Endovascular repair of abdominal aortic aneurysm without preoperative arteriography

Mark C. Wyers, MD, Mark F. Fillinger, MD, Marc L. Schermerhorn, MD, Richard J. Powell, MD, Eva M. Rzucidlo, MD, Daniel B. Walsh, MD, Robert M. Zwolak, MD, PhD, and Jack L. Cronenwett, MD, Lebanon, NH

Objective: Clinical trials of endovascular aortic aneurysm repair (EVAR) have required both preoperative aortography and computed tomography (CT). We codeveloped specialized three-dimensional (3-D) reconstruction and computer-aided measurement, planning, and simulation software (3-D CAMPS) based on CT or magnetic resonance imaging, to eliminate the need for preoperative arteriography.

Methods: EVAR with 3-D CAMPS as the sole preoperative imaging method was performed in 196 patients from 1996 to 2001, with six endograft types in three configurations. Physical examination, abdominal radiography, and CT (3D-CAMPS) were performed at 1, 6, and 12 months, then annually.

Results: For a subset of cases in which a comparison could be made, 3-D CAMPS was superior to angiography for prediction of endograft length and iliac access. Hospital mortality was zero, and 30-day mortality was 0.5%. In three patients immediate conversion to open repair (1.5%) was necessary because of previously unknown stent-graft mechanical limits. Incidence of endoleak was 15% at 1 month, 10% at 6 months, 6% at 12 months, and 7% at 24 months, and 92% of endoleaks were type II. Mean follow-up was 18 months. Aneurysm-related mortality was zero. Nineteen secondary procedures (all endovascular) were performed in 16 patients (8%). For all graft types, freedom from secondary procedure was 94% at 1 year and 90% at 2 years, and this was better for endografts ultimately approved by the US Food and Drug Administration (96% at 1 year, 95% at 2 years; P = .02). No known measurement-related complications occurred in the series. Results for secondary intervention and endoleak compare favorably to series with similar endograft types.

Conclusions: EVAR can be performed with 3-D CAMPS as the sole preoperative imaging method to achieve outcomes comparable to the best series published for each endograft type. CT with 3-D CAMPS can effectively eliminate the need for preoperative arteriography and avert associated morbidity, expense, and exposure to contrast agent and radiation. (J Vasc Surg 2003;38:730-8.)
uated marked catheter was required because of the limitations of conventional CT, namely, inability to measure length along the vessel axis and poor evaluation of occlusive disease. To eliminate the need for preoperative arteriography, we helped to develop three-dimensional computer-aided modeling, planning, and simulation software (3-D CAMPS) for evaluation of vascular anatomy. This system should not be confused with conventional CT, CT “angiography” (CTA), or CTA with conventional 3-D reconstruction. The purpose of this study was to evaluate the utility of 3-D CAMPS for preoperative evaluation of patients who might be candidates for EVAR.

METHODS

We reviewed our database of 202 consecutive primary endovascular AAA repairs performed at Dartmouth-Hitchcock Medical Center (Lebanon, NH) and the White River Junction Veterans Administration Medical Center (White River Junction, VT) from June 1996 to December 2001. This period encompassed all patients entered in “learning curve” clinical trials, including the interval when only aortoarterial tube grafts were available. Two hundred two patients had data available for analysis. However, early in our experience, arteriography was used in six patients to aid in graft sizing or assessment of occlusive disease, and data for these patients were excluded from the analysis.

CT imaging protocol. The primary preoperative imaging method used in all patients was spiral CT in conjunction with 3-D reconstruction and 3-D CAMPS software (Preview; Medical Media Systems, West Lebanon, NH). CT protocols for single-array scanners are designed to cover the area of interest, that is, celiac artery to common femoral arteries, with good detail of branch vessels and adequate resolution for high-quality 3D reconstructions. Primary features included contrast medium injection at 3 to 4 mL/s (timed via CT monitoring or timing of a test bolus), with total volume typically 120 mL of iodinated contrast agent; collimation (beam thickness) 3 mm in the visceral aortic segment and 5 to 7 mm in the distal abdominal-pelvis region; and pitch of 1 (ratio of table speed to collimation). The primary alternate protocol included collimation of 5 mm, with pitch of 1.5 to 2, to image the necessary length from celiac artery to femoral arteries. With newer multiple-array scanners the protocol is similar, with an effective collimation of 2.5 mm and pitch of 2. Reformatting in the axial, sagittal, and coronal planes was in 2-mm increments, and reformatting perpendicular to the vessel was in 1-mm increments. Patients with severe renal insufficiency but not receiving dialysis underwent magnetic resonance angiography (MRA) to delineate the anatomy with 3-D reconstruction (five patients), but also underwent unenhanced CT because MRA does not detect or display calcified plaque well. Alternate strategies included gadolinium-enhanced CT or, more recently, acetylestrenol prophylaxis and nonionic contrast agent in patients with moderate renal insufficiency (creatinine concentration, >2.5 <3). Electronic data from CTA or MRA was sent in Dicom format for postprocessing (Medical Media Systems), including multiplanar reformatting encompassing the entire volume of the scan in sagittal, coronal, and axial planes at 2 mm intervals. The cross-sectional image data are used to “segment” or delineate the boundaries of contrast-enhanced lumen, calcified plaque, and thrombus or noncalcified atheroma, which have the same density, as separate objects in a multi-object surface-shaded display 3-D model. The model retains all 3-D information, so the integrity of measurements in 3-D space can be maintained along with interactive display of measurements and CT data. The centerline of the vessel is recreated in 3-D space and reformatted in planes orthogonal (perpendicular) to this centerline along the entire 3-D model, in 1-mm increments. All of this information is loaded onto a CD-ROM disk along with software that enables display and measurement on a personal computer for 3-D CAMPS.

3-D CAMPS. 3-D CAMPS consists of several key components, all of which were used:

1. Source images from a high-quality axial imaging source that includes imaging of the vessel lumen (ie, CTA or MRA)
2. Multiplanar reformatted CTA or MRA data at small intervals in multiple planes
3. 3-D multi-object surface-shaded display of the vascular anatomy, with individual display of contrast-enhanced lumen, calcified plaque, and thrombus or atheroma
4. CT or MR reformatted data in planes orthogonal to the vessel in 3-D space
5. Length measurements along the centerline of the vessel lumen
6. Length measurements along a user-defined 3-D path
7. 3-D simulation of the endograft within the aortoiliac anatomy (“virtual graft”)
8. Interactive confirmation that the 3-D model is an accurate representation of the CT or MR data (“drop sections” where the CT reformat is displayed within the 3-D model)
9. Interactive measurements displayed simultaneously within the CT data and the 3-D model in real time
10. Ability to simulate the appropriate C-arm gantry angle for optimal views of the aortic and iliac attachment sites, including the renal and internal iliac artery origins

Preoperative planning. 3-D CAMPS software and images on personal computers were used by the implanting surgeon to obtain measurements of aneurysm neck diameter and length, neck-AAA body angle, iliac diameter, and iliac attachment site length. In all cases, CT reformatting perpendicular to the vessel was used for diameter, with real-time display in the 3-D reconstruction of all length, angle, and diameter measurements. Length measurements for seal and fixation length and length over the graft path were calculated with 3-D CAMPS. Iliac artery tortuosity and calcification were also analyzed to plan access and delivery of the intended device. Sagittal reformatting...
and the 3-D model were used to plan the optimal C-arm gantry angle for deployment at the proximal neck. The proposed graft was then simulated in the patient’s 3-D anatomy, anticipating that the stent graft will generally follow the lumen centerline, but allowing simulations that follow a user-defined path as well (Fig 1). Determination of a potential endograft path that did not follow the centerline was left to surgeon judgment, and the total length of

Fig 1. Composite of preoperative and postoperative three-dimensional reconstruction and computer-aided measurement, planning, and simulation (3D-CAMPS) images and intraoperative angiograms from the same patient. A, 3-Dimensional image of infrarenal abdominal aortic aneurysm with flow channel (red), calcified plaque (white) atheroma and thrombus (yellow). B, Same view as in A, with thrombus made invisible to simulate intraoperative arteriogram. C, Intraoperative arteriogram. D, Preoperative virtual graft simulation with “reversed limb” configuration to show intentional crossing of graft limbs within the aneurysm sac. E, Intraoperative completion arteriogram. F, One-month follow-up 3D-CAMPS study.
such a user-defined endograft path almost never differed by more than 1 cm (in total length) from the centerline endograft path. Endograft size was based on 3-D CAMPS, including a simulation of the proposed endograft within the AAA, accounting for the side of delivery (differences in ipsilateral and contralateral length), planned extensions, and delivery device size (differing for main device and contralateral limb). Planning also included determination of renal artery location on the basis of lumbar spine landmarks (for placement of the marker catheter if a pre-deployment “road map” was used). Last, the optimal C-arm gantry angle for viewing the infrarenal aortic neck attachment site and the internal iliac artery origins were determined.

**Intraoperative technique.** All EVARs were performed in the operating room, with a 12-inch digital C-arm fluoroscopy unit (Philips BV 312, Philips Medical Systems, Santa Ana, Calif; or GE/OEC 9800, GE Medical Systems, Milwaukee, Wis). 3D-CAMPS reconstructions were available on a personal computer in the operating room for reference as needed. For patients with renal insufficiency, contrast agent was limited by placing guide wires, sheaths, and the deployment device in the appropriate location, with the 3-D reconstruction as the road map. The gantry angles were adjusted according to the preoperative CAMPS plan. After early misjudgments based on arteriogram interpretations, we learned to refer to 3-D CAMPS if the arteriogram did not appear to correlate with the preoperative plan. Arteriograms were most commonly misinterpreted in two scenarios: before we routinely planned appropriate gantry angles for the aorta, common iliac, and internal iliac arteries, before the procedure; and when we relied on the marker catheter for length and the catheter took an unexpectedly much shorter path than the planned endograft. Completion arteriography was always performed, with anagrade contrast injection at the proximal attachment site and separate retrograde injection in both iliac arteries. Other injection sites were used, as deemed necessary, if endoleak was present (junction injection, separate views), to rule out type I or type III endoleak. Most grafts were placed with the patient under general anesthesia (74%), and the rest were placed with the patient under regional anesthesia.

**Patient follow-up.** Patients participating in phase II or phase III clinical trials and patients with commercially available grafts were seen at follow-up at 1, 6, and 12 months, with annual visits thereafter. Interim visits were scheduled as clinically indicated or per manufacturer recommendations for trial patients. Each visit included a patient interview, review of systems, physical examination, determination of ankle-brachial index, CT with 3D reconstruction including computer-aided volume measurements, and plain abdominal radiography (four views).

**Statistical evaluation.** Data were collected via retrospective review of electronic and paper medical records and organized into a File Maker Pro version 5.0 database (Filemaker Inc, Santa Clara, Calif) configured by us. Statistical evaluation including Kaplan-Meier analysis, with the log-rank or Mantel-Cox method for comparison of groups, was performed with StatView version 5.0 statistical software (SAS Institute, Cary, NC). Results are given as mean ± SD unless otherwise specified. \( P < .05 \) was considered statistically significant.

**RESULTS**

**Initial verification of accuracy.** Although validation was performed in objects of known size and in open AAA repairs before initiation of this series, validation during EVAR was performed also. Intraoperative intravascular ultrasound (IVUS) was used in the first 25 patients to confirm preoperative 3-D CAMPS arterial diameter measurements. IVUS and 3-D CAMPS diameter measurements agreed sufficiently (mean difference, 0.5 ± 0.3 mm; \( P = .2 \)) that the chosen graft diameter was not affected in any case. No changes in operative plan were made on the basis of these results. Similarly, intraoperative arteriography with a graduated marked catheter was used to confirm length measurements in the first 35 cases. The preoperative simulation of the endograft length (with virtual graft) was within 5 mm of the actual graft end point in all but one endograft limb, and within 10 mm in all endograft limbs (measured relative to the internal iliac artery or aortic bifurcation on completion graduated marked catheter arteriography in an appropriate plane). Graft length measurements with 3-D CAMPS and arteriograms were similar (141 ± 6 mm vs 136 ± 6 mm; \( P = .08 \)), but in 19% the measurements differed by 1 cm or more (shorter on arteriograms in all cases). Completion and postoperative studies of the actual graft demonstrated that 3-D CAMPS was more accurate in all discordant cases. Arteriography was not accurate for diameter measurements (mean error for aortic neck measurements compared with IVUS, 2.6 ± 2 mm, with arteriography underestimating diameter in 80% of cases).

Early in our experience (first 82 cases), 3-D CAMPS was prospectively used to identify patients with difficult but feasible access (\( n = 14 \)). In extreme cases when 3-D CAMPS predicted probable access failure (\( n = 4 \)), preoperative arteriography was performed to make the final determination of whether transfemoral access should be attempted. Arteriography was falsely reassuring in three of these four cases, resulting in the only three access failures in our experience. Arteriography is no longer used for determination of access issues, and no preoperative arteriogram has been obtained since December 1998. 3D-CAMPS alone was used to evaluate the access vessels in the 196 patients in this series without any access failure.

**Patient demographic data.** Mean patient age at primary endovascular graft implantation was 74 ± 7 years. Mean follow-up time was 18 ± 1 months. Most patients were men (83%) with significant associated comorbid conditions (Table I, online only). Six stent-graft brands were implanted (\( n = 196 \)): AneuRx (Medtronic/AVE, Santa Rosa, Calif), \( n = 107 \); EVT (now Ancure; Guidant, Menlo Park, Calif), \( n = 14 \); Excluder (W. L. Gore & Assoc, Flagstaff, Ariz), \( n = 42 \); LifePath (Baxter/Edwards Life Sciences, Irvine, Calif), \( n = 2 \); Vanguard I (Boston Scien-
tific, Meadox Medicals, Oakland, NJ), n = 30; and Talent (Medtronic/AVE), n = 1. The endograft types included the graft configurations available at the time, that is, tube, bifurcated, and aortouniiliac (Table II). Anatomic data (standard definitions) were as follows: maximum AAA diameter, 58 ± 9 mm; aortic neck diameter, 23 ± 2 mm; aortic neck length, 28 ± 11 mm; and 3-D neck-body angle, 32 ± 16 degrees. As compared with arteriography, no patent accessory renal arteries or inferior mesenteric arteries were missed at preoperative 3-D CAMPS (note in Fig 1, A-F, lowest left accessory renal artery preoperatively fills via collateral vessels postoperatively after intentional coverage).

**Technical success.** Successful graft implantation was achieved in 98.5% of patients, with the three exceptions (1.5%) all early in our experience. In these three patients immediate conversion to open repair was successful. Conversion was necessary because of previously unknown mechanical limitations of the devices in two patients (tortuosity limitations for one EVT graft and one Vanguard graft) and inadvertent dislodgement of the iliac graft limb in one patient. Angulation or tortuosity limits for these devices were subsequently measured preoperatively (before device redesign or discontinuation), and no other immediate conversion or access failure occurred in the subsequent 158 endografts implantations since March 1998.

**Adjunctive techniques.** Adjunctive techniques were used in 53 patients (27%) to assist graft implantation, including iliac stent (n = 6), iliofemoral conduit (n = 5), femorofemoral bypass for aortouniiliac grafts (n = 8), brachial artery access (n = 2), common femoral artery repair with patch angioplasty (n = 16), and intentional hypogastric artery occlusion to treat combined aortoiliac aneurysm (n = 32; previously reported17). In all but 6 patients the need for adjunctive techniques was predicted preoperatively on the basis of 3D-CAMPS images. The most common adjunctive procedure that was not planned preoperatively was iliac stenting (4 of 6), usually performed to stent a nonsupported endograft limb at the site of stenosis that did not respond to angioplasty after deployment (n = 2) or to treat external iliac dissection or kink secondary to the stent graft or its deployment (n = 1 each). One retroperitoneal approach to the common iliac artery with iliofemoral conduit was performed emergently to treat iliac artery injury caused by balloon rupture during angioplasty of stenosis before EVG deployment, with subsequent successful EVG deployment.

**Early results.** In-hospital mortality was zero. Thirty-day mortality was 0.5%; one patient was doing well until he had a stroke at home 2 weeks after discharge. This patient had a history of multiple strokes due to intracranial cerebrovascular occlusive disease. Mean length of stay for patients receiving EVAR was 2 ± 3 days (SD), with 56% of patients discharged on postoperative day 1 (median length of stay, 1 day). Eight patients required intensive care unit stay, for a combined total of 17 patient-days in the intensive care unit. All other patients were transferred to the inpatient floor after a 4-hour observation period in the postanesthesia care unit. In-hospital complications are shown in Table III. There were no apparent measurement-related complications.

**Late results.** Life table survival rate was 91% at 1 year and 78% at 3 years. Aneurysm-related mortality after 30 days was zero. Life table method did not show any significant difference in survival according to graft type (difference not significant).

**Endoleak.** Incidence of endoleak was 15% at 1 month, 10% at 6 months, 6% at 12 months, and 7% at 24 months; and 92% of endoleaks were type II (Fig 2, online only). All primary endoleaks were type II, most associated with iliac branch flow only. A minority of type II endoleaks involved branch flow from the inferior mesenteric artery or an accessory renal artery arising from the AAA sac (n = 1). The number of endoleaks decreased over time, primarily because of spontaneous resolution (86%). All type I and type III endoleaks were secondary endoleaks in three categories: aneurysm degeneration within attachment sites or adjacent arterial segments (n = 2, distal type I), stent-graft
deformation (n = 3, “buckling” associated with sac shrinkage), or small fabric wear or suture hole endoleak (n = 1).

**Secondary procedures.** Eighteen secondary procedures, all endovascular, were performed in 16 patients (8%). All type I and type III endoleaks were corrected with secondary interventions. Type II endoleaks were generally observed if the aneurysm was not enlarging. Early in the series, three type II endoleaks were coiled, without evidence of AAA enlargement, before evidence that not all type II endoleaks need intervention. Limb occlusion occurred in 5 grafts (2 EVT, 2 Vanguard, 1 AneuRx). There were two late ruptures, both in Vanguard I endografts with stent-graft degradation (small suture hole or fabric wear, n = 1; buckling of the trunk and migration of the “docking” limb attachment, n = 1; both >2 years postimplantation); both were successfully repaired with another endograft. Vanguard I endografts were involved in 15% of EVAR but 58% of secondary procedures (P < .01), although longer follow-up may account for part of this difference. For the entire series, overall freedom from secondary procedure was 94% at 1 year and 90% at 2 years. The results are significantly better for graft types that were ultimately approved by the US Food and Drug Administration (FDA) and those that were not approved. Freedom from secondary intervention at 12 and 24 months was 96% and 95%, respectively, for endografts ultimately approved by the FDA, significantly better than for non-FDA-approved endografts.

**DISCUSSION**

This study demonstrates that 3-D CAMPS can be used effectively for patient selection and stent-graft sizing for endovascular AAA repair. For each type of stent graft, clinical results with CAMPS are equivalent to or better than those of published series from large academic institutions of excellence in which preoperative arteriography was used in most or all cases (Table IV). In addition, our secondary intervention rate compares favorably with that of Eurostar, the largest multiple device study available (Fig 4). Our anatomic data are nearly identical to those of Eurostar, and mean AAA diameter, a predictor of adverse outcome, is larger for our series. Of course, our good results could be due to extremely conservative patient selection or large institutional experience, but that is not likely the case. Several patients in this series were turned down for endovascular repair at other large institutions, yet underwent successful endovascular repair with use of preoperative CAMPS for stent-graft sizing and procedural planning. Traditional measures of “degree of difficulty” for EVAR, such as aneurysm size, are typical for large published series. Most important, this report includes patients treated dur-

![Fig 3. Freedom from secondary intervention over time. There was a notable difference between grafts that were ultimately approved by the US Food and Drug Administration (FDA) and those that were not approved. Freedom from secondary intervention at 12 and 24 months was 96% and 95%, respectively, for endografts ultimately approved by the FDA, significantly better than for non–FDA-approved endografts.](image-url)
ing our early experience “learning curve,” dating back to 1996, when endovascular AAA repair was being performed in only a small number of US centers. This series does not exclude early experience with each endograft in each new clinical trial, early experience for multiple surgeons, and early experience performing endovascular AAA repair without preoperative arteriography. All of these factors would generally mitigate against good results.24,25

Although it is difficult to confirm the superiority of a technique without a prospective, randomized study, there are some areas where 3-D CAMPS has clear advantage over arteriography: it is less invasive, less expensive, and averts use of iodinated contrast agent and radiation required for arteriography. At our institution the cost (not charge) for 3-D CAMPS is currently less than half that for diagnostic arteriography alone ($550 vs $1109). Aortofemoral arteriography is not a “high-risk” procedure, but is associated with complications that may require intervention in 1.7% of patients undergoing transfemoral diagnostic arteriography (eg, bleeding, pseudoaneurysm, dissection) and can even

Table IV. Comparison with reported series that used preoperative angiography

<table>
<thead>
<tr>
<th></th>
<th>Mixed graft type series</th>
<th></th>
<th>Single graft type series</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EUROSTAR</td>
<td>Bush*</td>
<td>Datillo</td>
<td>DHMC (entire series)</td>
</tr>
<tr>
<td>Mean follow-up (mo)</td>
<td>27</td>
<td>18</td>
<td>18</td>
<td>17.5</td>
</tr>
<tr>
<td>Technical success (%)</td>
<td>98.4</td>
<td>94</td>
<td>98.6</td>
<td>98.5</td>
</tr>
<tr>
<td>Freedom from secondary intervention (2 y) (%)</td>
<td>NR</td>
<td>75</td>
<td>NR</td>
<td>90</td>
</tr>
<tr>
<td>Endoleak rate at 2 y (%)</td>
<td>24</td>
<td>25*</td>
<td>NR</td>
<td>7</td>
</tr>
<tr>
<td>Late rupture rate (%)</td>
<td>1</td>
<td>0</td>
<td>0.8</td>
<td>1</td>
</tr>
<tr>
<td>Survival (%)</td>
<td>87</td>
<td>86</td>
<td>NR</td>
<td>88</td>
</tr>
<tr>
<td>AAA-related mortality (%)</td>
<td>NR</td>
<td>2</td>
<td>1.3</td>
<td>0</td>
</tr>
</tbody>
</table>

DHMC, Dartmouth Hitchcock Medical Center; AAA, abdominal aortic; NR, not reported.
*“Low-risk” portion of Bush et al series.
†Rate at 1 y.
cause fatal complications (0.025%). In addition, the two advantages traditionally ascribed to arteriography, therapeutic intervention and evaluation of occlusive disease, are affected by the context of EVAR. A pre-existing stent along the path of the delivery system creates the potential for stent deformation and vessel damage while trying to pass the large delivery systems associated with EVAR. Most interventionalists prefer to dilate the lesion with an introducer sheath, then stent the lesion with the endograft or an uncovered stent at completion if necessary. Renal stents are similarly better placed after the endograft is deployed, because the typical renal stent must encroach into the aortic lumen, where it may interfere with device deployment or become damaged during EVAR.

In the small number of early cases where we used arteriography for decision-making, we quickly found that it was not the gold standard for issues such as determining diameter, device length, and iliac access, despite making these decisions in conjunction with proctors who had experience with more than 100 cases in which preoperative arteriography was used. The tendency of arteriography to underestimate true diameter has been reported previously. Determination of neck length is inferior because arteriography visualizes only the lumen and not thrombus. We also found that 3-D CAMPS ability to simulate the appropriate c-arm gantry angle for optimal views of the aortic and iliac attachment sites, including the renal and internal iliac artery origins, was important for obtaining appropriate attachment sites, limiting trial-and-error contrast injections, and limiting use of cuffs. We used only two aortic cuffs in this entire series, which is far fewer than most series that report this statistic. In our experience, preoperative arteriography has also been inferior for evaluating iliac occlusive disease and determining suitability of access for the delivery device. Even with two or more views, significant stenoses can be missed at arteriography because it gives a two-dimensional projection of a three-dimensional structure. Bilateral pressure gradients or “spin pelvis” systems can minimize this problem, but few centers routinely perform bilateral iliac pressure gradients, and the equipment for 3-D spin arteriography is expensive. Vessel calcification is often demonstrated poorly on arteriograms as well, and calcified plaque, even if not hemodynamically significant, may impede access or deployment.

On the other hand, while trying to minimize preoperative testing and expense, one might question whether CT alone, without 3-D CAMPS or arteriography, might be just as effective. We have no doubt that EVAR can be performed with CT alone, but it is unlikely that it can be performed without more conservative patient selection or without some additional risks compared with 3-D CAMPS. It must be emphasized that the 3-D CAMPS system we used in this study is not conventional CT, CTA, or even conventional CTA with 3-D reconstruction (see Methods). The protocols for all major clinical EVAR trials initially required CT and arteriography with a marker catheter, because with conventional CT it is difficult to assess occlusive disease, measure the length of potential attachment sites, or determine appropriate stent-graft length. CTA improves assessment of occlusive disease but has not been as effective as 3-D CAMPS in our hands, as evidenced by access issues in our validation series in which we used a combination of CT and angiography. Axial CT has the problem of slightly overcalling the true diameter, which is averted with 3-D CAMPS by CT reformating orthogonal to the vessel. Conventional 3-D reconstructions are based only on brightly contrasted structures (ie, contrast-enhanced lumen and calcified plaque), because of the problem with automated edge detection of thrombus and noncalcified atheroma. Thus they have the dual problems of overcalling the potential lumen for the device, because the calcified plaque is displayed identically with true lumen, and undercalling the true extent of the aneurysm, because the thrombus is not included in the 3-D reconstruction. Moreover, most 3-D reconstruction software lacks ability to measure length along the lumen centerline or along a user-specified path, display the CT reformating interactively with the 3-D model to confirm its accuracy, or display measurements in the context of the model. We have found all of these elements invaluable during evaluation of AAA for potential EVAR.

There are some caveats about 3-D CAMPS as well. Proper CT protocols are important, but these are a simple matter compared with more technician-dependent or software-dependent imaging, such as duplex scanning or MRA. CAMPS can be used with MR as well as CT, but one must remember the inherent limitations of MR: lack of differentiation for calcified plaque and lower resolution (generally half that of CT, but improved with the latest generation of scanners). There is significant training time for technicians if the 3-D CAMPS technique is to be performed in the hospital, but this time and expense can be resolved by using a third-party solution, as in this study. Most centers will likely wish to use a third-party solution, because this type of software is now reimbursed by the Center for Medicare and Medicaid Services and does not require the high initial training cost or high initial costs associated with in-house solutions. Training is also required for the surgeon or interventionalist who will use 3-D CAMPS for patient selection and planning, but the learning curve for this is relatively low for computer-literate persons. For those who are not computer-savvy, however, this technique will be more difficult to learn. The overall time for preoperative evaluation and planning is significant, but should ultimately be less tedious and time-consuming than using a combination of CT and arteriography, especially when results of these studies are contradictory. Last, there is no substitute for good judgment, that is, not “pushing the envelope” with marginal anatomy if there is a good option for open repair.

This study is not large enough to rigorously evaluate outcomes with the various endografts used. However, as one might expect, the best results were obtained with devices that have ultimately been approved for commercial use (Ancure, AneuRx, Excluder), and most of the second-
ary interventions were required after implantation of an early generation device that was ultimately discontinued (Vanguard I). No secondary interventions were necessary because of measurement errors, but because of device deformation, progression of aneurysm disease, or type II endoleak, none of which were related to preoperative planning.

In conclusion, this study demonstrates that 3-D CAMPS can be used effectively for patient selection and stent-graft sizing for EVAR, and provides results that are as good as or better than those of series in which preoperative arteriography was used. Compared with CT plus arteriography, CT or MR with 3-D CAMPS is less invasive, less expensive, and associated with lower contrast agent and radiation dose. We have made 3-D CAMPS the standard patient evaluation technique at our institution, and we believe elimination of preoperative arteriography will become more widespread as other centers gain experience with this technique.

REFERENCES


Submitted Nov 19, 2003; accepted Apr 9, 2003.