Color Duplex Evaluation of Endoluminal Aortic Stent Grafts

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ABSTRACT  Endovascular treatment of abdominal aortic aneurysm (AAA) is being investigated in many centers throughout the world with encouraging preliminary clinical results. This method of repair has the potential to offer shorter disability and recovery times while reducing healthcare costs. The Stanford Vascular Laboratory/Division of Vascular Surgery has performed more than 50 examinations in patients with endoluminal infrarenal abdominal aortic stent grafts (endografts) of various designs in the past year. We have developed a specialized protocol for pre- and poststent color duplex examination based on our early experience with previous endografts. The present examination is useful in determining whether a patient is a candidate for this type of AAA repair. In addition, this examination allows the physician to efficiently plan a patient's treatment. The poststent examination is used to monitor the effectiveness of the stent and AAA size. Comparable data of poststent color duplex findings and spiral computed tomography indicates that ultrasound can reliably determine persistent leaks and changes in residual AAA size. It is our hope that sharing our experience will be helpful to the vascular community as patients with these devices begin appearing in vascular laboratories around the country.

Pre-stent Examination

Pre- and postoperative ultrasound assessment for abdominal aortic endograft repair is significantly more detailed than a standard "rule-out aneurysm" ultrasound scan. In addition to technical expertise in the abdomen, examining the patient with an abdominal aortic aneurysm (AAA) endograft requires extensive clinical knowledge of aneurysmal disease, vascular anatomy, hemodynamics, physiology, and collateral pathways. Also of importance is a working knowledge of various stent graft devices, how and where they are deployed, and the anatomic limitations that exclude a patient from receiving a stent graft. Of further note is that the sound penetration capabilities of many types of ultrasound imagers are deficient and do not allow adequate two-dimensional visualization or color Doppler sensitivity to adequately evaluate abdominal endografts or collateral pathways. If, in skilled hands, it is difficult to demonstrate proximal and midrenal arteries or to see accessory renal arteries (average-sized patient) by color Doppler, it is likely that the imaging system is not adequate for evaluating abdominal endografts.

The present workup is usually the most lengthy because an accumulation of data is required to establish baselines and plan for treatment. However, familiarity with the protocol shortens the examination time (about 1 hr). Begin with a history and physical examination for both pre- and poststent vascular laboratory examinations. The goal is to determine whether the patient has peripheral occlusive disease or a history of previous revascularizations. Auscultate for abdominal and groin bruits to help differentiate new bruits from old at follow-up examinations. Evaluate pulses for increased or absent pulsatility. Determine the bilateral ankle/brachial index to obtain a baseline of the distal arterial status and note findings on a worksheet (Figure 1). The status of the arterial inflow will be determined later in the examination.

The aorta should be evaluated for size and the amount of thrombus and/or calcification present. The examination should include measurements of the external outer wall diameter and the internal lumen diameter. Most abdominal aneurysms are located between the renal arteries and the iliac bifurcation, but occasionally they may extend above the renal arteries or may include one or both iliac arteries. An aneurysm of the abdominal aorta may also be associated with aneurysmal dilatation of the common iliac, hypogastric, popliteal, and/or common femoral arteries (CFAs). The external iliac and superficial femoral artery may also have aneurysmal disease, but not as commonly as in the previously mentioned vessels.

The diameter of a normal abdominal aorta varies throughout its length, gently tapering in size as it descends to the aortoiliac bifurcation in the abdomen.
COLOR DOPPLER/2-D IMAGE DATA

- Image quality: good, fair, poor
- Obese: yes, no
- Overlying gas: yes, no
- Preprandial: yes, no
- AAA-infrarenal: yes, no
- AAA-suprarenal: yes, no
- Thrombus: yes, no
- Calcified: yes, no
- Dissection: yes, no
- Hypo. aneur. L/R: yes, no
- Iliac aneur. L/R: yes, no
- CPA aneur. L/R: yes, no
- Pop aneur. L/R: yes, no
- Stent patent: yes, no
- Stent leak: yes, no
- Note: ____________________________

OTHER MEASUREMENT DATA (cm)

- AAA Max. dimensions
- AAA Residual lumen
- Prox. infrarenal neck
- Dist. infrarenal neck
- Right Common iliac
- Hypogastric
- CPA
- Pop
- Left Common iliac
- Hypogastric
- CPA
- Pop

ANKLE/BRACHIAL (mmHg) INDEX

- Brachial
- INDEX
- INDEX
- Ankle PTA
- INDEX
- Ankle DPA
- INDEX

Patent Arteries (vel. m/s)
- Abd Aorta
- SMA
- IMA
- L Renal
- R Renal
- L Iliac
- R Iliac

PRELIMINARY FINDINGS

[Diagram of vascular system with measurements and notations]

Figure 1

Technologist

Physician
At the level of the renal arteries, the aortic diameter is approximately 2.0–2.5 cm. The prebifurcation region of the aorta measures approximately 1.2–1.8 cm. The aortoiliac bifurcation occurs near the level of the umbilicus, and each measures approximately 0.8–1.2 cm in diameter at the origin. The CFA measures approximately 0.8–1.0 cm, and the popliteal artery, 0.6–0.8 cm. Body habitus has some effect on the overall size of our arteries, that is, big people may have bigger arteries and vice versa. Also, mild overall enlargement of the arteries can be expected with age.

The present ultrasound examination of the abdominal aorta includes longitudinal and transverse images of the aorta from the diaphragm to the popliteal arteries. Maximum transverse and anterior-posterior diameter measurements are taken outer wall to outer wall. In the presence of a thrombus, the residual lumen diameter is also measured. Occasionally an aneurysm is better appreciated with the patient in a decubitus position and imaging in a coronal plane. In fact, this is the only plane that can be used to measure the distance from the renal artery origin to the top of the infrarenal AAA. The left renal artery is typically used in this measurement because it usually originates more inferiorly from the aorta than the right renal artery. This length measurement is important because an adequate proximal neck below the renal arteries is essential to anchor the proximal end of a stent device without covering the renal artery ostia. The diameter of this neck is equally important to determine the size of the stent to be used. If no infrarenal neck exists, a stent repair is not possible. Ideally, the length of the proximal or distal neck of an AAA should be 1 cm or more. The diameter at these sites should be 1.6–2.6 cm and only mildly diseased. The largest arterial diameter should be obtained in each of the following regions: above the renal arteries, at the renal arteries, below the renal arteries, at the prebifurcation region, common iliac artery, midiliac artery, CFA, and popliteal arteries bilaterally. It is important to make an effort to look closely at the origins of the hypogastric artery because people may die of undiagnosed ruptured hypogastric artery aneurysms (Figure 2). Once the status of the hypogastric arteries has been determined, the remainder of the scan down the legs is brief. Apply gel down the leg and perform a quick scan over the femoral and popliteal arteries to screen for gross vessel enlargement. Obtain a diameter measurement and pulsed wave spectral strip from the CFA and popliteal arteries bilaterally. Of course, document any other areas of enlargement that are encountered. The CFA waveform helps determine the status of the arterial inflow, and the color Doppler/two-dimensional image documents plaque and residual lumen at this site. This information is important to the physician planning the stent deployment procedure because the CFA is typically the site where the deployment catheter is inserted.

A Doppler waveform and velocity should be documented from the aorta at the region near the superior mesenteric artery and from the proximal iliac arteries, including any location that appears stenotic. A Doppler waveform from the site of aneurysmal dilatation, without other pathology, is not of clinical use. This is a good time to quickly screen the mesenteric vessels and renal arteries for stenosis or aneurysmal dilatation when gas and time permit. Be sure to note pre- or postprandial status on the worksheet. Also, note any of the major arteries that were not visualized. Of note, an accessory renal artery originating from an AAA may exclude a patient from endograft repair secondary to the risk of backbleeding into the AAA or obstruction of the accessory renal artery. Typically, AAA patients arrive with angiograms, computed tomography (CT) scans, or magnetic resonance angiograms (MRA) in hand, which can save a significant amount of time in the laboratory. There is no point in being redundant. Having these findings available certainly helps to determine one’s limitations and growth.

Color imaging is helpful for delineation of the lumen boundary in the presence of excessive thrombus
or calcification. Transverse images using color Doppler imaging should be used to demonstrate lumen filling of the aorta and patency of iliac arteries. Color Doppler imaging of an irregularly shaped aneurysm may be useful to isolate the opening to a mycotic pseudoaneurysm or other saccular aneurysms. All abnormalities should be documented in both scan planes.

**Poststent Examination**

A poststent vascular laboratory examination is important to rule out endograft leaks, which may lead to sudden death as a result of a ruptured aneurysm. Other complications that may be related to an aneurysm are dissection of the arterial wall or emboli to the lower extremity arteries. Another consideration is trauma to the vessels secondary to iatrogenic injury (interventional catheter-related complications). These complications include hematoma, pseudoaneurysm, arteriovenous fistulae, intimal flap, dissection, or embolus.

Femoral auscultations and ABIs are done at each visit to determine whether any changes have occurred to arterial outflow. Waveforms may also be required in the presence of calcified vessels where pressures are falsely elevated. Follow-up imaging of the femoral and popliteal arteries in the absence of disease or symptoms is not indicated postoperatively. In addition, the clinical assessment includes auscultation and palpation of the abdominal aorta. In our limited experience we are finding that the abdominal pulse over the aneurysm usually diminishes with successful exclusion of the aneurysm and often returns when exclusion is not complete.

The stented AAA is monitored regularly to document graft patency, changes in size of the aneurysm, possible leaks, or changes in thrombus formation. Early experience suggests that the AAA will diminish in size over time following successful exclusion by endograft. In the presence of an endograft leak, the AAA diameter does not get smaller compared to prestenent measurement. It will either remain the same size or become larger. The protocol used to evaluate a stent graft in the aorta is similar to the preliminary evaluation of the aneurysm. However, close attention

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(A) Cross-sectional diameter measurements of an AAA with bifurcated stent graft. (B) Color Doppler of stent graft limbs in cross section. (C) Endoleak (red) around the proximal end of a stent graft. (D) Small intimal flap on the posterior wall of the aorta located superior to the proximal end of a stent graft.
must be given to the stent/graft device to rule out potential leaks from the graft into the surrounding aneurysmal sac and possible migration of the graft from the intended locations proximally and distally. Though uncommon, other considerations include graft compression (lumen size) or twisting, moving parts, and intimal flaps (Figure 3). Also, it is important to increase the field of view to look for retroperitoneal fluid, which would indicate a leak outside the aorta.

Proximal migration of a stent may cover important aortic branches. Thus, patency of major branches from the aorta should be determined. These would include the celiac artery, superior mesenteric artery, renal arteries, and accessory renal arteries. A quick color Doppler and spectral strip of the origins of these vessels, when visualized, will suffice. Obviously, in the presence of any abnormalities further documentation is warranted. Distal migration of a stent may cover the hypogastric artery, also known as the internal iliac artery. The hypogastric artery may have been intentionally covered to exclude an iliac aneu-

rysm or otherwise obstructed during the stenting procedure. Thus, it is helpful to review the operative notes or to speak directly with a physician who was involved with the endograft procedure before examining the patient. Imaging the residual AAA requires sensitive color Doppler scale settings to determine low-flow leaks into the aneurysmal sac. Unfortunately, these lower scale settings also produce “bleed-over” of color beyond the stent wall and posterior reverberation artifacts behind the stent device. This occurs, most significantly, between the stent device and the posterior wall of the AAA as the pulsating echoes bounce back and forth like a hard rubber ball bouncing between a table and the floor. The color encoding is equally chaotic. However, an endoleak is reasonably uniform, reproducible, and demonstrates color beyond the stent wall that can be confirmed by a pulsed wave spectral strip. Also, an endoleak, of measurable volume, can be seen when the color is off. It is represented by gray-scale imaging as a pulsatile lucency within the thrombus-filled aneurysmal sac adjacent to the stent (Figure 4). Small, low-flow leaks

(A) Endoleak through a stent wall (arrow) that exits the aneurysmal sac via a patent IMA. Also note the reverberation artifact (red/blue) between the posterior stent wall and the back wall of the AAA. (B) Distal endoleak arising from a stent graft limb with a poor seal secondary to a tortuous iliac artery. (C) Low-velocity endoleak (blue) anterior to right stent graft limb. (D) Higher velocity endoleak (red) surrounding the stent graft.

Figure 4
Figure 5

(A) Small “pinhole” leak (arrow), in diastole, at stent graft wall. (B) Example of a PW spectral waveform from a small pinhole leak. (C) Prominent stent wall leak seen on both sides of the anterior stent wall throughout diastole. (D) PW spectral waveform of a prominent stent wall leak demonstrating its and fro flow.

Figure 6

Potential sources of endoleaks associated with AAA stent graft repair include flow around the proximal or distal end of a stent graft, flow through the wall of a stent, or backbleeding from a patent aortic branch.

may be seen as a small spot of color at the stent wall during diastole (Figure 5). To differentiate this type of a small leak from an artifact, it should be easily reproduced, and a Doppler signal must be confirmed by a pulsed wave spectral strip. A “leak” may occur through the stent wall, around either end of a stent, and/or secondary to backbleeding from patent aortic branches such as the inferior mesenteric artery (IMA) or a lumbar artery located at the posterior aspect of the aorta (Figure 6). It is important to identify and document patent branches and their flow directions associated with the residual AAA (Figure 7). The IMA is expected to be obstructed. IMA flow that is flowing away from the AAA indicates a leak that is originating from the stent or, possibly, from a patent lumbar artery. IMA flow into the AAA increases the risk of AAA rupture. Thus, a visit to the catheterization laboratory to obstruct the IMA may be required. Some of our preliminary findings suggest that early (1–2 weeks) postprocedure leaks near the stent wall that are small, and low in velocity, are not unusual and often spontaneously resolve over time. However,
more data must be collected to reach definitive conclusions.

Endograft Device

At this time there are three basic endograft designs for infrarenal AAA repair. These include the aortic tube stent graft, the aortoiliac stent graft with occlusion of the opposite iliac artery and femoral–femoral bypass, and the bifurcated stent graft (Figure 8). Current endografts for infrarenal AAA repair are commonly referred to as “covered” stents. This means that the metal framework of the graft is covered by synthetic material to prevent leakage through the stent. Alternate designs are of the “exoskeleton” variety with prosthetic material, usually Dacron polyester, inside the metallic stent. The tube stent graft design is ideal for a simple AAA with proximal and distal necks for implantation of the stent. However, advanced aneurysmal disease extends to the aortic bifurcation and often involves at least one iliac artery. Thus, the tube stent graft may be extended into the iliac artery to exclude the aneurysm. This type of endograft requires a femoral–femoral bypass because the contralateral common iliac artery must be obstructed to prevent backbleeding into the residual AAA sac. A newer modular bifurcated endograft design allows infrarenal aorta and bilateral iliac artery stent grafting without unilateral iliac artery occlusion and femoral–femoral bypass. This is achieved by inserting a 22F sheath containing the body of the stent with a unilateral limb into one CFA and deploying the self-expanding device at the proximal neck below the renal arteries. This is followed by inserting a 16F sheath containing the opposite limb of the stent into the contralateral CFA and introducing it into the sleeve of the body of the stent. After deployment this forms a bifurcated stent graft.

Several factors are involved in deciding who should be a candidate for stent repair. Because AAA endograft repair remains investigational, the requirements vary from site to site and device to device. However, at this time there are some anatomic limitations that the vascular laboratory can help determine. For example, a suprarenal or juxtarenal aortic aneurysm cannot be stented because the origins of the celiac, superior mesenteric, and renal arteries would be obstructed by the stent device. In addition, an aneurysmal proximal neck (near the renalis) prevents a proximal seal of the stent device. Also, a patent accessory renal artery originating from the AAA may eliminate the option of endovascular repair secondary to ischemic risk to the kidney. Another consideration includes mesenteric obstructive disease in which the IMA is the major collateral supplying the gut; thus, exclusion of the AAA would be devastating to the patient.

Summary

An expanded aortic duplex protocol is necessary and useful in two ways. The first is the pre-stent workup to assist the physician in planning the patient’s treatment. The second is the post-stent evaluation to monitor stability of the stent-grafted aneurysm and to rule out stent-related complications. It has been our experience that a sensitive, high-quality color duplex system can detect small low-velocity stent leaks more readily than computed tomography or angiography. Furthermore, vascular laboratory findings have demonstrated the origins of some leaks and other small
arterial branches originating from the aorta that were not identified by other imaging modalities. In skilled hands, we believe color duplex imaging to be an accurate and cost-effective method of evaluating and following aortic endoluminal stent grafts.

References