

MDCT Angiography to Assess Aortic Pathology and PAD

Diagnostic accuracy and improved spatial resolution make this an invaluable tool.

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Since its introduction nearly 5 decades ago, the technique of transcatheter digital subtraction angiography (DSA) has been widely regarded as the gold standard in evaluating patients with occlusive disease of the aortoiliac vessels and infrainguinal arterial circulation.¹ However, complications of this invasive imaging technique, including iatrogenic arteriovenous fistula, pseudoaneurysm, retroperitoneal hematoma, or even life-threatening access-site hemorrhage, are well described and can be associated with significant morbidity.^{2,3} Significant technological advances in helical computed tomography (CT) have occurred in the past 2 decades that have enabled evaluation of peripheral circulation based on a single contrast-material injection with thinner slice sections and faster acquisition time.

MULTIDETECTOR CT

The introduction of multidetector CT (MDCT) in the early 1990s represents a remarkable improvement in CT imaging, particularly in the diagnostic evaluation of cardiovascular systems. Detectors are image-capturing components of a CT scanner that analyze the x-ray beam as it passes through the body. A single-detector CT scanner has only one detector to capture and process imaging information. In contrast, an MDCT scanner has several detectors, greatly enhancing the speed of image processing. The first MDCT scanners had two detectors. In the years after its introduction, continuous advancement of MDCT technology has led to the development from 4-, 8-, 16-, and current 64-detector row CT scanners. With each new advance,

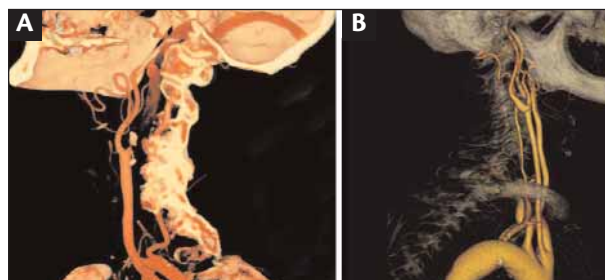


Figure 1. MDCT angiography of the carotid artery. Volume-rendered images of the carotid artery in a 64-year-old woman showing an internal carotid artery occlusion (arrow) with calcified plaques in the carotid bulb (A). Three-dimensional images of the carotid artery in a 52-year-old man displaying the entire segment of the carotid artery from the thoracic inlet to the base of the skull (B).

MDCT scanners became faster in image acquisition. MDCT scanners can now acquire hundreds of images in just a few seconds. Corresponding advances in computer hardware have kept pace with a newer generation of MDCT scanners. Advanced computer systems enable more efficient image-processing software, which provides more accurate diagnostic information that could not be reproduced a decade ago. Various advanced three-dimensional image processing techniques, including maximum-intensity projection or volume-rendering images, provide enhanced visualization of the peripheral vasculature. This imaging modality has created a new diagnostic strategy in peripheral arterial circulation, with widespread clinical applications

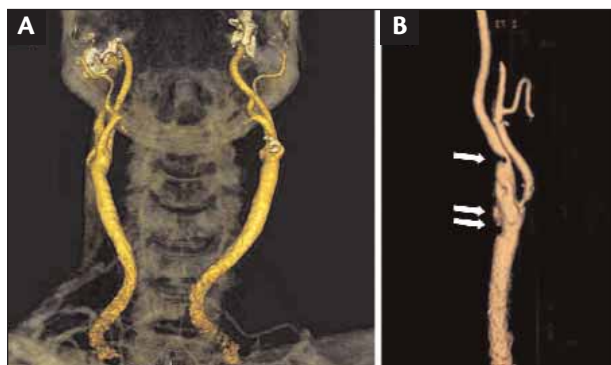


Figure 2. MDCT angiography of bilateral carotid arteries in a 62-year-old woman, which displayed the entire carotid segment from the proximal origin to the distal intracranial internal carotid artery (ICA) (A). An anterior oblique curved planar reconstruction of the left carotid artery showed a high-grade stenosis in the ICA (single arrow) and an ulcerated plaque in the distal common carotid artery (double arrows) (B).

in occlusive disease, aneurysmal disease, and traumatic vascular injuries.

Utility of MDCT

Two important differences exist between conventional spiral CT and MDCT. The first difference is that MDCT can acquire images at a significantly faster rate (0.37-second rotation speed), compared to a 1-second rotation speed for the conventional CT scanner. Additionally, and more importantly, MDCT acquires volume data as opposed to individual slice data, as is the case of a conventional CT scanner. The combined effect of these two features enables MDCT to acquire a thin-slice imaging section quickly without compromising the spatial resolution of the original axial images.

The noninvasive and rapid imaging acquisition of MDCT angiography, with a radiation exposure approximately four times less than that of conventional transcatheter DSA, has resulted in wide acceptance of this diagnostic modality from clinicians and patients.⁴⁻⁶ Additionally, the postimaging process of MDCT angiography at high spatial resolution and consistently high image quality renders a reliable and observer-independent diagnostic modality for evaluating various vascular structures.⁷ Many clinical investigations have also validated the high

diagnostic accuracy of MDCT angiography when compared to MR angiography, transcatheter DSA, and duplex ultrasound in the evaluation of peripheral vascular circulation and traumatic vascular injuries.^{5,6,8-11}

With the increased availability of MDCT in health care facilities worldwide, this imaging modality has been widely used in many interdisciplinary clinical vascular practices and in emergency rooms for patients with vascular injuries. MDCT is commonly offered as a 24/7 service in most tertiary hospitals, and as a result, it has replaced transarterial DSA as the preferred imaging study in many clinical practices for evaluating patients with aneurysmal or occlusive vascular conditions. We discuss clinical application of MDCT angiography and its relevant utility in the evaluation of various vascular systems.

PRINCIPLES OF CT ANGIOGRAPHY

Image processing of CT angiography encompasses many principles. First, adequate arterial contrast enhancement via intravenous injection is achieved during CT image acquisition. Second, adequate cranialcaudal scanning of the vascular system is performed during maximal arterial contrast opacification. Last, digital image processing of the acquired data is performed using various postprocessing algorithms, including maximum-intensity projection, volume-rendering technique, surface shaded display, and multiplanar reconstruction.¹² Optimal evaluation of the vascular circulation using MDCT angiography also requires two essential conditions: (1) maximal arterial contrast enhancement while reducing venous contrast interference to allow high-quality three-dimensional image reconstructions, and (2) high spatial resolution.

MDCT can provide image acquisition with a shorter scanning time and greater spatial resolution compared to a conventional CT scan. In a conventional single-detector CT angiography evaluation, for instance, the table speed varied from 5 to 10 mm/s. This speed could be increased to 36 mm/s using a 16-detector CT scanner. The section thickness decreased from 5.5 mm with single-detector CT angiography to 0.75 mm with 16-section MDCT angiography.¹² These technologic refinements have resulted in improved imaging quality with greater spatial resolution, while the scanning time from the aorta to the pedal vessels can be achieved with a single-bolus intravenous contrast injection.¹² Although faster scanning using the



Figure 3. MDCT angiography of the thoracic aorta in a 48-year-old man with acute onset of chest pain radiating to the back. Reconstruction of the CT angiography showed an aortic dissection with a distinctive false lumen (long arrow) and true lumen (short arrow).

MDCT system can theoretically reduce the amount of contrast medium used based on a single-bolus intravenous administration, the result may be lower spatial imaging resolution and imprecision in timing acquisition.

The technical parameters with regard to MDCT image acquisition are, in part, influenced by the type and model of the multidetector scanner (ie, 4-, 8-, 16-, or current 64-detector row CT scanners). Even with the current technological advancements in CT imaging, determining the optimal timing of arterial contrast enhancement when evaluating lower-extremity arterial circulation remains a challenge. This challenge is influenced, in part, by the individual hemodynamic and physiologic status of each patient. For instance, patients with compromised cardiac output with significant obstructive disease involving the lower-extremity circulation may have a substantial delay in achieving optimal contrast opacification of the pedal vessels.¹³ Additionally, the presence of an aortic aneurysm may further contribute to the timing delay due to prolonged contrast transit time within the aneurysm. Various techniques of determining acquisition parameters based on a single contrast bolus to improve the image quality and diagnostic accuracy of MDCT of the peripheral arterial circulation have been described.^{4,8,14-16}

Comparison With Other Dynamic Imaging Modalities

Various noninvasive imaging modalities, such as magnetic resonance (MR) angiography, have been used extensively in evaluating patients with peripheral arterial disease.¹⁷ Compared with CT angiography, MR angiography has significantly less spatial resolution, particularly in analyzing small-caliber vessels, such as the infrapopliteal circulation. Additionally, scanning a large body segment encompassing an arterial system based on a single-bolus contrast injection to achieve optimal arterial enhancement with minimal venous opacification represents a challenge for MR angiography. An advantage of MR angiography compared with CT angiography is that no ionizing radiation or iodinated contrast agents are needed in MR angiographic evaluation. To address this potential drawback, researchers have proposed methods to reduce the radiation dose required during a CT evaluation by automodulation of mA dose during CT image acquisition, lower dose protocol at 50 mAs, and low kV setting at 100 kVp.^{14,15,18,19} Further studies are currently underway to validate the diagnostic accuracy of CT angiography



Figure 4. MDCT angiography of the thoracic aorta in a 73-year-old man showed a fusiform descending thoracic aortic aneurysm.

using reduced radiation dose protocols in clinical practice.

An important drawback of MDCT angiography is suboptimal vessel assessment in calcified arteries. Several studies have noted a decreased diagnostic accuracy of MDCT angiography in vessels with severe calcification compared to arteries without vessel wall calcifications.^{8,11,20} Ota et al reported a series of 27 cases of MDCT angiography of peripheral arterial occlusive disease. Using a stratification system based on the severity of arterial calcification, the investigators reported decreased diagnostic accuracy of MDCT angiography in vessels with increased calcification.¹¹ This diagnostic inaccuracy can lead to potential overestimation of luminal stenosis due to arterial calcification, particularly in patients with diabetes.^{21,22}

When evaluating patients with lower-extremity arterial occlusive disease, MDCT angiography showed comparable

pooled estimates of sensitivity and specificity. Visser et al reported a meta-analysis of gadolinium-enhanced MR angiography during a 4-year period of all patients with lower-extremity arterial occlusive disease and reported a pooled sensitivity of 97.5% and a pooled specificity of 96.2% for MR angiography, in contrast to 87.6% and 94.7%, respectively, for color-guided duplex ultrasonography.²³ Koelemay et al similarly reported a meta-analysis that estimated a 94% sensitivity and specificity for three-dimensional gadolinium-

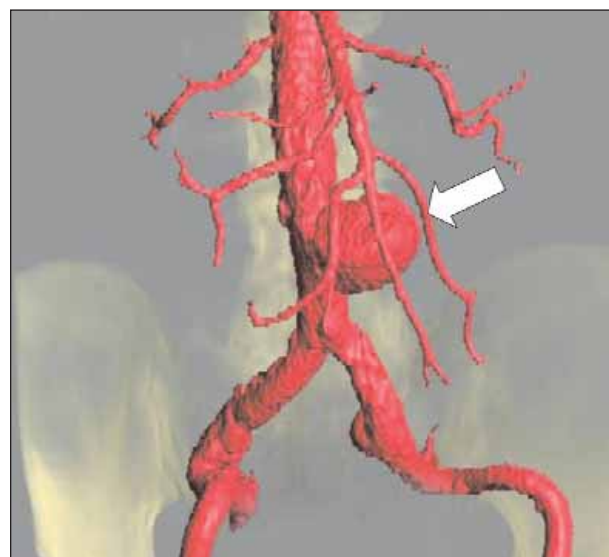


Figure 5. MDCT angiography of the aorta in a 68-year-old man showing a saccular infrarenal aortic aneurysm (arrow).

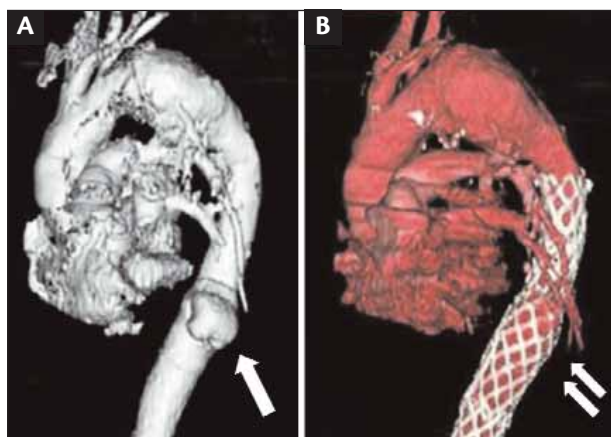


Figure 6. MDCT angiography of the thoracic aorta in a 62-year-old man showing a saccular descending thoracic aortic aneurysm (arrow) (A). Implantation of stent graft devices in the descending thoracic aorta successfully excluded the aneurysm (double arrows) (B).

enhanced MR angiography.²⁴ The advantages of MDCT angiography compared with MR angiography include relatively short imaging time, significantly greater spatial resolution, and lower cost for MDCT evaluation.²⁵ In vessels with low flow due to either small vessel caliber or compromised cardiac function, images of MR angiography frequently mimic luminal narrowing or overestimate the severity of arterial disease. Additionally, MR angiography is contraindicated in patients who have metallic prostheses or claustrophobia.

CAROTID ARTERY IMAGING

Atherosclerotic lesions of the extracranial carotid arteries are accountable for nearly two thirds of all ischemic strokes.^{26,27} Accurate evaluation of the carotid arteries to determine the severity of atherosclerotic lesions is critical because appropriate intervention based on accurate lesion evaluation can lead to stroke prevention and improved survival.^{28,29} Although carotid ultrasound is a widely adapted imaging modality in carotid artery screening, it is associated with certain limitations, including the inability to evaluate potential lesions in the distal carotid artery near the skull base or proximal carotid vessel near the thoracic inlet. Because of the recent advances in carotid stenting technology, many physicians have increasingly used transcatheter DSA as an imaging modality for carotid artery lesions. However, transcatheter DSA is associated with small but potentially serious complications, including catheter-related groin complications and distal cerebral embolization due to catheter manipulation.³⁰

Before the advent of MDCT technology, helical CT angiography was commonly used for evaluating atheroscle-

rotic lesions in the carotid arteries. However, the enhanced temporal and spatial resolution of MDCT scanners significantly improved the diagnostic accuracy of atherosclerotic disease involving the carotid artery (Figure 1). In contrast to carotid duplex ultrasound, MDCT can provide accurate evaluation of the intracranial as well as extracranial carotid artery in the same setting (Figure 2). In a study comparing the diagnostic accuracy of MDCT to intra-arterial DSA, Silvennoinen et al analyzed 73 carotid arteries in 37 patients who had carotid artery bifurcation lesions. The investigators reported a remarkable diagnostic accuracy for MDCT in which the sensitivity and specificity for high-grade stenosis were 75% and 96%, respectively. For moderate carotid stenosis, the sensitivity and specificity of MDCT were 88% and 82%, respectively.³¹ Additional studies using dynamic perfusion CT angiography to evaluate the composition of atherosclerotic plaques in the intracranial circulation and hemodynamic brain perfusion similarly underscored the diagnostic value of MDCT in these lesions.^{32,33}

Previous studies have shown a correlation between coronary vessel calcification, as determined by CT angiography, and coronary stenosis, as assessed by intra-arterial DSA.³⁴⁻³⁶ McKinney et al analyzed the correlation between calcium burden within the carotid arteries and the degree of carotid bifurcation lesion using contrast-enhanced MDCT of the neck in 61 patients.³⁷ The investigators reported a strong correlation between the amount of calcium within the vessel wall and the degree of stenosis at the ICA bifurcation.³⁷ This finding confirmed a high correlation between carotid calcium scores and the severity of coronary heart disease. Additionally, this study highlights a potential utility of MDCT in assessing the calcium burden of the ICA for

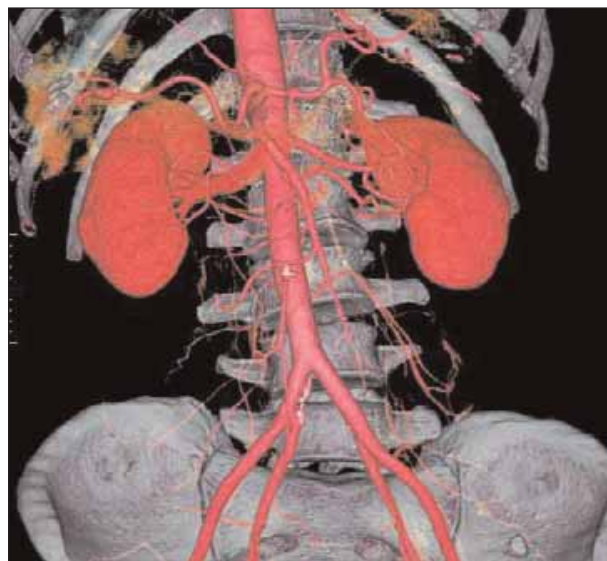


Figure 7. MDCT angiography of the aorta and its visceral vessels showing patent bilateral renal arteries in a 52-year-old man.

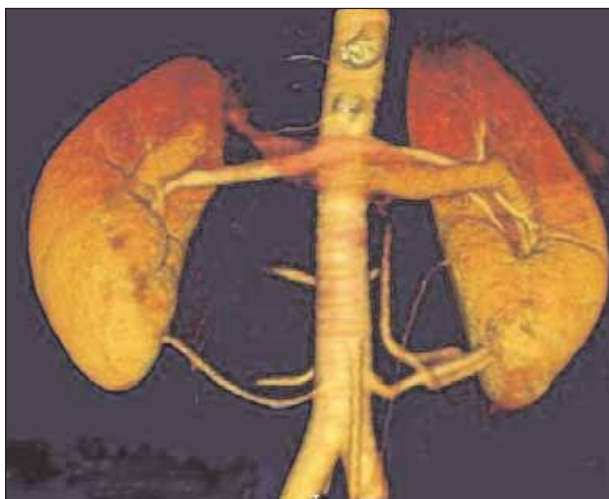


Figure 8. MDCT angiography of the aorta and renal branches showing patent bilateral renal arteries in a 72-year-old woman.

screening purposes. However, it is noteworthy that current evidence remains scarce in correlating calcium load with any prognostic significance in patients with nonhemodynamically significant carotid lesions. By extrapolating from the coronary literature, the role of MDCT in determining the diagnostic benefit of carotid calcium burden must be addressed by multicenter studies to validate the prognostic benefit of this imaging modality as a screening tool.

A potential diagnostic challenge of CT angiography in a carotid artery is the differentiation between total occlusion or pseudo-occlusion, which is defined as high-grade stenosis with a dramatically diminished flow that does not contribute to the perfusion of the ipsilateral cerebral hemisphere. Although no intervention is required in patients with complete carotid occlusions, patients with a pseudo-occlusion or string sign may require systemic anticoagulation with intravenous heparin administration and should be considered for either carotid endarterectomy or stenting. Carotid pseudo-occlusion is typically difficult to diagnose based on duplex ultrasound. Similarly, the diagnostic accuracy of MR angiography is limited because it frequently overestimates the severity of carotid lesions. Catheter-based DSA has long been considered the diagnostic study of choice for this condition. However, recent studies have revealed that contrast-enhanced MDCT provides similar diagnostic accuracy when compared to intra-arterial DSA in differentiating high-grade carotid stenosis, total carotid occlusion, or carotid pseudo-occlusion.^{38,39}

AORTIC ANEURYSM AND AORTIC DISSECTION IMAGING

Surgical revascularization has been the mainstay of therapy for patients with aortic aneurysms or aortoiliac occlusive

disease before the advent of endovascular technologies. In these patients, intra-arterial DSA was the primary imaging modality to assess the extent of aortoiliac pathologies. The development of endovascular stent graft technology has broadened the diagnostic utility of CT angiography in the evaluation of aortic disease.⁴⁰ In contrast to DSA, CT angiography is undoubtedly less invasive and more accurate in determining the aneurysm diameter and assessing mural thrombus burden. CT angiography also enables clear visualization of the aortic wall to assess the presence of an inflammatory aortic aneurysm. Additionally, it facilitates accurate detection of aneurysm rupture or contained leakage.

In patients with suspected acute aortic dissection, contrast-enhanced MDCT scanning of both the chest and abdomen should be performed because it is particularly useful in detecting intimal flap, the extent of aortic dissection, branch vessel involvement, patency of true and false lumens, potential pericardial effusion, and even the luminal patency of proximal coronary arteries.⁴¹ In this imaging modality, an initial noncontrast CT scan should be performed to rule out intramural hematoma because intravenous contrast may obscure this diagnosis due to uniform opacification of luminal structures. Intramural hematoma may appear as localized thickening of the aortic wall with internal displacement of intimal calcifications.^{42,43} Alternatively, it may present as a crescent-shaped, high-attenuation signal within the aortic wall. The diagnosis of aortic dissection is established by the visualization of the intimal flap separating the true and false lumen (Figure 3). Additional CT signs that are suggestive of aortic dissection include compression of the true lumen by the false lumen,

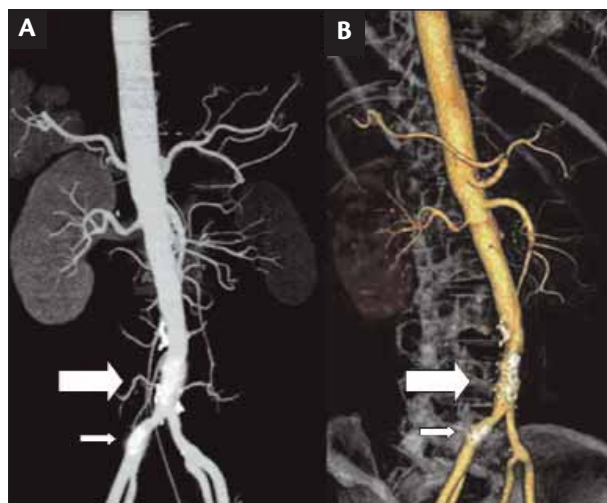


Figure 9. MDCT angiography of the aortoiliac artery circulation in a 63-year-old man with buttock claudication (A). Three-dimensional image reconstruction showing intra-arterial calcification of the aorta (large arrow) and right common iliac artery (small arrow) (B).

widening of aortic lumen, and displaced intimal calcification.^{42,43} Limitations of CT scanning include the inability to identify the location of the intimal tear, the necessity to administer iodinated contrast agents, and the difficulty of assessing aortic insufficiency. The diagnostic importance of CT angiography in the evaluation of aortic dissection is highlighted in the International Registry of Acute Aortic Dissection (IRAD) study, in which the contrast-enhanced CT scan was the most commonly performed initial diagnostic modality in patients with suspected aortic dissection.⁴⁴ CT scan sensitivity for diagnosing acute aortic dissection ranged from 83% to 100%, and the specificity ranged from 87% to 100%.¹⁻⁶

Current diagnostic evaluation of aortic aneurysm for endovascular repair relies primarily on CT angiography to assess the anatomical suitability for endograft implantation (Figures 4 and 5). The available software program is capable of reconstructing three-dimensional display of aortic morphology images from thousands of CT scans, providing an invaluable tool for preoperative planning and postoperative surveillance (Figure 6). The treatment objective of endovascular stent graft implantation is to exclude the aortic aneurysm from systemic circulation. CT angiography provides sensitive information regarding the presence of contrast within the aneurysm sac, or endoleak, after endograft placement. Multiple studies comparing the diagnostic accuracy of various imaging modalities have reported that CT angiography provides greater sensitivity and specificity than conventional angiography for endoleak detection or inadequate endograft exclusion.^{45,46} The success of endograft exclusion of an infrarenal aortic aneurysm is partly influenced by appropriate patient selection with suitable aortic morphology for stent graft implantation. Favorable anatomical criteria for successful aortic endograft implantation include 15 mm of proximal aortic neck below the renal arteries, absence of aortic thrombus within the aortic neck, aortic angulations $<65^\circ$ within the endograft landing zone, minimal iliac vessel tortuosity, and 15 mm of distal iliac artery neck for endograft implantation. Newer-generation endografts with fenestrated or branched stents allow treatment of juxtarenal, suprarenal, or even thoracoabdominal aortic aneurysms. Because these fenestrated or branched aortic endografts are custom made based on the individual patient's aortic morphology, MDCT scanning with three-dimensional image reconstruction provides critical preoperative anatomical information regarding visceral vessel angulations and distance from various aortic branches to allow endograft device customization.^{47,48}

RENAL ARTERY IMAGING

The most common clinical applications of renal artery angiography are to identify renal artery pathologies, includ-

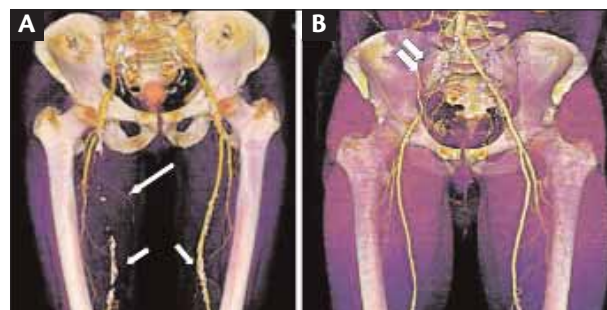


Figure 10. MDCT angiography of the iliofemoral arterial circulation in two patients with lower-leg claudication. A 50-year-old man with an occluded right superficial femoral artery (single long arrow) with reconstituted superficial femoral artery at the level of mid thigh. Arterial calcifications (single short arrow) in the bilateral distal superficial femoral arteries (A). A 53-year-old man with occluded right common iliac artery (double arrows) (B).

ing renal artery stenosis, fibromuscular dysplasia, or renal artery aneurysms, which may be responsible for conditions such as renovascular hypertension, renal parenchymal dysfunction, or pain-related symptoms.

Renovascular hypertension caused by renal artery stenosis is a curable condition that affects approximately 5% of patients with secondary hypertension.⁴⁹ Conventional screening using Doppler ultrasound to detect renal artery stenosis is highly dependent on the experience of the ultrasonographer as well as the patient's body habitus. Potential inaccuracy using ultrasound can occur when encountering lesions in the accessory renal arteries. Compared to transarterial DSA, duplex ultrasound for detecting renal artery stenosis is associated with a sensitivity and specificity of 75% and 89%, respectively.⁵⁰ Both MDCT and MR angiography can be used to evaluate renal artery occlusive disease, and they have similar diagnostic accuracy in evaluating renal artery stenosis (Figures 7 and 8). By comparing MR angiography and MDCT angiography of renal arteries in 46 patients, Willmann et al reported sensitivities of 93% and 92%, respectively and specificities of 100% and 99%, respectively.⁵ Despite the similar diagnostic accuracy in this study, the investigators reported a higher patient acceptance for MDCT angiography, due in part to potential claustrophobic effects associated with MR angiography. For patients who underwent renal artery stenting, MDCT angiography can also be used for poststenting surveillance to detect potential lesion recurrence.

Another important indication to perform renal artery angiography is to evaluate renal anatomy of live kidney transplant donors. In this scenario, it is important to detect any associated anatomical variance in kidney donors, including accessory renal arteries, multiple renal artery

branches, or incidental renal pathology, such as renal cysts. For evaluating the renal vasculature in transplant donor patients, MDCT angiography has the advantage over MR angiography in that it is more acceptable to patients and misses fewer accessory renal arteries.⁵

Studies that used MDCT angiography to determine the sensitivity and specificity for identifying accessory renal arteries have been compared to either intraoperative findings or conventional DSA as the standard. These studies reported sensitivity rates between 80% to 100% with specificity rates between 96% to 100% in the detection of accessory renal arteries.⁵¹⁻⁵⁴ The sensitivity and specificity of the identification of early arterial branching was reported as 100% by Kim et al, who analyzed 42 living renal transplant donor candidates by comparing MDCT angiography and MR angiography.⁵⁴ Laugharne et al analyzed renal artery anatomy in 156 patients undergoing live donor renal transplantation and compared the diagnostic accuracy of MDCT angiography with intraoperative findings.⁵¹ The investigators reported a sensitivity of 89% and a specificity of 100% using MDCT angiography when compared to intraoperative findings. These studies have consistently validated the diagnostic accuracy of MDCT angiography in assessing renal vasculature.

IMAGING OF AORTOILIAC AND LOWER-EXTREMITY ARTERIAL CIRCULATION

Duplex ultrasound evaluation and pulse volume recording with ankle-brachial index measurement are commonly

used diagnostic tools for both screening and assessing lower-extremity arterial occlusive disease. However, these noninvasive studies are associated with certain limitations. Noncompressive calcification in the lower-extremity arterial system frequently overestimates arterial blood pressure and yields suboptimal ultrasound evaluation. Additionally, duplex ultrasound is operator-dependent and may provide a detailed image of extraluminal pathologies, including popliteal entrapment syndrome or cystic adventitial disease of the popliteal artery.

Although conventional intra-arterial DSA remains the standard diagnostic technique for evaluating patients with lower-extremity arterial occlusive disease, CT angiography provides a less-invasive and fast imaging modality, which provides a high spatial resolution that scans over a wide region of the body (Figures 9 and 10). The additional advantages of CT angiography are the detection of extraluminal pathology, including adventitial cystic disease of the popliteal artery or popliteal artery entrapment syndrome in patients whose claudication syndrome may mimic peripheral arterial occlusive disease. MDCT angiography provides detailed evaluation of eccentric lesions and permits identification of greater arterial segments, particularly in the evaluation of peripheral arterial occlusive disease. The sensitivity and specificity of MDCT angiography in comparison to the conventional DSA are reported to be between 93% and 100% for the peripheral arterial circulation.⁵⁵⁻⁵⁸

For preoperative evaluation of peripheral arterial vessel mapping of upper or lower extremities, MDCT angiography provides an alternative imaging modality to duplex ultrasound or transarterial DSA evaluation. MDCT angiography is accurate for arterial mapping before complex extremity revascularization or free-flap reconstruction in the upper- and lower-extremity arteries.^{59,60} In a 14-patient study, Bogdan and associates demonstrated a 100% agreement between MDCT angiography and intraoperative findings regarding arterial anatomy in patients with complex upper-extremity reconstructions. In addition, preoperative images from MDCT angiography changed the surgical approach in two of the 14 patients.⁶⁰ In other studies that evaluated 10 patients undergoing microsurgical reconstructions of the head, neck, and peripheral upper and lower extremities, all patients underwent preoperative MDCT angiography with three-dimensional vascular and soft-tissue image reconstructions. The investigators reported that this preoperative imaging modality provided precise vessel mapping analysis for microsurgical reconstruction and was more cost effective compared to the traditional transcatheter DSA for vessel mapping purposes.⁵⁹

Several studies have recently examined the diagnostic accuracy of 4-detector row CT angiography in the evaluation of aortoiliac and infrainguinal arteries in patients with

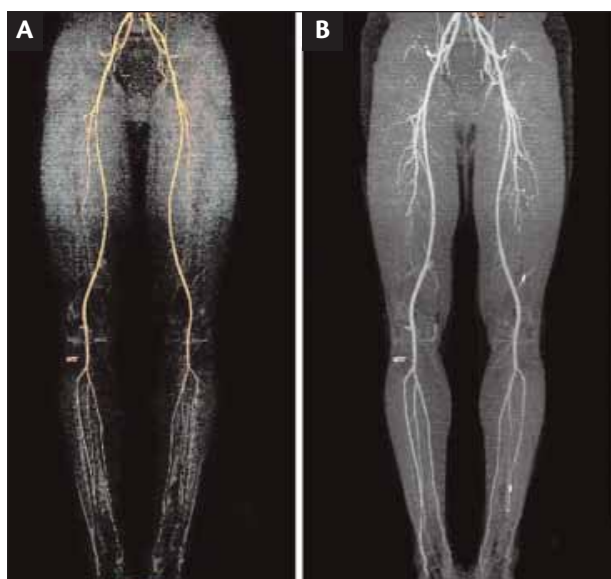


Figure 11. MDCT angiography of the lower-extremity circulation in a 56-year-old man with volume-rendered (A) and maximum-intensity projection images (B). Both images show normal lower-extremity arterial circulation.

peripheral arterial occlusive disease.^{22,61,62} Using slice thicknesses between 1.25 and 5 mm, 4-detector row CT angiography yields sensitivities and specificities between 91% and 99%.^{8-11,16} However, due to limited spatial resolution in vessels with diameters <3 mm, there remain technical challenges when using 4-detector row CT angiography to evaluate infrapopliteal or pedal arteries. Ofer et al reported 64% (14 of 22 vessels) of all radiographic mismatches between conventional DSA and 4-detector row CT angiography were located in small-caliber vessels, including the renal, infrageniculate, or pedal arteries.⁸ In a similar study that evaluated small-diameter peripheral arteries of the calves, Martin et al reported that all of the 22 infrapopliteal segments could not be adequately visualized by the 4-detector row CT angiography.⁹ However, with the enhanced spatial resolution of the 16-detector row CT angiography, researchers were able to achieve remarkable sensitivities and specificities of 96% and 97% for assessing luminal lesions in infrapopliteal and pedal vessels.⁶

Another advantage of MDCT angiography is that image comparison of contrast opacification can be made between the peripheral venous vessel and central aortic image, thus allowing better opacification of collateral vessels or arteries distal to an occlusion segment. Ota et al examined a total of 480 infrainguinal arterial segments in 24 patients and noted that 10 of these vessel segments (2%), which were clearly identified on MDCT angiography, could not be visualized using the conventional DSA.¹¹ The finding of this study was consistent with a similar study by Martin and colleagues comparing MDCT and conventional DSA in 35 patients with aortoiliac and infrainguinal occlusive disease.⁹ The investigators reported that 91 of 105 arterial segments (86.7%), which were inadequate by catheter-based DSA evaluation, were visualized without difficulty using MDCT angiography. With 16-detector row CT angiography, a sensitivity higher than 94% has been demonstrated for peripheral arterial circulation, which encompasses aortoiliac vessels, femoral arteries, infrapopliteal segments, and pedal arteries.⁶ Based on the current MDCT technologies, diagnostic evaluation using 16- or 64-detector row CT angiography can be recommended for patients with peripheral arterial occlusive disease involving infrageniculate or pedal vessels (Figures 11 and 12).

In a recent meta-analysis evaluating 12 studies of more than 400 patients that compared DSA and MDCT angiography, the pooled sensitivity and specificity were, respectively, 92% (95% confidence interval [CI], 87% to 95%) and 91% (95% CI, 87% to 95%) for the aortoiliac level, 96% (95% CI, 94% to 99%) and 85% (95% CI, 73% to 89%) for the femoropopliteal level, and 91% (95% CI, 85% to 97%) and 85% (95% CI, 72% to 97%) for the infrapopliteal level.¹² However, there has been significant heterogeneity among

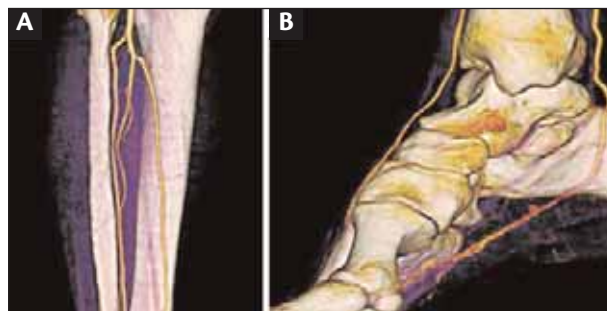


Figure 12. MDCT angiography of a 63-year-old man showing infrapopliteal arterial circulation (A) and pedal arterial circulation (B). The high spatial resolution and image quality of these images shows three patent infrapopliteal runoff vessels and patent pedal vessels at the foot level.

the studies in terms of scanning protocol and image acquisition, which can result in potential patient selection bias for image interpretation. The investigators from this meta-analysis report concluded that MDCT angiography has a high diagnostic value when compared with the conventional DSA modality. There remain several technical challenges for CT angiography of the lower-extremity circulation, including incorporation of a relatively large amount of intravenous contrast (140 to 160 mL), appropriate imaging acquisition speed so that it does not exceed 50 mm/s to avoid image scanning ahead of intra-arterial contrast arrival, and the need for postscanning image processing for three-dimensional image reconstruction because the large volume of images of the lower-leg circulation cannot be adequately viewed using axial images alone. Several recent studies have provided various imaging protocols for MDCT angiography to optimize scan enhancement and reduce the intravenous contrast requirement of lower-extremity arterial evaluation.⁶³⁻⁶⁵

Postoperative Surveillance

Postoperative bypass graft surveillance is a critical component of clinical care in patients who undergo peripheral vascular reconstruction because as many as 30% of patients develop graft-related complications within the first 2 years after surgery.^{66,67} Duplex ultrasound has long been considered the imaging study of choice in postoperative graft surveillance due to its low cost and wide availability. Frequently, when bypass graft lesions are detected by ultrasound, patients still undergo transarterial angiography to confirm the lesion before undergoing corrective surgical revision. Willmann et al performed a prospective study with 65 patients who underwent MDCT angiographic evaluation of 85 peripheral arterial bypass grafts.⁵ The investigators reported that 4-detector row CT angiography is feasible, accurate, and reliable. Additionally, this imaging modality is

accurate in detecting graft-related complications, including stenosis, aneurysmal development, and arteriovenous fistulae.⁵ Willmann et al recommend that MDCT angiography can be used to replace transarterial DSA to confirm potential bypass graft lesions as identified by duplex ultrasound. In postoperative bypass graft surveillance scans, MDCT angiography is particularly useful in assessing bypass graft integrity when placed in an extra-anatomical course because this may pose technical difficulty for duplex ultrasound evaluation.

CONCLUSION

With continual improvement of CT technology, faster imaging modality with MDCT angiography will enable image acquisition of larger anatomical segments with greater spatial resolution. MDCT angiography has broadened its clinical application in the peripheral vasculature with proven diagnostic accuracy in assessing occlusive disease as well as bypass graft surveillance. Current limitations of this imaging technology relate to vessel calcification, particularly in patients with diabetes. Further refinement of this modality will result in enhancing its diagnostic utility in preprocedural planning for patients undergoing peripheral vascular interventions. ■

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