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Published in:
Texas Heart Institute Journal

Citation for published version (APA):

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Use of Spiral Computed Tomographic Angiography in Monitoring Abdominal Aortic Aneurysms after Transfemoral Endovascular Repair

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ince the publication of the 1st clinical results of transfemoral endovascular repair of abdominal aortic aneurysms by Parodi and colleagues\(^1\) and Volodos and associates\(^2\) in 1991, many reports, focusing mainly on early results, have followed. These reports are difficult to compare, since there are no accepted reporting standards. Nevertheless, we can conclude from some of the larger series that transfemoral endovascular aneurysm management (TEAM) is technically feasible and has an acceptable complication rate.\(^3,4\) The reported early successes have led to an increasing number of implantations being performed all over the world, and early results seem favorable. However, the long-term efficacy (prevention of death from late aneurysm rupture) of TEAM has not been proved.

The recent introduction of reporting standards by the Ad Hoc Committee of the Society for Vascular Surgery/International Society for Cardiovascular Surgery\(^9\) and the consensus of an international multidisciplinary team of investigators\(^10\) will help determine the role of TEAM in the vascular surgeon’s armamentarium. The reporting standards recommend imaging techniques for follow-up; procedural success is defined as aneurysmal exclusion demonstrated by angiography, contrast-enhanced computed tomography, and/or duplex ultrasonography.\(^10\) For continuing clinical success, there should be no evidence of graft thrombosis, migration, infection, or dilatation greater than 20% by diameter; aneurysm degeneration proximal or distal to the graft; fixation device failure; aneurysm expansion by 0.5 cm or greater; or requirement for open conversion.\(^9\)

Spiral computed tomographic angiography (CTA) can answer most of the questions that arise during routine follow-up of TEAM patients; only in special circumstances will additional imaging techniques be necessary. Spiral CTA produces an accurate image of the contrast-filled vessel lumen, the mural thrombus, and the origins of major branches such as the renal and mesenteric arteries. Small tributaries such as patent lumbar arteries can also be visualized.\(^11\)

In the spiral computed tomographic (CT) scanner, both the x-ray tube and the detectors continuously rotate while the patient, who is in the supine position on the table, is pulled through the scanner. The total data acquisition time is approximately 50 seconds. This short scan time allows for maximum contrast enhancement of the aorta during intravenous contrast administration. All the necessary information is gathered and available for processing from a single spiral scan.

The scan protocol depends on the type of spiral CT scanner. An often-used protocol consists of an intravenous dose of 130 mL of contrast material administered in an antecubital vein at a rate of 2 mL/s and, 35 seconds later, 50 scanner...
rotations in 50 seconds with a table speed of 5 mm/s.\textsuperscript{14} This protocol produces 123 overlapping axial slices 5 mm thick, reconstructed at 2-mm intervals. The slice overlap of 3 mm improves anatomic resolution along the scanning axis and reduces “stair-step” artifacts in other image formats.\textsuperscript{15} Spiral CTA data can then be displayed in several 2- and 3-dimensional formats.

**Axial Slices**
The simplest format in which spiral CTA data can be displayed is the axial slice on film; however, complex anatomy such as tortuosity of the iliac arteries is difficult to interpret on these films. For optimal display of the data set, the axial slices are loaded into a computer workstation with an interactive cine display that facilitates the interpretation of anatomic data. Contrast effusions outside the endoluminal graft (endoleaks) can be clearly visualized because of the high in-plane resolution of computed tomography,\textsuperscript{16} although the origin of an endoleak often cannot be determined.

Measurements are not performed using axial slices because tortuosity of the aorta creates oval cross-sections. While some groups advocate using the smaller diameter of the oval as the cross-section diameter,\textsuperscript{17} we prefer to use the curved linear multiplanar format for accurate length and diameter measurements.

**Multiplanar Formats**
In the multiplanar image format, axial, sagittal, and coronal planes are linked and displayed simultaneously. The operator (preferably the surgeon) has interactive access to the images; cursor movement in one image is reflected in the others. The sagittal and coronal images have good longitudinal resolution because the original axial slices are overlapped, but the total length of curved vessels cannot be displayed. We therefore use the curved linear multiplanar format (MPR), which is based on a reference line in the center of the contrast-filled vessel lumen. The operator selects the center of the vessel lumen in a large number of axial slices (using visual feedback from the sagittal and coronal images), and these center points are then connected to form the central lumen line. This central lumen line is the vessel axis relative to which all reconstructions are performed.

Both the length and the diameter of vessel segments can be determined, taking the curved configuration of the vessel into consideration. Diameter measurements are performed in slices reconstructed perpendicular to the vessel axis. Length measurements are the distances along the central lumen line between selected slices perpendicular to the vessel axis (for example, the slices containing the cranial and caudal margins of the attachment system).\textsuperscript{18} The complete length of tortuous vessels can be projected in planes parallel to the curved central lumen line.

**Maximum Intensity Projection**
In maximum intensity projection (MIP) format, the entire scan is mathematically examined from different viewpoints, and only those voxels with the highest intensity in the selected view angle are displayed. High-density structures such as bone, calcified plaque, and the contrast-enhanced caval vein make it difficult to visualize the aorta, so an optimal aortic image is obtained by manual editing of the image, removing bone structures and veins. A single edited MIP image resembles a conventional angiographic image, showing only the contrast-filled lumen. The metal components of endovascular grafts are clearly visible but cause artifacts that make it difficult to see possible abnormalities at the attachment sites. The thrombus mass inside the aneurysm is not visible unless it contains contrast material (endoleak). When the wall of the aneurysm contains calcified plaque, the contours of the aneurysm will be visible. Combining a series of MIP images at different angles and displaying them as a cine loop helps in understanding the 3-dimensional anatomy of the aorta.

**Shaded Surface Projection**
The shaded surface projection (SSP) produces a virtual image of the vessel lumen and other selected structures. First, the complete data set containing voxels with a wide variety of grayscale densities is reduced to a set with voxels either displayed (on) or hidden (off); this semiautomated selection process is called segmentation. Then mathematical manipulation of selected voxels adds the illusion of depth by generating shaded surfaces on the selected object.\textsuperscript{19} However, the reliability of the segmentation depends on the skill of the operator. For complete evaluation of an aortic aneurysm, both the contrast-filled lumen and the mural thrombus should be segmented.\textsuperscript{13}

Shaded surface projection not only produces good images but provides a means for performing volume measurements. In a study on the EndoVascular Technologies tube graft (Menlo Park, Calif.), we compared maximum aneurysm diameter with thrombus volume in 9 patients.\textsuperscript{18} In most patients, changes in maximum aneurysm diameter and thrombus volume were similar. However, in 2 patients, 1 with and 1 without endoleak, the diameter remained unchanged while thrombus volume increased considerably (15% and 25%). This phenomenon could be a result of changes in aneurysm morphology, and on the basis of this observation, we advocate the use of volume measurements in follow-up of TEAM patients.
The Role of Spiral CTA in TEAM Patient Follow-up

Given the variety of options for image postprocessing, spiral CTA seems to be the ideal imaging modality for follow-up of TEAM patients, and it is also the best single preoperative imaging technique.20 In follow-up, spiral CTA can be used to visualize the endovascular graft and its metal components, detect problems such as endoleaks, and provide accurate length and diameter measurements. When problems are seen with spiral CTA, additional imaging techniques may be necessary to more specifically examine them. In patients with endoleaks detected with spiral CTA, the cause of the endoleak is often not seen because of the nondynamic nature of the scans, and dynamic studies such as duplex ultrasound or arterial angiography may be necessary. Diagnostic angiography can then be combined with intervention to treat an endoleak. Attachment site diameters can also be closely monitored with spiral CTA, and because the curved linear format allows for accurate length measurements, the evolution of an aneurysm after TEAM can be carefully followed.

New developments such as magnetic resonance angiography (MRA) and intravascular ultrasound (IVUS) appear to be very promising. However, MRA is not yet generally available, although the technique is rapidly improving. Magnetic resonance contrast media such as gadolinium improve image quality, but in-plane resolution remains less than that of spiral CTA. Magnetic resonance angiography is also very susceptible to metal, so the metal in attachment systems and endografts causes artifacts that interfere with accurate interpretation of images. As a consequence, MRA seems more useful in preoperative imaging.

Intravascular ultrasound is also evolving quickly, with the potential for becoming a powerful intraoperative imaging technique.22,23 Lengths and diameters of vessel segments can be measured with great accuracy, which is necessary for proper selection of graft size. Intravascular ultrasound can also be used during graft implantation to monitor the deployment of attachment systems and find possible causes of endoleaks that could be managed directly by balloon inflation or insertion of an extra stent. A disadvantage of IVUS is that an arterial puncture is required for insertion of the sensor. Additionally, IVUS cannot display the complex 3-dimensional anatomy of the aorta and the iliac arteries, because the curved vessel axes are reduced to linear axes.

Because of the power of spiral CTA and the shortcomings of other technologies, we conclude that spiral CTA is the ideal imaging technique for postoperative monitoring of TEAM patients. Only in selected cases will additional imaging techniques be necessary.

References


