered Hd-stable, and 44 (32%) were Hd-unstable. Both groups were similar with respect to comorbidities, including coronary artery disease, defined as patients with prior cardiac workup who were deemed so by their cardiologist, presence of coronary artery disease (63% vs 59%), hypertension (72% vs 75%), chronic obstructive pulmonary disease, defined as anyone with asthma, emphysema, with or without home oxygen dependency (21% vs 26%), and chronic renal insufficiency, defined as creatinine level $>1.8$ mg/dL (18% vs 18%), and maximum AAA diameter (6.6 vs 6.4 cm; Table I). There were notable differences between the groups in that before r-EVAR, a preoperative CT scan was available in a significantly higher percentage of Hd-stable than in Hd-unstable.
patients (92 of 92 [100%] vs 29 of 44 [66%]; \( P < .05 \)). Furthermore, when compared with Hd-stable patients, the Hd-unstable patients had a significantly higher intraoperative need for the AOB (18 of 44 [41%] vs 5 of 92 [5%]; \( P < .05 \)), higher mean estimated blood loss (744 vs 363 mL; \( P < .01 \)), a higher incidence of developing ACS (29% vs 4%; \( P < .05 \)), and a nonsignificant trend toward a higher incidence of conversion to OSR (3.2% vs 6.8%; Table II). Of the 15 patients without a preoperative CTA, one patient was converted to OSR, three patients with normal renal function underwent unilateral renal artery coverage, and one patient with chronic renal insufficiency underwent bilateral renal artery coverage. The patient who required conversion to OSR died. All unilateral renal artery coverage patients survived without the need for dialysis, and the bilateral renal artery coverage patient survived and currently requires dialysis.

Table II also indicates there were no significant differences between the Hd-stable and Hd-unstable groups in the incidence of nonfatal complications, including myocardial infarction, ischemic colitis, bleeding, wound infection, pulmonary, renal insufficiency, or multisystem organ failure (43% vs 38%), and the need for secondary interventions, including proximal or distal stent graft extensions, use of Palmaz stents at the proximal aortic neck for treatment of type I endoleaks, translumbar embolization for type II endoleaks, or stent graft explant (23% vs 25%) over a mean follow-up of 29 months. In all r-AAA patients, the overall incidence of ACS was 13% (17 of 136), and the overall mortality rate was 24% (32 of 136). Although the overall incidence of ACS after r-EVAR was only 13%, the incidence of ACS was significantly higher in the Hd-unstable patients than in the Hd-stable patients (13 [29%] vs 4 [4%]; \( P < .01 \)). Similarly, although the overall 30-day mortality of r-EVAR was 24%, this incidence was significantly higher in Hd-unstable patients than in Hd-stable patients (15 [33%] vs 17 [18%]; \( P < .05 \); Table III). Univariate analysis indicated ACS to have a significant impact on mortality in that the incidence of death in all r-EVAR with ACS was significantly higher compared with all r-EVAR without ACS (10 of 17 [59%] vs 22 of 119 [18%]; \( P < .01 \)).

**DISCUSSION**

During the past decade, the proportion of r-AAA patients being treated by EVAR is steadily increasing, and there is ample evidence of safety and efficacy of these procedures in academic tertiary medical centers as well as in community hospitals.5-11 In 2002, we established a standardized r-EVAR-first approach for all patients presenting with r-As,12 and this enabled us to evaluate and compare outcomes of Hd-stable and Hd-unstable patients undergoing r-EVAR. Our findings of 136 r-EVAR patients
Sadat et al. in their meta-analysis of 23 published studies indicated that one-third of patients with r-AAA are Hd-unstable at presentation, and these patients have several significant differences compared with the Hd-stable group, in that only two-thirds had a preoperative CT scan before r-EVAR, they require AOB more frequently, have a higher incidence of developing ACS, and have a higher 30-day mortality. Furthermore, ACS was a significant predictor of death: the mortality rate in all r-EVAR with ACS was 59% compared with 11% in all r-EVAR without ACS.

Today, most well-established centers performing emergent aortic procedures have developed strategies that facilitate a seamless transition of the patient from the emergency department to the OR for r-EVAR. Although the standardization of any approach will vary from one institution to another, the fundamentals are simple: success depends on the early diagnosis of r-AAA, the ability to have an expeditious CT scan to evaluate the aortoiliac morphology, and quick transition of the patient from the emergency department to the OR, which is equipped to perform EVAR as well as OR under these emergent circumstances.4,7

Table III. Abdominal compartment syndrome (ACS) and mortality difference in hemodynamically (Hd) stable vs unstable patients

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hd-stable, No. (%)</th>
<th>Hd-unstable, No. (%)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>91 (67.0)</td>
<td>45 (33.0)</td>
<td></td>
</tr>
<tr>
<td>ACS</td>
<td>4 (4.0)</td>
<td>13 (29.0)</td>
<td>.01</td>
</tr>
<tr>
<td>30-day mortality</td>
<td>17 (18.0)</td>
<td>15 (33.0)</td>
<td>.05</td>
</tr>
</tbody>
</table>

Depending on one’s comfort level and the logistics, EVAR for rupture can be performed under local anesthesia via percutaneous approach to general anesthesia and femoral artery cutdown. The potential benefits of local anesthesia and a percutaneous approach are that it might avoid the loss of sympathetic tone in the compromised r-AAA patients. Although earlier in our experience we routinely performed femoral artery cutdown for all r-AAA patients, similar to others, we have evolved to a percutaneous approach for select patients, particularly those who are Hd-unstable. In Hd-stable patients, particularly in the hands of experienced operators, these percutaneous procedures are quite feasible, and this approach needs to be individualized on the basis of the patient’s access suitability and Hd status. In our experience, percutaneous techniques were used in 43.2% (19 of 44) of Hd-unstable patients during r-EVAR, and there were no significant differences on outcomes among these groups.

Overall, 17% (23 of 136) of all r-EVAR patients required the AOB. The need for AOB was significantly higher in Hd-unstable patients than in Hd-stable patients (41% vs 5%; P < .05), and 65% (15 of 23) of patients requiring the AOB developed ACS. Univariate analysis indicated the need for AOB during r-EVAR was an independent significant risk factor for developing ACS. The appropriate use of AOB is Hd-unstable patients is vital to the success of EVAR in these emergent circumstances. Our preferred method for placing AOBs is to use the femoral approach, and we 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 AOB are often hypotensive and percutaneous brachial access in these patients can be difficult and more time-consuming than femoral cutdown; and
3. The currently available AOBs 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 stroke.

If inflation of the AOB is required to maintain a viable blood pressure, then the remainder of the EVAR should be

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conducted expeditiously to limit the time of aortic occlusion, and further limit the development of complications of ongoing bleeding such as ACS and multisystem organ failure.\(^1\)\(^7\) During the procedure, just before deployment of the stent graft main body, the AOB should be deflated from the suprarenal level and withdrawn. The stent graft main body is subsequently deployed. This will avoid trapping the compliant AOB between the aortic neck and the stent graft. This temporary deflation of the AOB rarely results in Hd collapse and usually is of little consequence. In Hd-unstable patients, the occlusion balloon can be redirected into the aortic neck from the side ipsilateral to the stent graft main body and reinflated at the infrarenal aortic neck within the stent graft main body. This allows for aortic occlusion and does not interfere with the remainder of the endovascular procedure.

Implementation of a standardized protocol for emergent r-EVAR has been demonstrated to improve outcomes and allow for emergent treatment of Hd-unstable patients in our experience, as well as others. Moore et al\(^1\)\(^8\) demonstrated evidence of a significant reduction in mortality (17.9% vs 30%; \(P < .05\)) after introduction on an emergency endovascular therapy protocol for r-AAA. A significant percentage of r-AAA patients present with Hd instability, and without a standardized protocol, these patients are often not considered suitable for EVAR and undergo OSR.\(^1\)\(^9\) It is these Hd-unstable patients who have the highest mortality of OSR and might be the ones to experience the greatest benefit of EVAR, and further studies on Hd-unstable r-AAA patients are needed.\(^5\)\(^9\) Lastly, health care cost implications play a major role in evolution of treatments and technology, and a recent report by Hayes et al\(^2\)\(^1\) in the cost-effectiveness analysis of EVAR vs OSR of r-AAAs, based on worldwide experience, indicates significant cost reduction and improvements in quality-adjusted life-years in patients who undergo EVAR.

Our study has some inherent weaknesses. It is a nonrandomized study, and the Hd stability status was predetermined on the basis of sustained SBP of $< 80$ mm Hg for $> 10$ minutes before r-EVAR. Although we have defined preoperative Hd instability, the transient times from patient presenting to outside institutions vs our medical center where r-EVAR was performed are lacking, and there is a selection bias in the survivors of r-AAAs who did undergo EVAR. We were not able to analyze anatomic inclusion and exclusion criteria for particular stent grafts to better understand the implications of favorable vs unfavorable aortoiliac morphology during emergent r-EVAR. Lastly, we could not account for the surgeon’s selection bias in treating the Hd-stable as well as Hd-unstable patient via EVAR; surely, many Hd-unstable patients during the course of this study with favorable and unfavorable aortoiliac morphology for EVAR underwent OSR who were not included in this analysis.

**CONCLUSIONS**

The findings of this study suggest that r-EVAR is feasible and relatively safe, regardless of the patient’s Hd status before repair. However, Hd-stable patients do have a significant early survival advantage. Our findings also suggest that the patient’s Hd status does not affect nonfatal complications and secondary interventions after EVAR. An evaluation of the outcomes of Hd-unstable r-AAA patients who undergo r-EVAR vs OSR was beyond the scope of this analysis; historically, it is well reported that emergent OSR in all-comers is associated with mortality rates of 40% to 70%. Even the most contemporary data would suggest that the lowest r-OSR mortality rates are $\sim 35%$.\(^2\)\(^0\) It would be reasonable to speculate that Hd-unstable patients who undergo emergent OSR would tend to have a higher mortality, substantially higher than the 33% mortality of r-EVAR. Therefore r-EVAR could be considered the first-line therapy in all r-AAA patients, regardless of their Hd status. Although future randomized studies\(^2\)\(^2\)\(^,\)\(^2\)\(^3\) will further enhance our understanding of how patients’ Hd status might impact outcomes, this nonrandomized study is the first r-EVAR analysis based on patient Hd status, and the outcomes identify several important variables that negatively affect survival after r-EVAR in Hd-unstable patients. The need for AOB and development of ACS are factors that negatively affect survival in an Hd-unstable patient. We hope that improvements in AAA awareness, diagnosis, and treatments will continue to evolve and improve our abilities to diagnose rupture early, and implement strategies to diagnose and prevent ACS.

**AUTHOR CONTRIBUTIONS**

Conception and design: MM, JB
Analysis and interpretation: MM, PP
Data collection: MM, RD
Writing the article: MM, PP
Critical revision of the article: MM, AL
Final approval of the article: MM
Statistical analysis: MM, JT
 Obtained funding: MM, KO
Overall responsibility: MM, AL

**REFERENCES**


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