Hypothesis: Percutaneous endovascular repair of ruptured abdominal aortic aneurysms (RAAAs) has better outcomes than traditional open surgical repair.

Design: Single-center retrospective review.

Setting: University hospital tertiary referral center.

Patients: Thirty-seven RAAAs treated using endovascular repair (n=15) or open surgery (n=22).

Interventions: From January 1, 2000, through December 31, 2005, 15 RAAAs were treated with endovascular stent graft exclusion using commercially available systems. Twenty-two other patients undergoing standard open surgical repair during the same interval comprised a control group for comparison.

Main Outcome Measures: Early outcomes of percutaneous endovascular repair of RAAAs.

Results: Among the endovascular group, the mean±SD age was 73±9.8 years, 86.6% were men (n=13), and 20.0% had a preoperative systolic blood pressure of 80 mm Hg or lower (n=3). An entirely percutaneous procedure was performed in the final 11 patients using arterial closure systems. Technical success of attempted endovascular exclusion was 100.0%. The mean±SD procedure time (107±30 minutes), transfusion requirements (6.6±4.7 U), and length of stay (3.0±6.8 days) were statistically significantly reduced compared with open surgery. The 30-day mortality was 6.7% (1 of 15) compared with an open surgery 30-day mortality of 13.6% (3 of 22). No late complications (pseudaneurysm, infection, lymphocele, or neuropathy) occurred after a completely percutaneous technique during a mean follow-up of 12 months.

Conclusion: Percutaneous endovascular repair of RAAAs is a more expedient and less morbid alternative than open surgical repair.

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Despite improvements in emergent care, the mortality rate of ruptured abdominal aortic aneurysms (RAAAs) remains too high. Since the initial report by Parodi et al1 more than a decade ago, endoluminal exclusion of abdominal aortic aneurysms (AAAs) has revolutionized contemporary treatment options for elective cases. Less frequently cited is a study2 from the Nottingham group demonstrating successful endovascular repair of an RAAA. Subsequent case series3-14 have been published touting the potential advantages of endovascular repair for ruptures as an alternative first-line approach. Perceived benefits focus on the avoidance of a laparotomy, which can be troublesome and may delay quick aortic control in the event of free rupture or a large retroperitoneal hematoma. Recognized risks with open repair include hypothermia, substantial insensible fluid loss, and iatrogenic injury to venous structures, ureter, or bowel.15,16

Since its original description, endovascular repair of AAAs has been conducted mainly through open bilateral femoral artery exposure, allowing for safe introduction of stent graft delivery systems under direct vision. A completely percutaneous modification of this technique using a suture-mediated arterial closure system has been previously reported.17 Advantages of an entirely percutaneous procedure are reduced procedure times, shorter hospital length of stay, earlier ambulation, and fewer wound complications (ie, infection, lymphatic leak, and neuropathy). In cases of RAAAs, an added benefit is the ability to expeditiously access the femoral artery and to place an aortic occlusion balloon to circumvent hemodynamic collapse before the ini-

See Invited Critique at end of article
tiation of general anesthesia. This study reviews outcomes after attempting this approach compared with those of a contemporary group of patients treated with traditional open surgical repair.

METHODS

PATIENTS

From January 1, 2000, through December 31, 2005, 37 patients with RAAAs were treated at Northwestern Memorial Hospital. Among this group, 22 underwent open repair and 15 were treated using an aortic stent graft. Only patients with documented contained or free rupture were included in the analysis; solely symptomatic patients were excluded in this retrospective review.

OPERATIVE PROCEDURE

All procedures were performed in a fully functional operating room angiosuite by board-certified vascular surgeons (M.D.M., J.S.M., and M.K.E.) who had extensive endovascular experience. Patients were under general anesthesia. The mean ± SD time elapsed from computed tomographic (CT) scan to the beginning of the operation for all patients was 76.3 ± 40 minutes. Selection of open vs endovascular repair was based on CT images regardless of the presence or absence of active extravasation. Open surgical repair was conducted in standard fashion through a midline laparotomy with selective supraceliac control and selective use of systemic heparin sodium. The proximal anastomosis was in the infrarenal location, and the distal anastomosis was to the aortic bifurcation, iliac artery, or femoral artery.

Anatomical requirements necessary to attempt endovascular repair included the following CT measurements: (1) proximal neck length of 10 mm or longer, (2) proximal neck diameter of 26 mm or narrower, (3) external iliac artery diameter of 7 mm or wider, and (4) lack of excessive calcification or tortuosity of the iliac vessels. Endovascular repair was performed as previously described using the preclose technique.17 Briefly, femoral access was achieved under local anesthesia using an 18-gauge needle and a J-wire, which was secured with an 8F sheath. Access in the common femoral artery was confirmed using fluoroscopic imaging. If needed, an aortic occlusion was used. After the introduction of general anesthesia and achievement of hemodynamic stability, access to the contralateral femoral artery was also secured. Next, a 10F suture-mediated arterial closure device (Prostar; Abbott Vascular Devices, Redwood City, California) was introduced and deployed at each femoral puncture site. The sutures were retrieved, and stent graft delivery sheaths were placed. Sheath sizes ranged from 18F to 12F. Stent graft systems (AneuRx [Medtronic Vascular, Santa Rosa, California] or Excluder [W. L. Gore & Associates, Inc, Tempe, Arizona]) were used. Complete exclusion of the ruptured aneurysm was obtained in a similar fashion to standard elective endovascular repair. At the conclusion of the procedure, the sheaths were removed, and hemostasis of the arteriotomy was obtained using the deployed sutures. Minimal or no systemic heparin treatment was used during these procedures.

STATISTICAL ANALYSIS

Measured variables included patient demographics, aneurysm size, preoperative hemoglobin level, operative time, hospital length of stay, and 30-day mortality. Data are expressed as mean ± SD. Unpaired t test (2-tailed) was used for continuous variables and Fisher exact test for categorical variables, with P < .05 considered statistically significant.

RESULTS

PATIENT CHARACTERISTICS

The clinical patient characteristics are given in Table 1. The mean age ± SD of the total cohort was 73.0 ± 9.6 years, with most patients being male. Roughly one-third of the total cohort had a systolic blood pressure of 80 mm Hg or lower at the initial examination, and all cases were ruptures. Permissive hypotension to maintain a systolic blood pressure of higher than 80 mm Hg was used in all cases. In comparing the 2 groups, age, sex, aneurysm size, systolic blood pressure, and hemoglobin levels were essentially similar on admission.

PERIOPERATIVE DATA

As summarized in Table 2, an appreciable difference in procedure times, transfusion requirements, and length of stay were evident when comparing open vs endovascular repair. All of these variables achieved statistical significance at P < .05. The 30-day mortality results also trended in favor of endovascular repair (P = .61).

Among the endovascular group, an aortic occlusion balloon was never required. The first 4 cases were performed via a traditional bilateral femoral artery cutdown approach using the AneuRx endograft system. In 1 case, abdominal compartment syndrome necessitated a decompressive laparotomy, and uncorrectable coagulopathy resulted in this patient’s subsequent death. The

<table>
<thead>
<tr>
<th>Repair Method</th>
<th>No. of Patients</th>
<th>Age, y</th>
<th>Male Sex, No. (%)</th>
<th>Aneurysm Size, cm</th>
<th>Neck, mm</th>
<th>Preoperative Blood Pressure ≤ 80 mm Hg, %</th>
<th>Hemoglobin Level, g/dL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>22</td>
<td>72.0±9.7 (50-89)</td>
<td>19 (86.4)</td>
<td>7.6±2.0 (5.5-13)</td>
<td>6.4±2.9 (1-10)</td>
<td>28.5±6.1 (23-40)</td>
<td>33.0</td>
</tr>
<tr>
<td>Endovascular</td>
<td>15</td>
<td>73.0±9.8 (53-88)</td>
<td>13 (86.6)</td>
<td>8.0±2.2 (4.5-12)</td>
<td>23.0±11.1 (15-50)</td>
<td>22.4±1.9 (19-25)</td>
<td>20.0</td>
</tr>
<tr>
<td>Total</td>
<td>37</td>
<td>73.0±9.6 (32-86.4)</td>
<td>32 (86.4)</td>
<td>7.8±2.1</td>
<td>18.1±12.3</td>
<td>24.1±4.0</td>
<td>27.7</td>
</tr>
</tbody>
</table>

SI factor conversion: To convert hemoglobin to grams per liter, multiply by 10.0.

Data are given as mean ± SD (range) unless otherwise indicated.

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remaining 11 operations were performed through a completely percutaneous approach using the Excluder endoprosthesis. Two of the last 11 cases were ruptures resulting from delayed failures of a prior elective stent graft (AneuRx). One was a proximal type-1 endoleak due to migration of the graft, and the other was a type-3 endoleak from a fabric tear. The proximal type-1 endoleak was treated using a proximal aortic extension cuff, and the type-3 endoleak was relined. In these 11 cases, percutaneous closure of the arteriotomy failed on 1 side in 1 patient, requiring intraoperative open repair of the femoral artery. Otherwise, there have been no early or late complications (pseudoaneurysm, infection, lymphocele, or neuropathy) attributed to the closure systems. During a mean follow-up of 12 months (range, 3-24 months), 2 type-2 endoleaks have been demonstrated without associated aneurysmal sac enlargement; these were managed with surveillance alone. No instance of proximal or distal type-1 endoleaks, migration, or infection has been identified in follow-up.

**COMMENT**

Although many individuals with RAAAs arrive at the hospital alive, those who do require prompt recognition and treatment of their problem to survive. Time, experience, personnel, and blood product availability are the basic institutional components needed to improve the outcomes of traditional open surgical repair. The era of endovascular interventions has added another level of institutional commitment. Although case series have demonstrated the feasibility of successful emergent endovascular repair of RAAAs, the following 2 key items are mandatory: (1) rapid imaging and (2) on-the-shelf endovascular supplies. This becomes evident when reviewing the outcomes of this study.

Preprocedural CT imaging is essential before embarking on an attempt at elective or emergency repair of aneurysms. Even a noncontrast CT scan can provide the crucial elements necessary to make the decision to proceed with endovascular repair. These elements include an assessment of aortic neck diameter and morphologic structure, as well as access vessel anatomy. Future fluoroscopic imaging units may obviate this need by providing intraoperative CT imaging at the time of the diagnostic angiogram. Nevertheless, intraoperative fluoroscopic imaging with a portable C-arm or preferably a fixed imaging unit in an operating room is an absolute requirement. Desirable adjuncts include a dedicated radiology technician, a well-trained endovascular personnel, and a power injector. Having such a readily available operating room angiosuite allows for expedient access and control of the aorta.

Control of the aorta and prevention or correction of hemodynamic collapse in cases of rupture can be ob-

### Table 2. Perioperative Outcomes

<table>
<thead>
<tr>
<th>Repair Method</th>
<th>Procedure Time, min</th>
<th>Transfusion Requirements, U</th>
<th>Intensive Care Unit</th>
<th>Total</th>
<th>30-Day Mortality, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>205±31 (175-240)</td>
<td>11.0±5.3 (4-22)</td>
<td>4±3.8 (2-16)</td>
<td>11.5±6.9 (5-28)</td>
<td>13.6 (3/22)</td>
</tr>
<tr>
<td>Endovascular</td>
<td>107±30 (67-160)</td>
<td>6.6±4.7 (2-16)</td>
<td>1±1.1 (1-5)</td>
<td>3.0±6.8 (2-23)</td>
<td>6.7 (1/15)</td>
</tr>
<tr>
<td>Total</td>
<td>141±56</td>
<td>9.0±5.5</td>
<td>2±3.4</td>
<td>8.9±7.2</td>
<td>10.8 (4/37)</td>
</tr>
</tbody>
</table>

* Data are given as mean±SD (range) unless otherwise indicated.

### Table 3. 30-Day Morbidity

<table>
<thead>
<tr>
<th>System</th>
<th>Specific Complication</th>
<th>No. of Patients With Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Endovascular Repair</td>
<td>Open Repair</td>
</tr>
<tr>
<td>Renal</td>
<td>Renal failure requiring dialysis</td>
<td>0</td>
</tr>
<tr>
<td>Cardiac</td>
<td>Myocardial infarction</td>
<td>0</td>
</tr>
<tr>
<td>Pulmonary</td>
<td>Pneumonia</td>
<td>0</td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>Ischemic colitis</td>
<td>0</td>
</tr>
<tr>
<td>Wound</td>
<td>Dehiscence</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Abdominal compartment syndrome</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 2. Perioperative Outcomes**

**Table 3. 30-Day Morbidity**
tained by brachial or femoral artery access and inflation of an occlusion balloon in the suprarenal aorta. 4, 5 Some have advocated permissive hypotension as long as the patient is conscious, as well as avoidance of excessive preoperative resuscitation. 6, 7 In this study, we favored femoral access as a means for placing an aortic occlusion balloon for the following reasons: (1) It provides the easiest and largest access to the aorta. (2) Access can be achieved under local anesthesia before initiation of general anesthesia. (3) The site may be incorporated as part of the percutaneous stent graft repair. Others have reported on the success of a brachial approach 8, 9; however, this adds another access site and often requires open surgical repair of the arteriotomy after removal of a delivery sheath capable of accommodating the larger profile of most occlusion balloons. Fortunately, aortic occlusion was not required in any of the cases in this study.

The original descriptions of RAAA endovascular repair were of procedures that were performed outside the United States, where regulatory restrictions are less stringent, or that use custom-made devices. 10 From a practical viewpoint, the custom-made approach lacks widespread application. The development of commercially available devices has provided all surgeons access to materials usable in an emergent setting. Stacking of aortic stent grafts and other endovascular supplies (ie, occlusion balloons and closure devices) is not only a matter of convenience but also a necessity for institutions that treat emergent cases such as RAAAs. During the past several years, all elective endovascular AAA repairs in our practice have been performed entirely percutaneously using suture-mediated closure systems. As a result, these items are always on hand. Success using this technique prompted us to begin treating all RAAAs in a similar manner. As we have demonstrated, this approach led to a reduction in operative time, transfusion requirements, length of stay, morbidity, and mortality compared with a contemporary group of patients undergoing traditional open repair.

CONCLUSIONS

Open surgical repair of RAAAs continues to be associated with exceedingly high morbidity and mortality rates. Endovascular repair of RAAAs is a feasible option. The addition of a readily available operating room angioplasty, a stock supply of stent graft systems, and attempts at a completely percutaneous technique improve early outcomes compared with open repair.

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REFERENCES