PICTORIAL REVIEW / Cardiovascular

Three-dimensional MDCT angiography for the assessment of arteriovenous grafts and fistulas in hemodialysis access

S. Ahmed, S.P. Raman*, E.K. Fishman

Johns Hopkins University, Department of Radiology, JHOC 3251, 601 N. Caroline Street, 21287 Baltimore, United States

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Abstract Arteriovenous grafts and fistulas are placed for long-term hemodialysis access, and their associated complications can lead to considerable morbidity. Multi-detector computed tomography (MDCT) images provide accurate delineation of hemodialysis access anatomy and show potential complications. This review makes the reader more familiar with vascular access anatomy and configurations, describes the appearance of access complications encountered on MDCT, and discusses endovascular and surgical treatment options for complications, which should aid in post-treatment evaluation.

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A growing number of patients with end-stage renal disease (ESRD) are undergoing long-term hemodialysis. According to the latest statistics from the United States Renal Data System, more than 871,000 persons were being treated for ESRD in 2009, which represented an increase of nearly 600% between 1980 and 2009, and accounted for 6% of the 2009 Medicare budget ($29 billion) [1]. Complications of hemodialysis access account for a sizable proportion of these costs, and provide challenges for physicians involved in their management [1,2].

Tunneled and non-tunneled central venous catheters provide short-term (days to weeks) access when urgent or emergent hemodialysis is required. Alternatively, arteriovenous
(AV) fistulas and grafts are placed for long-term usage. Several studies have demonstrated longer patency and lower complication rates in patients with autogenous AV fistulas by comparison to AV grafts and catheters [3,4]. According to the Dialysis Outcomes Quality Initiative (DOQI) and Society of Vascular Surgery (SVS) guidelines, there are several basic principles with regards to dialysis access. In this regard, autogenous hemodialysis access is favored over prosthetics, distal extremity access sites should first be utilized in order to preserve more proximal options, and upper extremity access is preferred over the lower extremity.

Vascular access complications lead to substantial morbidity and high rates of hospitalization in these patients [5]. The most common complications include infection, stenosis, thrombosis, arterial steal syndrome, aneurysms, and pseudoaneurysms. DOQI emphasizes the importance of monitoring programs to detect vascular access at risk [5]. Diagnostic imaging plays a critical role in the management of hemodialysis access, and promotes early management of complications. Conventional angiography and duplex Doppler ultrasonography have established roles in delineating access anatomy and complications [6,7]. However, magnetic resonance angiography (MRA) and multi-detector computed tomography (MDCT) with three-dimensional reconstructions are being employed for this indication with increasing frequency [7].

Rapid advancements in MDCT have led to short acquisition times and unsurpassed spatial and temporal resolution for the accurate assessment of the peripheral vasculature [8]. Unlike older generation technology, studies can now be reliably acquired at peak arterial enhancement, allowing exquisite imaging of the peripheral vasculature on a consistent basis. However, a limited number of studies have investigated the utility of evaluating hemodialysis access with MDCT, and the growing use of MDCT for this indication has been a relatively recent phenomenon. In order to appropriately interpret these often complex studies, the radiologist must be familiar with vascular access anatomy and configuration, as well as the appearance of a number of common access complications encountered on MDCT angiography. In addition, an understanding of endovascular and surgical treatment options for complications is critical to allow the radiologist to help appropriately guide treatment and properly conduct post-treatment radiographic evaluation. The goal of this review was to make the reader more familiar with vascular access anatomy and configurations, describe the appearance of access complications encountered on MDCT, as well as discuss endovascular and surgical treatment options for complications.

**Vascular access anatomy and configuration**

A general understanding of the vascular anatomy utilized to create vascular access for hemodialysis, as well as knowledge of both autogenous and synthetic access configurations, are critical for properly diagnosing complications on MDCT angiography. The superficial venous system of the upper extremity is considered the most important for dialysis access creation. Alternatively, while the deep veins are not ideal, they may be utilized as options become limited, a not uncommon situation in an aging population [2,4].

The cephalic vein is the preferred and most commonly utilized superficial vein of the upper extremity. It travels along the radial aspect of the forearm, communicates with the basilic vein via the median cubital vein at the elbow, and traverses in the superficial fascia along the anterolateral surface of the biceps brachii muscle. A radiocephalic AV fistula at the wrist, created by anastomosing the forearm segment of the cephalic vein and radial artery, is generally regarded as the first choice for hemodialysis access [5]. The preferred alternative is to connect the cephalic vein to the posterior radial carpal artery, which lies beneath the extensor tendons of the thumb (’snuffbox’ AV fistula).

A brachiocephalic fistula at the elbow (Fig. 1), utilizing the proximal segment of the cephalic vein and brachial artery, is generally the second choice site [5]. The proximal cephalic vein can also be anastomosed to the proximal radial artery, which is generally considered inferior to the brachiocephalic option. In cases where the cephalic vein does not reach the forearm brachial artery, it can be transposed to the upper arm brachial artery. The basilic vein on the ulnar aspect of the forearm and the median cubital vein near the elbow are sometimes used for dialysis access. The median cubital vein is typically anastomosed with the proximal radial artery.

If choices for vascular access are limited in the forearm, upper arm options may alternatively be utilized. The most commonly used deep vein is the basilic vein in the medial aspect of the upper arm, which is mobilized and transposed superficially through the deep fascia for fistula creation (Fig. 2). Alternatively, the transposed brachial vein can be anastomosed to the brachial artery in situations where the cephalic and basilic veins are not suitable options. Saphenous and femoral vein fistulas are exceedingly rare, and are usually not favored over prosthetic upper arm access.

AV grafts are created by anastomosing a straight or looped synthetic conduit between an artery and vein. The two primary options in the forearm are a straight graft connecting the radial artery to the cephalic vein, or alternatively, a looped graft between brachial artery and cephalic vein. In the upper arm, a graft connecting the brachial artery and axillary vein can be created.

Lower extremity access is typically constructed in situations where all upper extremity options have been exhausted. Given their higher rates of infection and steal, as well as their poorer overall patency, the lower extremities are generally considered less desirable for hemodialysis access. The great saphenous vein, which travels along the medial leg, can be anastomosed to the superficial femoral artery in the groin. An autogenous fistula can also be constructed between the femoral artery and vein, which run alongside each other within the femoral sheath in the upper medial leg, adjacent to the femur. The third autogenous option is mobilizing the distal end of the great saphenous vein to connect to the posterior tibial artery, which travels dorsal to the tibia in the posterior compartment of the lower leg. The primary prosthetic access in the lower extremity is a looped graft between the femoral artery and vein (Fig. 3).
Figure 1. A 45-year-old man with an uncomplicated left upper extremity brachial artery to cephalic vein arteriovenous fistula. A. Coronal maximum intensity projection of MDCT data shows the fistula (arrow) to be widely patent with no apparent narrowing, aneurysmal dilatation, or other complication. B. Coronal volume-rendered MDCT image provides another reconstruction method for visualizing the fistula (arrow), and again demonstrates it to be widely patent without narrowing.

Figure 2. A 36-year-old woman with an uncomplicated left upper extremity brachial artery to transposed basilic vein arteriovenous fistula. A. Oblique maximum intensity projection of MDCT data demonstrates that portions of the fistula do demonstrate a mildly dilated, somewhat "corrugated" appearance (arrow), a common imaging feature that should not be confused with the focal dilatation associated with an aneurysm. B. Volume-rendered image demonstrates the normal mildly dilated appearance of the mid-fistula (arrow).
Doppler ultrasound provides both structural and functional information, and is widely used for pre-surgical planning and access management [10]. Ultrasound can be used to detect and characterize vascular complications related to hemodialysis access, including stenosis, occlusion, thrombosis, arterial steal, and pseudoaneurysms [10]. Slow blood flow (<500 cm²/min) and significant stenosis (>50%) detected on vascular ultrasound correlates with access thrombosis within 6 months, which reinforces its utility in forecasting complications [11]. However, as in other parts of the body, vascular ultrasound is highly user dependent and offers limited anatomical detail. Overlying scar tissue or calcification secondary to overlying puncture sites, as well as subcutaneous edema or hematoma, may limit image resolution and depth. Moreover, ultrasound remains unable to accurately detect central venous stenoses [12]. An alternative non-invasive modality is MR angiography, which provides three-dimensional, high-resolution depiction of vessels. However, magnetic resonance artifacts associated with endoprostheses and turbulent flow at the AVF site can limit its utility. In addition, MR angiography may underestimate stenosis severity [13]. Finally, MR imaging is often limited in this particular group of patients with ESRD, as the utilization of gadolinium-chelate in patients with diminished renal function is now strongly discouraged due to concerns regarding nephrogenic systemic fibrosis (NSF).

Over the last several years, driven by improvements in technology (including dramatic improvements in both spatial and temporal resolution), MDCT angiography is becoming more widely employed for assessing the peripheral vasculature. 3D angiography techniques, including maximum-intensity projection (MIP) and volume rendering (VR), have proven useful in evaluating hemodialysis access [7]. Unfortunately, given the relatively recent utilization of MDCT for this indication, there is still a paucity of literature on MDCT angiographic evaluation of hemodialysis complications.

Initial work by Ko et al. using 4-slice MDCT demonstrated its clinical feasibility for evaluating both AVF and grafts [14]. Among the 36 patients in this study, MDCT angiography showed no significant difference compared to conventional angiography or surgery in revealing vascular stenoses, aneurysms, and thromboses from the in-flow artery to the central veins. The authors of this study reported sensitivity and specificity values of 98.7% and 97.5%, respectively. Karadeli et al. evaluated 30 patients referred for failing hemodialysis access using 16-slice MDCT angiography [7]. The design of this study incorporated axial MIP, coronal MIP, and VR images that were reconstructed from the axial source images. Their results showed low sensitivity for detecting central vein stenosis (35%) and moderate sensitivity (61%) for central venous occlusion. VR images used in combination with multi-planar reconstructions were shown to be highly sensitive and accurate in diagnosing aneurysms (100%). Not unexpectedly, partially thrombosed aneurysms that were missed on conventional fistulography were very well characterized on MDCT. MDCT angiography was also accurate in diagnosing occluded stents, venous collaterals, and arterial pathology, including juxta-anastomotic stenosis, poststenotic aneurysms, and atherosclerotic changes.

In a 2006 study by Ye et al., 22 patients with suspected vascular access dysfunction were evaluated using 16-slice...
MDCT [15]. MIP, VR, and MPR images were shown to nicely delineate the anatomy of the AVF, as well as stenoses at multiple sites and venous collateral formation. This study also demonstrated a high correlation between findings on MDCT and conventional angiography, reinforcing the value of noninvasive imaging for access surveillance. Heye et al. demonstrated the diagnostic value of 64-slice MDCT angiography [16]. The study authors were able to detect greater than 50% stenosis or occlusion of hemodialysis fistulas with an accuracy, sensitivity, and specificity of 92%, 90%, and 93%, respectively, and also reported very high inter-observer agreement. However, five stenoses that were significant on conventional angiography were not detected on MDCT. Two of these false-negatives were at the edge of or in a previously placed nitinol stent. False-positives were pseudo-stenoses caused by vein compression secondary to arm positioning.

Although the literature is limited, available studies demonstrate the utility and accuracy of MDCT angiography in diagnosing hemodialysis access complications. In general, results have shown good correlations between MDCT and conventional angiography. It should be noted that none of these studies were conducted using the latest generation of scanners, and one could argue that the latest dual-source scanners might provide even superior results.

**MDCT angiography technique**

Rapid advancements in MDCT technology have resulted in new applications, including imaging of AV grafts and fistulas. Current MDCT protocols utilize dual-phase technique, with acquisition in the arterial phase at 30 seconds after injection of intravenous contrast, and venous phase image acquisition at approximately 60 seconds after injection. A rapid injection rate of 4–6 cm²/s is critical in order to maximize enhancement of the vasculature. Contrast is typically injected in the arm contralateral to the fistula site in order to decrease streak artifacts that may limit evaluation of the vasculature, especially of the central venous system.

Thin collimation technique is now standard on all modern MDCT scanners, with images acquired at a slice thickness of 0.625–0.75 mm, which are then reconstructed into 3- and 5-mm sections for standard axial interpretation. A second set of images reconstructed at 0.5 mm are used for multiplanar reformations (MPR) and 3D reconstructions. Two sets of 3D images are created for each case:

- maximum intensity projection (MIP);
- volume-rendered (VR) images

MIP imaging involves selecting the highest attenuation voxels in a data set and then incorporating these high-attenuation voxels into a 2-dimensional image. VR requires a more complex computer algorithm. It analyzes the content of each voxel within a data set, assigns a specific color and transparency based on its underlying attenuation, and subsequently presents the data in a 3D display. MIP imaging is optimized for evaluating vascular anatomy, while VR allows for optimal visualization of the soft tissues, muscles, osseous structures, and vasculature in a single image and is best for demonstrating complex 3D relationships. MIP and VR have proven invaluable for evaluating AV grafts and fistulas [7,8,14,15] and our own clinical experience has also strongly supported the utility of these reconstruction methods.

**MDCT angiography of hemodialysis complications**

Maintaining long-term hemodialysis access function is has always proven to be quite challenging due to the high frequency of complications. Familiarity with the spectrum of complications on MDCT and treatment options is critical for any radiologist interpreting these studies, both in terms of allowing complication diagnosis and post-treatment evaluation.

Early AV failure, which is defined as failure within 3 months of initial usage, is quite common, with an incidence ranging between 20–60% [17–20]. Juxta-anastomotic stenosis (JAS), one of the most common causes of early fistula failure, occurs within 5 cm of the anastomosis and is more frequently found on the venous end [21,22]. However, JAS can also observed in late fistula failure [22].

Venous stenosis is the most common cause of both early and late fistula failure [2]. Proximal vein stenosis, between the anastomosis and central veins, is readily detected on MDCT angiography (Fig. 4A). Intervention prior to the formation of thrombus is critical for prolonged access survival. Percutaneous balloon-assisted angioplasty (PTA) of peripheral stenotic vessels is the treatment of choice with greater than 90% salvage rate [2,22].

Central venous stenosis (CVS), including the subclavian vein, brachiocephalic vein, and superior vena cava, is best seen on MDCT angiography [14,23]. Patients with a prior history of central venous catheterization are prone to developing CVS and/or thrombosis, with rates as high as 40% [2]. Vascular stents are typically used to restore patency, but surgical bypass may also be performed. MDCT can also demonstrate complications associated with vascular stents, such as int- stent stenosis (Fig. 5), which is not uncommon in an aging population.

The ideal outflow tract for an AVF is a single vein without side branches. However, accessory veins originating from the vein that is to become part of the AVF are frequently encountered on MDCT, often in conjunction with JAS [22]. Accessory veins lead to dissipation of the upstream resistance that is required for AVF maturation. Accessory veins less than one fourth the diameter of the main AVF are unlikely to be significant [22]. However, larger side branches may be coil embolized to restore functionality [24]. These side branches are generally easily identified on MDCT, particularly when 3D reconstructions are utilized to better delineate the complex anatomic relationships between vessels.

MDCT angiography is able to accurately delineate stenotic lesions from the aorta to the feeding artery. The risk of arterial stenosis increases with time, and is reported to be as high as 15–30% in the literature [25,26]. Arterial intervention, typically PTA, is undertaken in cases of greater than 50% stenosis with associated functional or hemodynamic abnormalities [5]. Arterial stenosis (Fig. 6) can also predispose to steal syndrome (Fig. 7), which is most commonly observed in radiocephalic fistulas [27]. Problems of arterial inflow due to thrombosis (Fig. 8) are not uncommon and require angiographic evaluation. Endovascular methods,
Figure 4. A 58-year-old man with a right upper extremity brachial artery to transposed basilic vein arteriovenous fistula. A. Coronal maximum intensity projection shows a segment of stenosis in the axillary vein (arrow). B. Sagittal maximum intensity projection demonstrates a short segment of stenosis in the axillary vein just beyond the venous anastomosis (arrow).

such as pharmacologic thrombolysis or mechanical lysis, are favored over surgical thrombectomy in the management of AVF thrombosis [24].

AV grafts have lower primary and secondary patency rates in comparison to AVF [2,4,28]. Complications of AV grafts are also well demonstrated on MDCT angiography. Stenosis with resulting thrombosis is most commonly noted at the venous anastomotic site of an AV graft (Fig. 4B), likely secondary to intimal hyperplasia [29]. Venous anastomotic stenosis is typically treated with percutaneous balloon angioplasty with or

Figure 5. A 54-year-old man with a left upper extremity brachial artery to axillary vein looped arteriovenous graft. A. Coronal maximum intensity projection image demonstrates the looped arteriovenous graft with a juxta-anastomotic stent at its venous end. The patient also has a history of left subclavian vein stenosis and demonstrates extensive collateralization in the left upper arm. B. Coronal MDCT image nicely demonstrates in-stent stenosis (arrow), easier to appreciate on the source image rather than the MIP reconstruction.
without stenting [30]. Surgical patch angioplasty and bypass grafts are less common. Endovascular methods and surgical thrombectomy with revision are both considered effective therapies for AV graft thrombosis [2,31].

Aneurysms and pseudoaneurysms occasionally disrupt vascular access function and may be detected on MDCT angiography (Fig. 9). Aneurysmal dilatation is defined as greater than 150% of the normal diameter of a vessel. True aneurysms may form secondary to increased venous pressure proximal to a more central stenosis or due to immunosuppression. Pseudoaneurysms can result from repeated punctures in the same area or from deterioration of graft material over an extended period of time. Aneurysms and pseudoaneurysms are both at increased risk of rupture and infection, and may also cause erosion of the overlying skin. An AV graft pseudoaneurysm that measures greater than twice the diameter of the graft (usually >4 cm) requires surgical or endovascular intervention [28].

Non-vascular complications of vascular access are also quite common. The incidence of dialysis access infection ranges from 0.5%--5% for autogenous AV fistulas and 4%--20% for AV grafts [2]. Infection is the primary cause of vascular access failure in up to 20% of cases [2]. Risk factors for vascular access infection include pseudoaneurysms (Fig. 9) and hematomas. MDCT is able to demonstrate soft tissues changes associated with infection, such as subcutaneous soft tissue and fat stranding, as well as the formation of abnormal fluid or air collections around the AVF.

Non-infectious fluid collections, such as hematomas, seromas, or lymphoceles, may also develop at the vascular access site [27]. A seroma can form secondary to ultrafiltration of plasma across a prosthetic graft, most commonly in the arterial limb of the graft [32]. While seromas form slowly, hematomas typically develop with greater rapidity.

Figure 6. A 56-year-old man with a left upper extremity brachial artery to axillary vein arteriovenous fistula. Oblique maximum intensity projection of MDCT data shows a discrete stenosis in close proximity to the arterial anastomosis (arrow). A second discrete stenosis is noted in the midportion of the fistula (arrowhead). Luminal narrowing and irregularity, as well as a small filling defect, are noted in the midportion of the arteriovenous fistula, which may reflect a focal dissection in this location.

Figure 7. A 40-year-old man with a left radial artery to cephalic vein arteriovenous fistula. A. Coronal maximum intensity projection. B, C. Volume-rendered images demonstrate extensive forearm collateralization surrounding the fistula secondary to arterial steal syndrome.
Figure 8. A 68-year-old man with a left brachial artery to cephalic vein arteriovenous fistula. A. Oblique maximum intensity projection. B. Volume-rendered images demonstrate a relatively normal appearance of the fistula (arrow) without appreciable narrowing. C. Axial MDCT image shows partial thrombus formation within the arteriovenous fistula (arrow). As in this cases, thrombus or filling defects can sometimes be obscured on the 3D reconstructions (particularly using MIP technique), making careful appraisal of the source images critical.

Figure 9. A 59-year-old man with a left brachial artery to basilic vein arteriovenous fistula. A. Coronal MDCT image demonstrates a juxta-anastamotic brachial artery pseudoaneurysm (arrow). An abscess is also noted in the distal upper arm, superior and medial to the arteriovenous anastamosis (arrowhead). B. Axial MDCT image again demonstrates the soft tissue abscess (arrowhead) with tiny punctate foci of internal gas. C. Coronal maximum intensity projection demonstrates two fusiform aneurysms (arrows) in the mid-portion of the fistula.
These fluid collections are readily detected on MDCT and may require drainage or surgical revision.

Conclusion
Complications associated with hemodialysis access lead to significant morbidity and high rates of hospitalization in ESRD patients. Non-invasive diagnostic imaging allows for early diagnosis and treatment of at-risk AV fistulas and grafts. MDCT angiography with 3-D reconstructions can accurately delineate vascular access anatomy and its complications, and can serve as a powerful tool in the management of ESRD patients. While ultrasound has traditionally been employed in the non-invasive imaging of these patients, one could argue that MDCT could serve as a powerful adjunct imaging tool in the evaluation of a wide range of complications. However, in order to properly utilize MDCT for this indication, it is critical for both diagnostic and interventional radiologists to be familiar with hemodialysis access configurations, as well as the appearance of vascular and non-vascular access complications on MDCT angiography. Accurate diagnosis of these complications may lead to improved clinical outcomes for hemodialysis patients.

Ethical approval
This article does not contain any studies with human participants or animals performed by any of the authors.

Disclosure of interest
The authors declare that they have no competing interest.

References
MDCTA of arteriovenous grafts and fistulas for hemodialysis access

