Stent-graft repair of traumatic thoracic aortic disruptions

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Objective: Blunt traumatic thoracic aortic disruption results in pre-hospital death in 80% to 90% of patients. Because of the significant surgical morbidity and mortality associated with open operative repair, endovascular stent-graft repair has been investigated. The objective of this study was to evaluate the efficacy of thoracic aortic disruptions treated with commercially available proximal aortic extension cuffs.

Methods: Nine patients with multiple system trauma (age range, 16-42 years) were seen after motor vehicle accidents between January 1, 2003, and April 1, 2004. Chest x-ray findings warranted thoracic computed tomography scans, which revealed disruptions of the thoracic aorta. Aortograms delineated the extent of the aortic injuries and identified a “landing zone” (neck length range, 1.5-2.0 cm) distal to the subclavian artery but proximal to the tear. The repairs were performed with AneuRx (n = 8) and Excluder (n = 1) proximal aortic extension cuffs. A left femoral artery approach was used in 6 patients, a suprainguinal retroperitoneal approach with an iliac conduit in 2 patients, and direct tunnel in 1 patient. An Amplatz super-stiff wire was placed in the right axillary artery to enable easy tracking of the endografts, and left brachial artery access was used for arch arteriography.

Results: In each patient the stent-graft cuff was deployed adjacent to the left subclavian artery, with successful exclusion of traumatic disruptions verified at intraoperative arteriography and on computed tomographic scans obtained within 48 hours of initial repair. One patient required a second cuff for exclusion of a type I endoleak at the distal attachment site 1 month after the initial endograft repair. There were no procedure-related deaths; 1 patient, however, died of other injuries.

Conclusions: Stent-graft repair of traumatic thoracic aortic disruptions is technically feasible. Placement of a stiff wire in the right axillary artery and percutaneous left brachial artery access for arteriography are useful adjuncts during endograft deployment. Endovascular stent grafts may enable definitive repair or serve as a bridge until the patient is stable enough to undergo an operation, if necessary. This technique warrants further investigation. (J Vasc Surg 2004;40:1095-1100.)

Traumatic rupture of the thoracic aorta is often immediately fatal, and patients who survive frequently have multiple system injuries, including pulmonary contusions, cranial injuries, multiple fractures, and solid organ injuries.1,2 Operative repair of a thoracic aortic injury in the setting of these other injuries is associated with significant morbidity and mortality, and studies3,4 have reported mortality rates approaching 18% to 28% and paraplegia rates of 2.3% to14% among survivors. Because of the high risk of immediate surgery, some have advocated delaying intervention with antihypertensive therapy until the patient is more stable.5,6 Although this has enabled surgery after recovery from the acute trauma, complications remain high.

Since initial reports of stent-graft repair of abdominal and thoracic aneurysm disease, surgeons have considered this minimally invasive approach for treatment of traumatic thoracic aortic disruptions.7 Operative complications associated with traumatic thoracic aortic disruptions are devastating, and use of a minimally invasive approach seems ideally suited for treatment of this injury. Anecdotal reports have been published with small series of patients with traumatic thoracic aortic disruptions treated with an endovascular approach.8-22 The objective of this study is to report our initial clinical experience with endoluminal repair of traumatic thoracic aortic disruptions with commercially available devices.

METHODS

Between January 1, 2003, and April 1, 2004, a retrospective review of endoluminal repair of traumatic thoracic aortic disruptions from 3 medical centers in Georgia was performed. All patients had been in motor vehicle accidents and sustained severe blunt trauma (Table). All patients underwent chest x-ray studies. Any suspect x-ray findings for traumatic thoracic aortic disruption mandated computed tomography (CT). If a traumatic thoracic aortic disruption was identified, arch arteriography was performed to confirm the CT findings and to further delineate vascular anatomy. Measurements of the proximal and distal thoracic aortic diameter and the neck length between the left subclavian artery and the tear were obtained from the CT scan.

Repairs were performed in the operating room with the patient under general anesthesia, with a standby cardiovascular surgery team available. Percutaneous left brachial artery access was used for aortography. A 5F sheath was placed in the brachial artery, and a diagnostic catheter was passed under fluoroscopic guidance to the origin of the left
subclavian artery. The left femoral artery was exposed in standard fashion for stent-graft access, and an 8F sheath was placed. With use of a selective catheter, access to the right axillary artery was obtained. An Amplatz (Meditech/Boston Scientific) super-stiff wire was placed in the ascending arch or via this catheter into the right axillary artery for endograft placement (Figs 1 and 2). When necessary, a suprainguinal incision was made for proximal access to the larger common iliac artery. Dacron conduits for access were sutured to the iliac artery in 2 patients. In 1 patient a tunnel was created between the iliac artery and left femoral artery in the same manner as for an aortobifemoral bypass. The stent-graft device was tunneled under the inguinal ligament for easy direct access to the common iliac artery. This approach obviated the need for a conduit and provided a flatter path for access. The endografts were oversized approximately 10% to 20%, and neck lengths of 1.5 to 2.0 cm were considered adequate for stent-graft placement. The stent grafts were deployed in the same fashion as with abdominal aneurysms. CT scans were obtained within 48 hours after implantation, and follow-up CT scans were obtained per typical endograft surveillance.

RESULTS

Nine of 10 patients with traumatic thoracic aortic disruptions (age range, 15-37 years) underwent endoluminal stent-graft repair between January 1, 2003, and April 1, 2004. One patient in this series was excluded because of neck diameter too large to accommodate available devices. All patients were hemodynamically stable at the time of repair. In 8 patients AneuRx (Medtronic/AVE) aortic extension cuffs were used, and in 1 patient Excluder (W. L.

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Sex</th>
<th>Associated injuries</th>
<th>Length from subclavian artery to tear (cm)</th>
<th>Device access vessel</th>
<th>Device</th>
<th>Result</th>
<th>Complication</th>
</tr>
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<tbody>
<tr>
<td>32</td>
<td>M</td>
<td>Closed head injury, pulmonary contusion, splenic laceration (splenectomy), hemothorax, pneumothorax</td>
<td>2</td>
<td>Left common iliac artery conduit</td>
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<td>Exclusion</td>
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<tr>
<td>35</td>
<td>F</td>
<td>Liver laceration, pelvic fracture, pulmonary contusion</td>
<td>2</td>
<td>Left femoral artery</td>
<td>AneuRx 22-mm cuffs × 2 AneuRx 24-mm cuff</td>
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<td>None</td>
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<tr>
<td>16</td>
<td>F</td>
<td>Facial fractures, mainstem bronchus injury</td>
<td>1.5</td>
<td>Left femoral artery</td>
<td>Gore 23.5-mm cuffs × 2</td>
<td>Exclusion</td>
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<tr>
<td>21</td>
<td>F</td>
<td>Ankle fracture, facial laceration</td>
<td>4.5</td>
<td>Left common iliac artery conduit</td>
<td>AneuRx 26-mm cuffs × 2</td>
<td>Exclusion</td>
<td>Iliac artery injury</td>
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<tr>
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<td>Splenic laceration (splenectomy), pelvic fracture, femur fracture, closed head injury</td>
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<td>Left femoral artery</td>
<td>AneuRx 26-mm cuff</td>
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<td>15</td>
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<td>Intraabdominal hemorrhage, paralysis, closed head injury, spinal fracture</td>
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<td>AneuRx 28-mm and 26-mm cuffs</td>
<td>Exclusion</td>
<td>Death</td>
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<td>17</td>
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<td>1.5</td>
<td>Right femoral artery</td>
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<td>Delayed distal endoleak, repaired with additional 20-mm cuff</td>
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<td>2.5</td>
<td>Left femoral artery</td>
<td>AneuRx 28-mm cuffs × 2</td>
<td>Exclusion</td>
<td>Femoral artery injury</td>
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<tr>
<td>21</td>
<td>M</td>
<td>Hemothorax, multiple fractures</td>
<td>2</td>
<td>Left common iliac artery</td>
<td>AneuRx 28-mm cuffs × 2</td>
<td>Exclusion</td>
<td>None</td>
</tr>
</tbody>
</table>
Gore & Associates) aortic cuffs were used. Mean stent-graft diameter was 25 mm (range, 20-28 mm). Two stent grafts were used in 7 patients, 3 grafts in 1 patient, and 1 graft in 1 patient. The aortic length from the subclavian artery to the tear (“landing zone”) averaged 2.3 cm (range, 1.5-4.5 cm). Blood loss in all operations was 100 to 200 mL.

Access for deployment varied based on patient body habitus. Left femoral artery access was attempted for placement in all but 1 patient. In 6 patients deployment from the femoral exposure was successful, with 1 patient requiring significant repair of the femoral artery, because of extensive iatrogenic injury. In 1 patient, a woman 5 feet 3 inches tall, passage of the device injured the external iliac artery, and suprainguinal retroperitoneal exposure of the common iliac artery enabled placement of a conduit to the iliac artery that was also used for iliofemoral bypass. In 1 patient the device was not of sufficient length to reach the subclavian artery. The common iliac artery was exposed through a suprainguinal retroperitoneal exposure, and the device was tunneled under the inguinal ligament for direct access to the common iliac artery. Another patient had undergone kidney-pancreas transplantation; consequently, a common iliac approach above the pancreas was chosen, to protect the kidney that was based off the contralateral iliac artery.

After endograft deployment, completion intraoperative aortograms demonstrated patent grafts without endoleaks in all patients (Fig 3). Postoperatively, 1 patient had a distal attachment site type I endoleak, which was detected at CT a month after repair; a second device was deployed uneventfully to seal the endoleak. There were no procedure-related deaths, paraplegia, renal failure, or other complications. One patient who had a massive cerebral injury died. After 1 month, CT scans in the remaining patients showed no endoleaks. Two patients at 1-year follow-up had minimal evidence of aortic injury and no evidence of endoleak. Two patients did not undergo CT at 1 year, because of financial issues. The remaining patients are scheduled for 12-month CT in the coming months.

**Fig 1.** Traumatic thoracic aortic disruption before endovascular repair. Note that a super-stiff wire has been placed in the right axillary artery, and a diagnostic catheter through the left brachial into the arch for aortography.

**Fig 2.** AneuRx stent graft is easily tracked to a juxta-subclavian location with use of the axillary artery, and is deployed without incident.

**Fig 3.** Repaired traumatic thoracic aortic disruption, with no endoleak.
DISCUSSION

Since the initial report by Dake et al\textsuperscript{7} of successful repair of thoracic aneurysms and traumatic thoracic aortic disruptions with endoluminal stent grafts, several case reports and small institutional reviews have reproduced their results.\textsuperscript{8-22} The results have been promising in comparison with large surgical series, which report mortality rates of up to 28\% and associated paraplegia rates of up to 14\%.\textsuperscript{3,4}

The long-term results of open surgical repair of traumatic thoracic aortic disruptions make this procedure the gold standard. The attendant morbidity and mortality of this operation, however, have spurred interest in less invasive and less traumatic methods of repair. Since Parodi et al\textsuperscript{23} first reported the use of an endoluminal stent graft for repair of abdominal aortic aneurysms, use of the endoluminal stent-graft procedure has expanded rapidly. Its use for repair of traumatic thoracic aortic disruptions eliminates the need for extensive surgery with the attendant hazards of anticoagulation, single-lung ventilation, aortic cross-clamping, and thoracotomy.

The primary difficulties encountered with commercially available endograft devices have been related to delivery system length and size. The AneuRx, Zenith (Cook Inc), and Excluder aortic cuffs are designed for delivery to the infrarenal aorta. This allows for only 55 cm of length in the AneuRx and Zenith delivery devices and 61 cm of length in the Excluder delivery device to reach the left subclavian artery. These device lengths are usually sufficient for delivery to a juxta-subclavian artery landing zone; however, a retroperitoneal conduit and insertion through the iliac artery may be needed. In our experience, patients less than 6 feet tall can be treated with the commercially available devices through a femoral approach. In taller patients, it may be necessary to use an iliac conduit or an easier tunneled approach under the inguinal ligament for direct iliac access. For more proximal landing, that is, in the junction between the left common carotid artery and the left subclavian artery, these devices would require higher exposure in the common iliac artery. With the coming release of endoluminal devices specifically designed for thoracic aortic endografting, this problem will be obviated.

Another difficulty encountered with currently available devices is the size of the devices (18F-22F) relative to the access artery. These devices are fairly large, and in young patients the femoral artery may not be large enough to accommodate them. Therefore we approach the iliac artery through a suprainguinal approach, and create an “inguinal tunnel” for device access. Although improvements in stent-graft design may resolve the size problem, the current thoracic devices in trial use are as large or larger than the commercially available abdominal aortic cuff delivery systems.

Most traumatic thoracic transactions occur distal to the left subclavian artery. The distance from the subclavian artery landing zone to the tear is variable, with a recent study\textsuperscript{12} citing a mean length of 28.5 mm, which is similar to our mean length of 22.5 mm. However, a review of traumatic thoracic angiograms cited a mean length of 14.9 mm along the greater curve of the aorta, and 5.8 mm along the lesser curve.\textsuperscript{22} Current recommendations for thoracic aneurysm repair require a proximal landing zone of 10 to 20 mm.\textsuperscript{15} These guidelines come from experience with the Talent and Excluder TAG grafts. Most of these patients underwent thoracic aneurysm repair, and an aneurysmal thoracic aorta may not correlate with the necessary landing zone for traumatic thoracic aortic disruption repair, especially in younger patients who have nondiseased aortas that may enable easier seal, better fixation, and decreased chance for migration. Furthermore, the nature of the injury may result in a different healing process around the stent graft that would not necessitate 20 mm for fixation and seal. In fact, on the 2 CT scans obtained at 1 year there was minimal evidence of the initial injury and no migration. If there is not an adequate landing zone, the subclavian artery can be covered and a carotid-subclavian bypass performed if upper extremity ischemia develops. This approach has been advocated, and can be used in a short neck landing zone.\textsuperscript{17} As experience with traumatic thoracic aortic disruption increases and devices for the arch become available, the necessary length and anatomic location of the landing zone will be more adequately delineated.

Two technical maneuvers simplified endograft deployment. The first was placement of an Amplatz super-stiff wire into the right axillary artery from the access artery. This allowed excellent tracking of the device to the level of the left subclavian artery. The second maneuver was placement of a percutaneous left brachial artery sheath and diagnostic catheter, which allowed continuous aortography during and after deployment of the device. It also served as a marker of the left subclavian artery.

Traumatic thoracic aortic disruption is often associated with multiple system injuries. Many patients are unstable, making care difficult. Typically, hemodynamic instability is related to other processes, such as intraabdominal injuries or orthopedic injuries, but not the traumatic thoracic aortic disruption. Despite this, the validity of placing an endograft in an unstable patient is questioned. Certainly any device used in an investigational manner will lead to extra caution; yet it may be that stent grafts are the best treatment in patients who can be managed with permissive hypotension. If, however, the patient is truly unstable as a result of the disruption, it is hard to justify anything short of immediate surgical control of the thoracic aorta.

Patients with trauma are typically difficult to follow up after discharge from the hospital. This issue presents an ethical dilemma in repair of traumatic thoracic aortic disruptions with stent grafts. Should treatment be withheld because of the possibility of losing the patient to follow-up? Postoperative imaging should include CT scans at 1 and 12 months for the first year, and then yearly. Strategies for tracking these patients will need to be developed, similar to those used for patients with abdominal aortic stent grafts, that also takes into consideration the instability of this population, and their often poor insurance status and inability to pay for CT scans. The importance of postopera-
tive surveillance cannot be overemphasized, because these devices are not specifically constructed for this indication, the long-term durability of this method of repair is truly unknown, and the effect of an oversized stent graft in a young person’s aorta is yet to be determined.

CONCLUSIONS
Stent-graft repair of traumatic thoracic aortic disruptions is technically feasible. Placement of a stiff wire into the right axillary artery and left brachial access for aortography are useful adjuncts to facilitate deployment. Endovascular stent grafts may enable definitive repair or serve as a bridge until the patient is stable enough to undergo open operative repair, if necessary. This technique warrants further investigation.

REFERENCES

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DISCUSSION
Dr Linda Harris (Buffalo, NY). Endovascular interventions, as we’ve heard earlier today, have certainly improved outcomes in ruptured aneurysms, and are likely to see a similar benefit in patients who have traumatic vascular injuries.

Dr Wellons and colleagues evaluated 9 patients over approximately 1 year who underwent stent-graft repair of traumatic thoracic aortic transections using commercially available aortic extension cuffs. They report success in the 9 patients, but do not really give us a great deal of outcome information or follow-up.

They do give 2 technical suggestions to increase ease of deployment, which include use of the Amplatz super-stiff wire in the right axillary artery and percutaneous placement of a left brachial sheath for a diagnostic marker.

I have several questions for the authors. First of all, during this period how many patients with multisystem trauma were evaluated for thoracic aortic injuries, and how many patients were refused this type of technology and treated in a more conventional fashion, either with open surgery or with delayed repairs?

What are your outcomes? You state transection was repaired with 2 stent grafts in 7 patients, 3 grafts in 1, and 2 grafts in the remaining patients. Did the patients survive? Did any of them require open repair after bridge therapy? You mentioned this as a possible bridge to open repair, but never stated that any of these patients required bridge therapy.

What is your long-term and short-term follow-up on the stability and lack of migration in these patients? Along these lines, one of the problems with trauma patients is that they don’t tend to follow up. And with endovascular repair, one of our concerns has been long-term outcomes. Is there an ethical issue in which these patients should be converted after they have been stabilized to an open repair? These patients are young, or many of them may be young, they may have dilatation of the aorta as they grow older, when we may not follow up with them, and they may come in later with a recurrent rupture because the grafts have migrated.
Last, what site of access would you recommend for graft deployment? You did mention difficulty with graft access link. Do you have any recommendations based on patient size, gender, and artery size, so that we don’t waste time using a femoral artery approach in a patient when it’s not going to be successful. 

Dr Eric Wellons (Atlanta, Ga). During the period of the study there was only 1 patient with a thoracic aortic tear who was not offered this treatment option, because of a short neck. This patient was treated with an immediate open repair. There was only 1 death in the group of patients treated, and this was related to other injuries suffered in the accident. As all repairs were considered satisfactory at the time of operation and latest follow-up, to a year, there has been no need for bridge therapy. The latest follow-up data we have on these patients is 1 year. At this juncture there is no evidence of migration, and the repairs look excellent. The problem regarding maintaining adequate follow-up in trauma patients is a difficult one, and I am afraid I do not have a good solution. Is this an ethical dilemma? Yes. However, the potential benefits of stent-graft repair versus open repair seem to outweigh the follow-up difficulties.

Regarding suggestions for access, we have used CT scan measurements, marker catheters, and simply placing the device on the patient to get an idea of the access point. While this has helped, it has not provided definitive information, and higher access has had to be obtained after femoral cutdowns. Furthermore, the femoral and external iliac size has been an issue that also has required higher access. I don’t think there are any particular guidelines that we can give you, because we do not have enough experience to say which patient is suitable or not.

Dr D. Bhaskar Rao (Wilmington, Del). One question: Is there good literature from trauma and other publications that CT scans are very reliable for sizing or for diagnosis of traumatic transection. And with these patients in ICU, and sometimes they’re unstable, do they really need preoperative angiography?

Second question: What is the timing between the trauma and your intervention? And how do you manage preoperative in terms of hypotension?

Third question: Do you give heparin? Some of these patients may have a cranial injury that may contraindicate heparin. 

Dr Wellons. Your point regarding aortography is very accurate. As you mentioned, much of the planning can be done based on CT scans. In our institution the trauma service typically obtains a CT scan and consults radiology immediately for an aortogram before we become involved.

In all of these cases the patients have been stable or relatively stable. In fact, most patients have been normotensive or hypertensive. This has allowed us to perform the operations in a timely and deliberate fashion, without significant haste or delay.

Regarding heparin, we have been selective with use of heparin. If there are not any intracranial injuries, we’ve used low doses of heparin. Is it necessary or not? The operations go pretty quick once you obtain access, and heparin has not been thought essential.

Dr Manish Mehta (Albany, NY). Your paper truly highlights the adjunctive procedures we can do to solve difficult problems endovascularly.

On a more a technical note, I think the problems that you might have had in deploying stent grafts across the arch, especially high arches, is that there is bending of the AneuRx device, not necessarily because of the arch, but I think it’s the wire. I think they are stiffer wires than the Amplatz. And especially for thoracic procedures, the Lundquist is probably a better choice. We use that routinely. And even in much more difficult arches, we have not found that problem.

Dr Wellons. Certainly the Lundquist wire may be the answer to our initial problems. However, we have had good success with the auxiliary wire, and it should be considered in difficult cases.

Dr Christian D. Schunn (Morgantown, WVA). I have 2 questions: Given equal size, which of the 3 cuff extenders would you prefer? How do you cover your back legally in terms of off-label use of these cuffs?

Dr Wellons. Of the 3 stent-graft cuffs, I believe they all will work well in fixing the tear. In discussions with Dr Milner, the Gore Excluder seems to have the benefit of tip flexibility and additional length (6 cm), which may make it more usable in taller patients. The AneuRx device, though, has worked well, and it would be hard to say which is the best. I do not have experience with the Zenith graft.

Dr Schunn. Have you seen an age group in which the natural size of the aorta is too big to prevent you from using something that’s not designed to be big enough for this?

Dr Wellons. One person had an aorta that was too big for available devices.

I have not talked about the medical-legal issues. We discuss the options with the patient’s family, present the historic data regarding open thoracic repair, and tell them this is an investigational off-label use of an FDA-approved device, with the potential risks and benefits and the need for long-term follow-up. Everybody has been happy, because outcomes have been fantastic. But I don’t know what will happen when we have a poor outcome.

Dr Ronald M. Fairman (Philadelphia, Pa). My interest in this has sort of waxed and waned over the last couple of years. The early results of treating these patients endovascularly had about a 50% mortality, so I think your results are just wonderful in the short term.

Just 2 points. I’d be interested to hear, perhaps, what Bill Flinn has to say about this. But at Penn we have a very big trauma service also, and these patients get flown in all the time, and they frequently have intracranial bleeding and other injuries. Our trauma surgeons believe that if a patient arrives at Penn with a stable transection, then actually the natural history of that, over the first few months, is pretty benign. So if they arrive and they’re stable, and they’re not symptomatic from the transection, their enthusiasm for me treating that early is not very high. And you may want to comment, Bill, about what the people at Maryland do.

The other issue is, my understanding is that virtually all of these lesions tend to occur within a few millimeters of the left subclavian. And therefore we wonder about the stability of your proximal attachment site, certainly to a year or 2. I almost wonder, if you’re going to treat these patients with a thoracic stent graft, whether you have to always do something with the left subclavian in order to get your 20-mm or 30-mm proximal seal.

Dr William R. Flinn (Baltimore, Md). It really sounds like we have just about the same uncertain relationship with the trauma service at Maryland as you do in your situation. But again, our trauma surgeons, the ones who are the most forthright, and that’s certainly a variable, do manage stable patients conservatively. For reasons that perhaps are politically clear but therapeutically unclear to me, they haven’t developed any enthusiasm, or a very, very modest enthusiasm, for going out on the edge on some of these things.

Dr Wellons. Our trauma surgeons are very happy that we’re doing this and the thoracic surgeons are even happier, because of the poor results they’ve had in the past.

The issue with regard to neck fixation and length is an interesting one to me. These are different patients than those with aneurysmal disease, and I am not sure the same rules should apply. Theoretically, the proximal and distal aorta is smaller and relatively healthy. This may mean that a shorter landing zone, say 10 mm, is sufficient to ensure seal. Furthermore, one would expect less migration if landing in a normal distal aorta. Another question is, how will the aortic tear heal around this stent graft? It may be that the healing will be relatively quick, with later complications being more from in-stent stenosis than degeneration of the aorta. Because of these issues, I think it’s reasonable to be more aggressive with these patients, especially a young person with a significant chance of paraplegia.