

Impact of CT Angiography on Endovascular Therapy

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Abstract

In the last ten years, computed tomography (CT) angiography has evolved from an experimental diagnostic tool to the preferred imaging study for a variety of disease processes. At the same time, endovascular surgery has become the first-line therapy for several types of peripheral vascular disease. With the recent introduction of multidetector computed tomography, CT angiography of the entire peripheral vascular system is possible in mere seconds. This imaging modality has become critical for the pre-procedure planning and post-procedure follow-up of several endovascular procedures, including endovascular aneurysm repair, lower extremity revascularization, and renal artery revascularization. A thorough knowledge of the current applications of CT angiography with respect to the peripheral vasculature is essential for the endovascular specialist.

Key Words: CT angiography, angiography, vascular imaging, endovascular therapy, minimally invasive.

Introduction

COMPUTED TOMOGRAPHY (CT) angiography has become the preferred screening tool for vascular disease since it was first described in 1992 (1). This study tool is faster and more minimally invasive than previous tools, making it the imaging modality of choice when planning endovascular procedures as well as when performing routine follow-ups of these patients. The recent technologic advancements with regard to multidetector CT (MDCT) have allowed this powerful imaging tool to perform more rapid imaging while at the same time permitting more coverage of the patient, with higher spatial resolution (Fig. 1). This article reviews the technical factors that must be taken into consideration in planning and interpreting CT angiograms (CTA), as well as the applications that are most relevant to the endovascular specialist.

Imaging Techniques

The most important step in CT angiography is determining the area of the patient to be im-

aged. With current commercially available systems, a reasonable area to be covered is the chest and abdomen down to the patient's knees, or the abdomen and pelvis down to the patients' feet. It is important to realize that most endovascular procedures are performed from the common femoral artery approach. As a result, routine imaging of this anatomic region is mandatory.

To guarantee that all relevant anatomy will be included, a noncontrast scout view may be obtained and reviewed in order to visualize certain landmarks to be imaged prior to angiography. Following this, an intravenous non-ionic bolus of contrast media, usually about 15 mL, is injected to time the delay between the injection and image acquisition. After the extent of the delay is determined, the angiogram can be performed. Typically, 80–100 mL of intravenous non-ionic contrast agent is administered at an injection rate of 4–5 mL/sec.

Clinical Applications

Aortic Aneurysm

Conventional angiography has long been the preferred technique for evaluating aortic aneurysms. While it is invasive, it is rarely associated with complications such as puncture site hematomas and arterial dissection. How-

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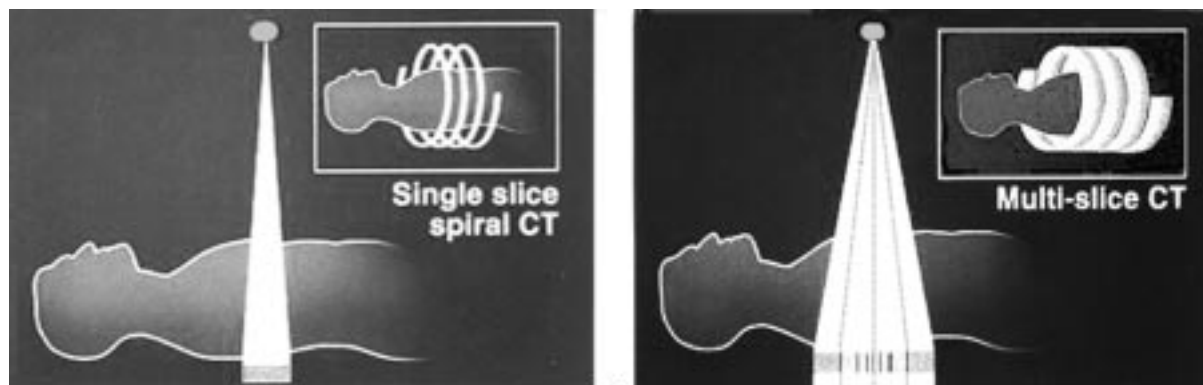


Fig 1. Diagrammatic representation of multidetector CT. Four channels are shown revolving around the patient as compared to one channel for single-detector helical CT. Multidetector CT allows more volume of the patient to be scanned in a shorter period of time. Diagram courtesy of Siemens Medical Systems.

ever, it is only able to indirectly detect mural thrombi within an aneurysm.

On the other hand, CT angiography is less invasive and more accurate in determining the true size of the aneurysm sac. It is also far superior in its ability to detect mural thrombus. CTA can directly visualize the wall of the aorta and the surrounding structures. This is of great importance when characterizing inflammatory aneurysms as well as aneurysm rupture. Moreover, CTA has been shown to accurately characterize juxtarenal

or suprarenal extension of an abdominal aneurysm and to be highly accurate in the evaluation of branch vessel stenosis (2, 3) (Fig. 2).

Aortic Stent-Grafts

Until recently, open surgical repair was the only treatment option available for patients with abdominal aortic aneurysms. But, with the introduction and now widespread use of endovascular stent-grafts, patients once consid-

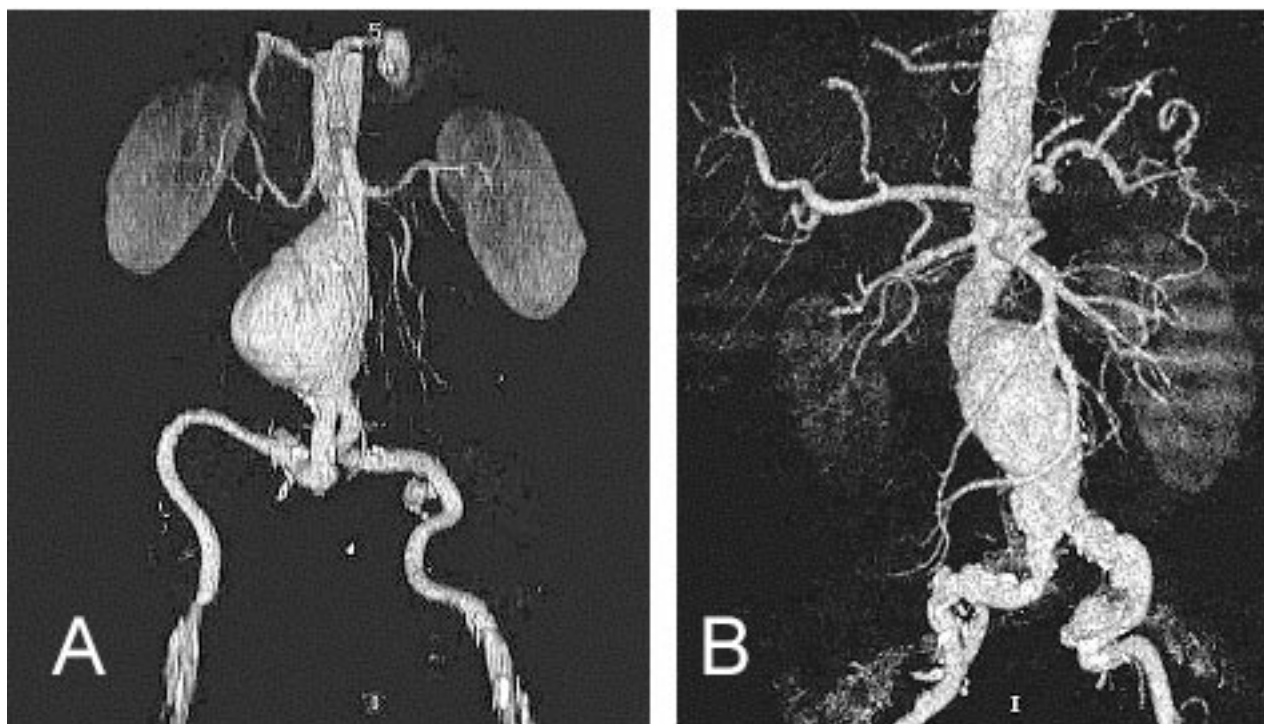


Fig. 2. (A) 3D reconstruction of a preoperative CTA of a patient being evaluated for endovascular repair. Note the poor spatial resolution of the branch vessels as well as the motion artifact at the bottom of the study. (B) 3D representation of a preoperative CTA on an 8-row multidetector CT. This study is able to characterize the vessels branching from the aorta and gives an accurate representation of the extent of the aneurysm.

ered poor surgical candidates are undergoing successful endovascular repair. The key to a successful outcome when using endovascular techniques is the ability to measure the maximum aneurysm diameter, the length of the abdominal aorta, and the degree of tortuosity of the aorta. These factors must be taken into consideration in the planning of these stent-graft procedures, since each stent-graft must conform to the patient's anatomy if complications are to be avoided. Routinely, a 15 mm proximal neck is required for adequate sealing of the vessel to the stent-graft. The endograft diameter is usually 2–3 mm larger than the vessel lumen. If the endograft diameter is too small or if the length of the proximal neck is too short, there may be an inadequate seal, which can lead to perigraft flow or endoleak. Too large a diameter may lead to folding of the endograft and an endoleak. Endografts that are too long or too short can lead to seal problems and ultimately to endoleaks, limb kinking or limb occlusion.

Transverse CT aortic measurements have been previously used to measure the diameter of the aorta. These measurements can greatly overestimate the true diameter because of obliquity. Similarly, craniocaudal measurements can substantially underestimate the true aortic length by not accounting for tortuosity.

One method of obtaining an accurate cross-sectional measurement is the creation of oblique multiplanar reformats perpendicular to the longitudinal axis of the aorta. This mean centerline can accurately determine the length of the aortic lumen that the endovascular device must cover, which is typically from the lowest renal artery to the origin of the internal iliac arteries bilaterally. A recent article examined this technique with respect to its accuracy in determining the length of the endovascular device (4). The article also described an algorithm used to determine the shortest path within the aortic lumen for the device to follow and demonstrated that the shortest path is the most accurate in predicting the true *in vivo* length of the device. Expanded use of this measurement may allow for more accurate preoperative measurements that can reduce the number of device-related complications. The median centerline can also give accurate luminal diameter measurements at any location along the aorta. Aortic length measurements of importance in the planning of these devices are the length from the lowest renal artery to the origin of the aneurysm, the length of the aneurysm itself, and the length from the aortic bifurcation to the ori-

gin of the internal iliac artery. Diameters of critical importance are those at the proximal attachment site at the lowest renal artery, the maximal diameter of the aorta, the diameter at the aortic bifurcation, and the diameter of the iliac arteries at the origin of the hypogastric artery.

Another parameter that can be determined using MDCT is the degree of tortuosity of the aneurysm. This variable can be critical in predicting the complexity of the procedure preoperatively and in choosing the site of primary access of the device. Wolf et al. reported that the degree of tortuosity correlated with increased complexity of the endovascular repair and with immediate device failure or endoleak (5).

Aneurysm volume has recently attracted a great deal of interest. This measurement has been theorized to be a more accurate method of detecting subtle postoperative changes in the aneurysm. A recent report demonstrated this measurement to be very powerful in its ability to predict endoleak (6). Volume changes can be detected earlier than diameter changes and can therefore be used to predict patients who are likely to have device failures (Fig. 3).

Postoperative Surveillance

CTA is very useful in the post-procedure monitoring of patients who have undergone endovascular repair of abdominal aortic aneurysm. The success of the treatment is dependant on continued exclusion of blood flow into the aneurysm sac. Persistent flow into the sac (or endoleak) is a sign of treatment failure. Because CTA relies on general arterial opacification, it is quite sensitive in detecting perigraft flow.

In 2000, Armerding et al. (7) studied the ability of helical CT to detect the presence of endoleak, as compared to conventional angiography. Forty patients underwent both helical CT and conventional angiography after stent-graft placement for abdominal aortic aneurysm. Twenty perigraft leaks were detected in the results of 46 examinations. CT was found to be more sensitive and specific than angiography.

When a CTA scan is performed postoperatively, it is imperative that prior administration of contrast be withheld in order to differentiate the presence of calcium within the sac thrombus from any true perigraft enhancement. Immediately following this examination, the scan can be repeated with contrast. This technique has been shown to increase the sensitivity of the study in detecting endoleaks (Fig. 4).

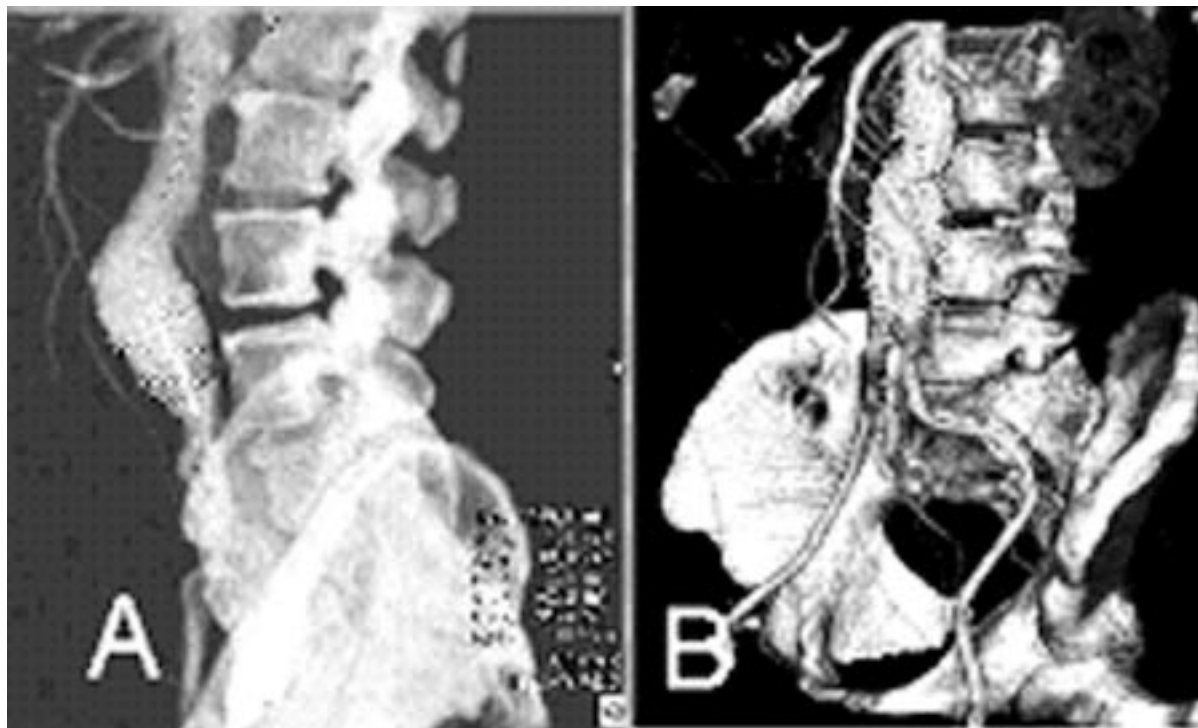


Fig. 3. (A) Median Center Line program determines length of the endovascular device from the renal artery to the internal iliac artery origin, as well as maximum and minimal luminal diameter. (B) A 3D data set of an infrarenal aneurysm in which the surface area (112 cm²) and volume (81 mL) of the aneurysm have been calculated. This information can be used to compare with postoperative studies to monitor the success of the endovascular repair.

The current classification used by the American Association of Vascular Surgeons (AAVS) to describe endoleaks is:

- Type 1 endoleak is caused by an incomplete seal at the proximal or distal attachment site or at the site of an iliac occluder device. It is relatively uncommon.
- Type 2 endoleak results from retrograde filling of the aneurysm sac from a patent branch vessel. It is the most common type of endoleak. The most frequent sources of type 2 endoleaks are via the inferior mesenteric artery and/or the iliolumbar artery to a lumbar artery arising off the sac.
- Type 3 endoleak is due to a tear in the fabric of the device from shear stress or from a fracture of one of the metallic struts of the framework. It is rare.
- Type 4 endoleak occurs when there is flow through the fabric of the graft due to increased porosity. It is very

rare but is seen with Dacron grafts. It is usually a transient phenomenon occurring immediately after implantation of the graft, and resolves after a few days (8).

3D reconstruction of MDCT data sets is extremely helpful for the postoperative evaluation of these patients. The 3D image processing allows excellent visualization of aneurysm and endograft deformation. Endograft deformation leading to type 1 and 3 endoleaks may result in catastrophic consequences, including aneurysm rupture. 3D reconstruction can also aid in the characterization of endoleak by delineating the inflow or outflow sources (Fig. 5).

As mentioned above, measuring the volume of the aneurysm can be an effective method of following up with these patients. A recent article (9) reported that successful treatment correlates with decreasing volume of the aneurysm, and that patients whose aneurysms do not decrease in volume may be at risk for endoleak formation.

A typical recommended schedule of follow-up studies includes 1 month after the procedure, 6 months after the procedure, 1 year after the

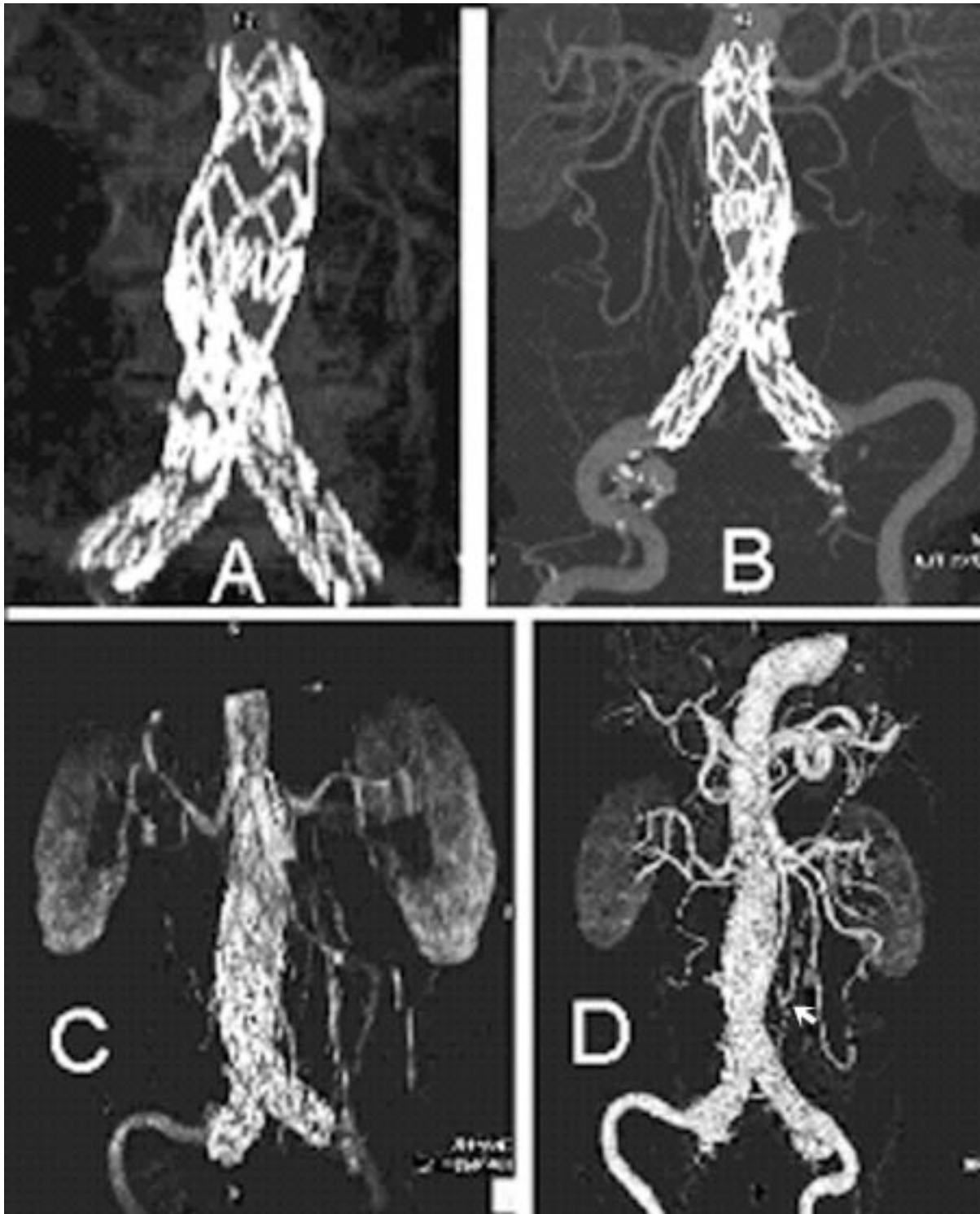


Fig. 4. (A) 3D reconstruction with single-row helical CT. The image is windowed to allow visualization of the metallic stent framework of the aortic endoprosthesis. (B) 3D reconstruction with 8-row multidetector CT (MDCT) of same patient. Notice excellent visualization of the stent framework, as compared to previous study. (C) Postoperative study of the same patient with a single-detector helical CT. (D) Postoperative CTA of same patient with 8-row MDCT. Notice exquisite resolution of the aortic vasculature. There is excellent detail of all aortic branches and the endovascular device. There is a suggestion (arrow) of perigraft flow or endoleak anterior to the device.

procedure, and then yearly. For patients in whom an endoleak is identified, the interval decreases

to 3 months in order to monitor the stability of the leak and possibly plan future intervention.

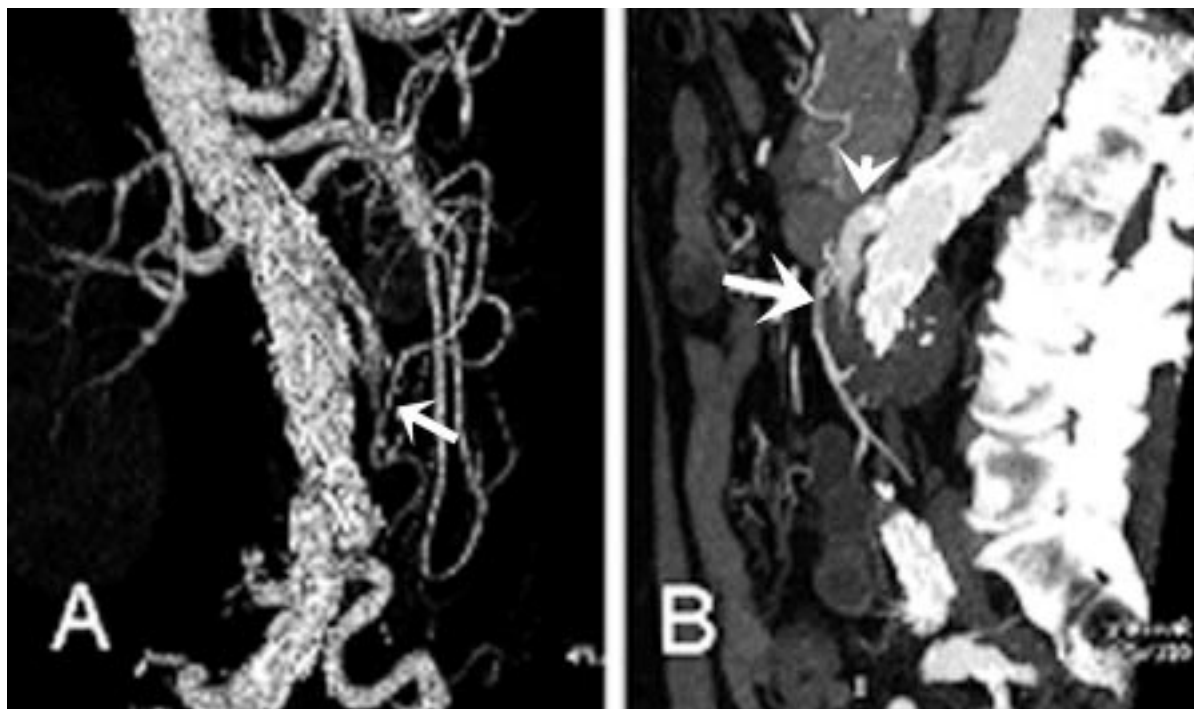


Fig. 5. (A) Right anterior oblique projection of same data set from Fig. 4 demonstrates perigraft flow in communication with the inferior mesenteric artery probably representing a Type 2 endoleak (arrow). (B) Curved multiplanar reformat of a maximum intensity projection shows the endoleak (arrowhead) to directly communicate with the inferior mesenteric artery (arrow).

Lower Extremity Occlusive Disease

A great deal of interest has arisen over a noninvasive method of screening for lower extremity vascular disease. While duplex sonography and plethysmography are quite reliable in identifying and localizing the general anatomic region involved, these tests cannot be used alone in planning endovascular procedures for the lower extremities. The specificities of these examinations are diminished in the presence of multilevel disease.

CTA has recently emerged as an attractive alternative for the screening of patients with presumed lower extremity occlusive disease as well as for those planning possible endovascular treatment. It is important to realize that the region of interest in these studies must be more than one meter in length, so as to include images depicting both inflow and runoff.

Single-detector spiral CT cannot provide imaging of the entire lower extremity. In 1995, Lawrence et al. reported imaging a portion of the lower extremity from the groin to the proximal calf in six patients with single-detector spiral CT angiography. The patients were studied with 5 mm slices. The studies

were performed over an area of interest of 60 cm and took more than two minutes to acquire (10). A later study performed by Beregi et al. imaged the popliteal arteries in patients suspected of having popliteal artery disease. This study demonstrated increased sensitivity and specificity in the detection of patients with popliteal artery aneurysms, as well as improved characterization of arterial compression by adventitial cysts and entrapment syndromes (11).

MDCT has three primary advantages over single-row detector CT: shorter scanning durations, thinner sections of entire anatomic territories, and greater longitudinal coverage.

A recent study by Rubin et al. used MDCT angiography on 24 patients with symptomatic lower extremity occlusive disease. The study used 2.5 mm slices to acquire images extending from the abdominal aorta to the feet. The average study time was a little over one minute and covered 1.2 meters. This study demonstrated a 100% concordance between CT and conventional angiography at direct comparison (12).

Our current protocol includes 2 mm slices from the diaphragm to the feet with a 16 row MDCT. Our studies take less than 30 seconds to acquire (Fig. 6).



Fig. 6. Whole body CT angiogram performed on a 16-row multidetector scanner. This study was performed from the carotid arteries down to the feet in less than one minute.

Renal Arteries

Renovascular hypertension and ischemic nephropathy have become topics of interest to all endovascular specialists, with the increasing use of endovascular stent technology to treat

these conditions. One limitation of CT angiography is the fact that the renal arteries typically course in the plane of the axial sections in which the data is collected.

A study designed to visualize the renal arteries should include not only the abdominal aorta but also the iliac and femoral arteries bilaterally, since these are the approaches used in the treatment of this disease entity.

Many studies have been performed to analyze the utility of CT angiography in the diagnosis of renal artery stenosis. In 1994, Galanski et al. reported a comparison of single-detector helical CTA with conventional angiography and found that the former technique provided the correct identification of renal artery stenosis in 22 of 54 renal arteries examined. Demonstration of the degree of stenosis was found to be comparable to that with conventional angiography in all but four patients (13). When compared to conventional angiography, the sensitivity and specificity of CTA was 92% and 95% respectively.

In 1997, Kaatee reported an important study which showed that false positive diagnoses of renal artery stenosis were in fact false negative studies during conventional angiography performed in suboptimal projections (14). Specifically, the techniques for conventional angiography did not optimally visualize the renal arteries and missed several stenoses. Other studies have shown that ancillary findings that may aid in the diagnosis of renal artery stenosis include post-stenotic dilatation and asymmetric renal parenchymal enhancement. The presence of renal artery calcification has not been shown to correlate strongly with renal artery stenosis.

A recent study by Behar et al. compared CTA and conventional angiography for the follow-up of patients who had undergone renal artery stent placement. In a total of 15 patients, all 17 stent lumina were well visualized. The CT angiograms appeared to underestimate the lumen of the vessel slightly as compared to conventional angiograms. The cause for this was unknown (15) (Fig. 7).

Summary

The imaging requirements for endovascular procedures are much more complex than those previously required for open vascular procedures. Many details must be evaluated before the physicians can select those procedure(s) and devices that will optimize the outcome. Poor planning usually results in a technical failure, with the need for repeat procedures or (ulti-

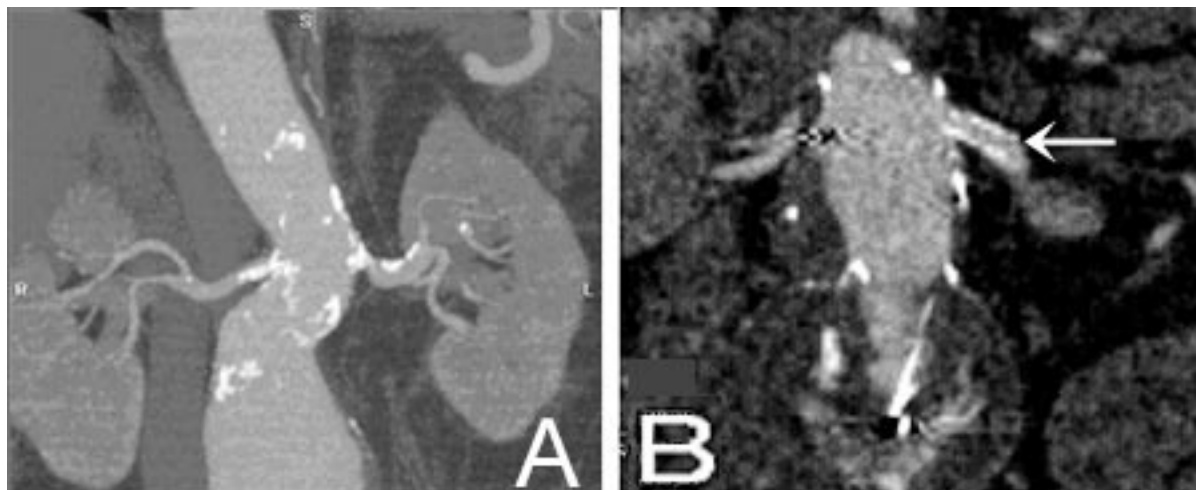


Fig. 7. (A) 3D reconstruction of a CTA of the abdomen. The patient is noted to have a left renal artery stenosis. (B) Coronal section of a Maximum Intensity Projection MultiDetector CTA data set in a different patient who had undergone left renal artery stenting. The lumen of the left renal artery can be visualized on this study and is noted to be patent (arrow).

mately) conversion to an open surgery. As a result, post-procedure imaging is essential for monitoring the success of the procedure and planning any further interventions. The endovascular specialist must be well versed in the latest imaging technology, in order to achieve technical success and adequately follow up patients who have undergone these minimally invasive procedures.

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