American College of Radiology
ACR Appropriateness Criteria®
Dialysis Fistula Malfunction

Variant: 1 Suspected dysfunction of upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Initial imaging to guide interventional radiologic therapy options.

Procedure	Appropriateness Category	Relative Radiation Level
Fluoroscopy fistulography hemodialysis access area of interest	Usually Appropriate	☢☢☢
US duplex Doppler hemodialysis access area of interest	Usually Appropriate	O
MRA extremity area of interest without IV contrast	Usually Not Appropriate	O
CTA extremity area of interest with IV contrast	Usually Not Appropriate	Varies
CTV extremity area of interest with IV contrast	Usually Not Appropriate	Varies
MRA extremity area of interest without and with IV contrast	Usually Not Appropriate	O
MRV extremity area of interest without and with IV contrast	Usually Not Appropriate	O
MRV extremity area of interest without IV contrast	Usually Not Appropriate	O

Variant: 2 Suspected dysfunction of the upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Treatment and procedures.

Procedure	Appropriateness Category	Relative Radiation Level
Fluoroscopy fistulography hemodialysis access with intervention	Usually Appropriate	
US duplex Doppler hemodialysis access area of interest	Usually Appropriate	O
Surgical consultation	May Be Appropriate	
Continued hemodialysis access use with surveillance	May Be Appropriate	
Placement of a new tunneled dialysis catheter	May Be Appropriate	

Variant: 3 Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Initial imaging to guide interventional radiologic therapy options.

Procedure	Appropriateness Category	Relative Radiation Level
Fluoroscopy fistulography hemodialysis access area of interest	Usually Appropriate	☢☢☢
US duplex Doppler hemodialysis access area of interest	May Be Appropriate	O
CTA extremity area of interest with IV contrast	Usually Not Appropriate	Varies
CTV extremity area of interest with IV contrast	Usually Not Appropriate	Varies
MRA extremity area of interest without and with IV contrast	Usually Not Appropriate	O
MRA extremity area of interest without IV contrast	Usually Not Appropriate	O
MRV extremity area of interest without and with IV contrast	Usually Not Appropriate	O
MRV extremity area of interest without IV contrast	Usually Not Appropriate	O

Variant: 4 Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Treatment and procedures.

Procedure	Appropriateness Category	Relative Radiation Level
Fluoroscopy fistulography hemodialysis access with intervention	Usually Appropriate	
Surgical consultation	Usually Appropriate	
Placement of a new tunneled dialysis catheter	May Be Appropriate	
US duplex Doppler hemodialysis access area of interest	Usually Not Appropriate	O

Variant: 5 Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Initial imaging to guide interventional radiologic therapy options.

Procedure	Appropriateness Category	Relative Radiation Level
Fluoroscopy fistulography hemodialysis access area of interest	Usually Appropriate	☢☢☢
US duplex Doppler hemodialysis access area of interest	Usually Appropriate	O
CTV extremity area of interest with IV contrast	Usually Not Appropriate	Varies
MRA extremity area of interest without and with IV contrast	Usually Not Appropriate	O
MRA extremity area of interest without IV contrast	Usually Not Appropriate	O
MRV extremity area of interest without and with IV contrast	Usually Not Appropriate	O
CTA extremity area of interest with IV contrast	Usually Not Appropriate	Varies
MRV extremity area of interest without IV contrast	Usually Not Appropriate	O

Variant: 6 Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Treatment and procedures.

Procedure	Appropriateness Category	Relative Radiation Level
Fluoroscopy fistulography hemodialysis access with intervention	Usually Appropriate	
Surgical consultation	Usually Appropriate	
US duplex Doppler hemodialysis access area of interest	Usually Appropriate	O
Placement of a new tunneled dialysis catheter	May Be Appropriate	

Variant: 7 Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Initial imaging to guide interventional radiologic therapy options.

Procedure	Appropriateness Category	Relative Radiation Level
Fluoroscopy fistulography hemodialysis access area of interest	Usually Appropriate	☢☢☢
CTA extremity area of interest with IV contrast	Usually Not Appropriate	Varies
CTV extremity area of interest with IV contrast	Usually Not Appropriate	Varies
MRA extremity area of interest without and with IV contrast	Usually Not Appropriate	O
MRA extremity area of interest without IV contrast	Usually Not Appropriate	O
MRV extremity area of interest without and with IV contrast	Usually Not Appropriate	O
MRV extremity area of interest without IV contrast	Usually Not Appropriate	O
US duplex Doppler hemodialysis access area of interest	Usually Not Appropriate	O

Variant: 8 Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Treatment and procedures.

Procedure	Appropriateness Category	Relative Radiation Level

Fluoroscopy fistulography hemodialysis access with intervention	Usually Appropriate	
Continued hemodialysis access use with surveillance	May Be Appropriate	
US duplex Doppler hemodialysis access area of interest	Usually Not Appropriate	O
Placement of a new tunneled dialysis catheter	Usually Not Appropriate	
Surgical consultation	Usually Not Appropriate	

Variant: 9 Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Initial imaging to guide interventional radiologic therapy options.

Procedure	Appropriateness Category	Relative Radiation Level
US duplex Doppler hemodialysis access area of interest	Usually Appropriate	O
Fluoroscopy fistulography hemodialysis access area of interest	May Be Appropriate	☢☢☢
CTV extremity area of interest with IV contrast	Usually Not Appropriate	Varies
MRA extremity area of interest without and with IV contrast	Usually Not Appropriate	O
CTA extremity area of interest with IV contrast	Usually Not Appropriate	Varies
MRA extremity area of interest without IV contrast	Usually Not Appropriate	O
MRV extremity area of interest without and with IV contrast	Usually Not Appropriate	O
MRV extremity area of interest without IV contrast	Usually Not Appropriate	O

Variant: 10 Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Treatment and procedures.

Procedure	Appropriateness Category	Relative Radiation Level
Surgical consultation	Usually Appropriate	
Placement of a new tunneled dialysis catheter	Usually Appropriate	
Fluoroscopy fistulography hemodialysis access with intervention	May Be Appropriate	
Continued hemodialysis access use with surveillance	Usually Not Appropriate	

Variant: 11 Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Initial imaging to guide interventional radiologic therapy options.

Procedure	Appropriateness Category	Relative Radiation Level
Fluoroscopy fistulography hemodialysis access area of interest	Usually Appropriate	☢☢☢
US duplex Doppler hemodialysis access area of interest	Usually Appropriate	O
CTA extremity area of interest with IV contrast	May Be Appropriate	Varies
CTV extremity area of interest with IV contrast	Usually Not Appropriate	Varies
MRA extremity area of interest without and with IV contrast	Usually Not Appropriate	O
MRA extremity area of interest without IV contrast	Usually Not Appropriate	O
MRV extremity area of interest without and with IV contrast	Usually Not Appropriate	O
MRV extremity area of interest without IV contrast	Usually Not Appropriate	O

Variant: 12 Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Treatment and procedures.

Procedure	Appropriateness Category	Relative Radiation Level
Surgical consultation	Usually Appropriate	
Continued hemodialysis access use with surveillance	May Be Appropriate	
Fluoroscopy fistulography hemodialysis access with intervention	May Be Appropriate	
Placement of a new tunneled dialysis catheter	May Be Appropriate	
US duplex Doppler hemodialysis access area of interest	Usually Not Appropriate	O

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Summary of Literature Review

Introduction/Background

Chronic kidney disease is a common disease that as of 2018 affected 14.9% of the surveyed adult United States population [1]. Chronic kidney disease can result in end stage renal disease, a condition with high morbidity and mortality that affects 725,000 patients in the United States as of 2016 [2]. End stage renal disease patients account for 7.2% of paid Medicare claims at a cost of $35.4 billion, a cost that is increasing every year [2]. In the United States, hemodialysis persists as the single most prevalent mode of renal replacement therapy. Hemodialysis care alone resulted in $28 billion in Medicare costs in 2016 [2].

The creation and maintenance of a dialysis access is vital for the reduction of morbidity, mortality, and cost of treatment for end stage renal disease patients. Since the National Kidney Foundation (NKF) Kidney Disease Outcomes Quality Initiative (KDOQI) guidelines were released in 2006, the composition of dialysis access has changed with the prevalence of arteriovenous fistulas (AVF) for dialysis access, increasing from 32% in 2003 to 62.8% in 2017 [2]. The 2006 KDOQI guidelines recommended AVF as the preferred vascular access for hemodialysis due to increased patency rates and decreased risk of infection and thrombosis when compared to arteriovenous grafts (AVG) and central venous catheters (CVC) [3,4]. In the 2019 KDOQI guidelines, a paradigm shift was made from the previous "Fistula First" approach to a call for providers to consider not only what access may be first, but rather "what's next" in the planning of the first access. In doing so, the KDOQI guidelines refocused on a P-L-A-N for every patient represented by Patient Life-Plan first, followed by their corresponding Access Needs [5].

One's longevity on dialysis is directly dependent upon the quality of dialysis. This quality in turn hinges on the integrity and reliability of the access to the patient's vascular system. This vital vascular connection represents the hemodialysis vascular access. An optimal hemodialysis vascular access is one that provides reliable, complication free access, which facilitates the required dialysis and supports each patient's specific care needs [4]. All methods of dialysis access will eventually result in dialysis dysfunction and failure [6]. The restoration of a dysfunctional or thrombosed hemodialysis access may be facilitated by image-guided surgery, percutaneous interventional procedures, or a combination of these methods [4]. However, endovascular interventions have

become the first-line treatment for dialysis access thrombosis and dysfunction, when possible, with more than two-thirds occurring in the outpatient setting [7,8].

A stenosis that develops secondary to neointimal hyperplasia becomes the primary precipitator of a vascular access failure. Such stenoses augment pressure within the access and decrease blood flow. If the stenosis is hemodynamically significant and left untreated, it can result in thrombosis of the access. Access thrombosis is the primary cause of loss of vascular access patency and is associated with an increase in health care expenditure and compromise of quality of life [9]. The occurrence of a stenosis is an event that recurs throughout the life of the access. While a vein-graft anastomosis in a patient with an AVG or juxta-anastomotic region in a patient with an AVF represent the sites with high propensity for stenosis formation, these lesions may occur at any point within the access system, notwithstanding central and feeding arteries. A stenotic lesion can provoke access dysfunction regardless of its site within the access circuit [9].

Arteriovenous (AV) access dysfunction includes 3 distinct classes of events, namely thrombotic flow-related complications or dysfunction, nonthrombotic flow-related complications or dysfunction, and infectious complications [5]. Thrombotic flow-related complications or dysfunction include those events exclusively related to thrombus formation that provokes a clinically important decrease in intra-access flow and in turn threatens the required access patency needed to achieve requisite hemodialysis. These include stenoses and thromboses, and routinely result in specific heralding clinical signs and symptoms. Nonthrombotic flow-related complications or dysfunction include those events that may or may not threaten the flow or patency of an access circuit, but which are related to associated clinical symptoms and signs, such as in the case of steal syndrome or AV access cannulation site aneurysms. Finally, infectious complications or dysfunction include infections that involve the vascular access whether intraluminally, extraluminally, or peri-access, including the cannulation site, and that provoke clinically significant infectious symptoms and signs [5].

To preempt adverse outcomes and identify lesions with the vascular access before they provoke complications, the KDOQI guidelines suggests that the performance of the following be considered, namely 1) monitoring, supported by physical examination. Such abnormal clinical signs and symptoms may include changes in the access thrill or bruit, prolonged bleeding after decannulation post dialysis, or arm swelling. As high as 90% of accesses with abnormal physical examinations will have an underlying clinically significant finding on imaging [10]; and 2) surveillance, performed periodically with the aid of noninvasive and invasive device-based methods to assess blood access flow rate (Qa), access recirculation, and dialysis venous pressure; c) diagnostic imaging, such as Doppler ultrasound (US) or diagnostic fistulography upon detection or suspicion of an access abnormality [4].

In this document, when it is noted that the entire extremity is imaged or treated, for the upper extremity, this is assumed to cover the shoulder through the hand, and for the lower extremity, this is assumed to cover the hip through the foot. Moreover, when surgical consultation is discussed as an intervention, it connotes consulting or referring a patient to a surgeon, be they vascular or transplant surgeon, in order to assess the patient for the specific clinical presentation in question. This may be in settings where a surgical procedure such as new access creation, access revision, or access ligation is deemed to be a fitting therapy.

Discussion of Procedures by Variant

Variant 1: Suspected dysfunction of upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Initial imaging to guide interventional radiologic therapy options.

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A. Fluoroscopy Fistulography Hemodialysis Access Area of Interest

Fistulography reflects a standard technique that integrates diagnosis and therapeutic management of an at-risk AVF or AVG. Limitations include the invasive nature of the procedure as an imaging modality [11]. The Society of Interventional Radiology's (SIR) Quality Improvement Guidelines suggest diagnostic fistulography or digital subtraction angiography (DSA) as the reference standard for imaging a dysfunctional dialysis access due to its diagnostic accuracy and the ability to perform percutaneous endovascular interventions during the procedure [7]. While catheter-based venography and arteriography represent invasive procedures, they provide the simultaneous ability to image the AV access from the arterial anastomosis to the heart (venography) as well as the entire AV access circuit (arteriography), while concomitantly supporting a platform for any needed therapeutic interventions. Fistulography can be performed by an interventional radiologist, vascular surgeon, or interventional nephrologist to assess the patency of a hemodialysis vascular access circuit. This includes components of the arterial inflow, the anastomosis site, the venous outflow of the fistula or graft, including the ipsilateral central veins, vena cava, and right atrium. Multiple projections may be performed to better visualize the access lumen and assess for the presence of hemodynamically significant stenoses. When hemodynamic parameters or clinical findings are not explained by the fistulographic evaluation, assessment of the arterial inflow may be performed [12].

Fistulography allows for comprehensive imaging evaluation of the entire hemodialysis vascular access and is routinely conducted with iodinated contrast material [13]. Ehrman et al [14] suggests that when using iodinated contrast material as the reference standard, the sensitivity, specificity, and accuracy of carbon dioxide is 94%, 58%, and 75%, respectively. A shortcoming is that carbon dioxide is not as reliable in assessing venous anatomy and may overestimate the extent of a visualized stenosis. In addition, when given intra-arterially, there is a possibility that carbon dioxide may create a vapor lock with resultant transient ischemia or loss of consciousness or other neurologic events due to its passing into the cerebral arterial circulation [15,16]. As such, it is not used in retrograde or reflux techniques to image the arterial anastomosis.

While DSA allows for assessing vascular stenoses, most investigators tend towards an antegrade puncture at the distal aspect of the efferent vein for diagnostic fistulography. This necessitates retrograde opacification of the juxta-anastomotic segments to illustrate a possible stenosis. In identifying a stenosis in the proximal inflow segments during DSA, the interventionalist has to achieve retrograde sheath access to facilitate treatment, increasing procedure time [17]. Wasinrat et al [17] reported that DSA posed a limitation in facilitating stenosis detection on 2-D projections in the coronal view. Similarly, Heye et al [18] demonstrated an underestimation of stenoses on DSA when compared to multidetector CT (MDCT) angiography, where a stenosis was viewed in

transverse and sagittal planes of planar reconstruction.

It should be noted that the European Best Practice Guidelines Expert Group on Hemodialysis recommends against performing diagnostic fistulography without the intention to intervene on significant findings which may be causing the access dysfunction [19]. Diagnostic fistulography is useful for suspected dialysis access dysfunction if there is an intention to perform endovascular intervention on significant findings or if it is needed to support surgical planning [7].

Over 90% of dialysis access dysfunction is caused by an anatomic stenosis [7]. A venous stenosis is the most common cause of dysfunction within an AVF [20]. In an AVG, the most common site of stenosis is the venous anastomosis [21,22]. A hemodynamically significant stenosis, as defined by the Society of Intervention Radiology (SIR) standards of practice and the KDOQI guidelines, is a ≥50% narrowing of the lumen with at least 1 associated abnormal clinical or hemodynamic indicator [3,23]. Even though it allows for the evaluation of dialysis access dysfunction, hemodynamically significant stenoses detected by pressure gradients can be occult on fistulography; however, this is not routinely performed [24].

Variant 1: Suspected dysfunction of upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Initial imaging to guide interventional radiologic therapy options.

B. US Duplex Doppler Hemodialysis Access Area of Interest

US performed in B-mode and duplex Doppler US settings have sensitivity and specificity comparable to diagnostic fistulography for hemodynamically significant stenoses within the dialysis vascular access circuit. A study by Vardza Raju et al [25] examined the accuracy of the assessment of AVG and AVF using duplex US in comparison to noted findings on angiography in patients with failing vascular accesses in 51 accesses (35 AVF, 16 AVG). They reported that duplex Doppler US had 95.5% sensitivity and 57.1% specificity for stenoses >50% when using a ratio of peak systolic velocities. Measurement of the residual diameter of a stenotic lesion using B-mode US has also been proposed as a method for identifying a stenosis within an AVF or AVG [26]. The measurement of AVF or AVG blood flow by US is not considered as accurate when compared to other methods of measuring blood flow through the dialysis vascular access.

Data on duplex Doppler US flow volume assessments suggests that an optimally functioning AVF demonstrates a flow rate of 700 to 1,300 mL/min [27]. Values of <500 mL/min [4] and <300 mL/min [27] serve as predictors of access dysfunction and pending thrombosis, respectively. In addition to such absolute measurements, it has been demonstrated that a vascular access with prior stability of flow volumes >1,000 mL/min followed by a reduction of >25% over a relatively short time interval of 1 to 4 months may predict access dysfunction [28]. Some issues with obtaining diagnostic images with US include limitations related to patient anatomy. Given that systematic assessment of an AVF by duplex US may be challenging, its use is encouraged when monitoring or surveillance has suggested abnormalities or when limitations to performance of routine dialysis arise. Such abnormalities or limitations may be reflected by reports of difficulty cannulating the access for hemodialysis, inadequate blood flows, high venous pressures, or prolonged bleeding after removal of dialysis access needles.

While a few studies have shown the feasibility of US-guided angioplasty for the treatment of stenosis, the majority of endovascular treatment is still performed using fluoroscopically-guided

fistulography in an angiography suite [29,30]. The use of physical examination findings and other indicators of a dysfunctional dialysis access can be used to identify patients with a probable hemodynamically significant stenosis. These patients can in turn be referred directly for diagnostic fistulography and the needed endovascular intervention [31]. During fistulography to treat a stenosis, venography may reveal a narrowing that may represent a stenosis or vasospasm. Preprocedural US has the added advantage of differentiating structural stenoses from transient self-limiting vasospasm [32]. Duplex Doppler US can aid monitoring of the response postangioplasty or stenting. The extent of residual stenoses postangioplasty may also be accurately quantified [33].

Variant 1: Suspected dysfunction of upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Initial imaging to guide interventional radiologic therapy options.

C. CTA Extremity area of Interest With IV Contrast

CT angiography (CTA) represents an alternative diagnostic study for many peripheral vascular interventions. However, it carries practical and logistical limitations in imaging of dialysis access imaging.

Li et al [11] conducted a meta-analysis with the goal of comparing the diagnostic efficacy of CTA and MR angiography (MRA) in the assessment of autologous hemodialysis accesses and the detection of culprit stenoses. Both CTA and MRA were demonstrated to be accurate modalities with sensitivities of 96.2% and 95.4%, specificities of 97.1% and 96.1%, as well as diagnostic odds ratio of 393.69 and 211.47, respectively, in imaging hemodialysis vascular accesses. Even in subgroup and meta-regression analyses, no statistical difference relative to the 2 modalities was demonstrated. As such, there were no statistically significant differences when comparing the diagnostic performance of MRA and CTA in the detection of stenoses within hemodialysis vascular accesses. Both techniques serve as highly accurate alternatives or as trouble-shooting diagnostic complements to conventional DSA.

In per segment analyses of ≥50% stenoses of native hemodialysis accesses, Wasinrat et al [17] demonstrated that the accuracy, sensitivity, specificity, positive predictive value, and negative predictive value (NPV) were 95.9%, 100%, 94.8%, 84.2%, and 100%, respectively. In the detection of hemodialysis accesses, the specificity was 94.5% [17]. However, there were false positives in 6 segments of the vascular access that were not detected on DSA but which appeared to be significant stenoses on MDCT angiography. The vascular segments were located at the proximal portion of the cephalic vein (n = 4), in the mid portion of the cephalic vein (n = 1), and within the subclavian vein (n = 1). Such false positives may be due to the patient's position, where patients raising their arms above their heads with stretched arms resulted in compression of the soft tissue of the medial region of the upper arm. The pseudostenosis reported in the subclavian vein is similar to the false-positive stenoses reported by Heye et al [18], who noted 2 pseudostenotic lesions in the axillary vein, even with the patient in supine position and with arms at their side. In evaluating the proximal (superior vena cava [SVC], brachiocephalic vein, and subclavian vein) and distal segments of hemodialysis access, overall subgroup analysis reveals that MDCT angiography stenosis detection accuracy of 98.4% and 94.0%, respectively.

In comparing MDCT angiography with conventional DSA in the assessment of stenoses within vascular accesses in hemodialysis patients, Wasinrat et al [17] did not identify a false negative rate and demonstrated 100% sensitivity and 100% NPV. Heye et al [18] conducted per segment analysis of 64-slice MDCT angiography in evaluating hemodialysis access. The reported overall accuracy, sensitivity, specificity, positive predictive value, and NPV in the detection of ≥50% stenoses were 92.0%, 90.2%, 92.8%, 85.2%, and 95.4%, respectively. Such a high NPV rate suggests MDCT angiography is a dependable tool that may be employed to exclude a stenosis in the setting of suspected hemodialysis access dysfunction.

An advantage of MDCT angiography is that it may facilitate 3-D volume data that provides multiple different views that help to overcome the challenge of vessel overlap experienced in DSA [17]. Wasinrat et al [17] reported that DSA posed a limitation in facilitating stenosis detection on 2-D projection in the coronal view. Similarly, Heye et al [18] demonstrated an underestimation of stenoses on DSA when compared to MDCT angiography, where a stenosis was viewed in transverse and sagittal planes of planar reconstruction.

Variant 1: Suspected dysfunction of upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Initial imaging to guide interventional radiologic therapy options.

D. CTV Extremity Area of Interest With IV Contrast

CT venography (CTV) represents an alternative diagnostic study for many peripheral vascular interventions. However, it carries practical and logistical limitations in dialysis access imaging. There is no relevant literature to support the use of CTV with intravenous (IV) contrast in the evaluation of suspected dysfunction of a hemodialysis access.

Variant 1: Suspected dysfunction of upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Initial imaging to guide interventional radiologic therapy options.

E. MRA Extremity Area of Interest Without and With IV Contrast

Though not used in practice to visualize an AV access, MRA is a technique that has the potential to visualize the arterial and venous systems using IV contrast material. MRA represents a cross-sectional imaging modality that is noninvasive. It has been utilized for the assessment of vascular access failure, although it is relatively constrained by flow-related artifact, and limited field-of-view. In the meta-analysis by Li et al [11], they reported that MRA was an accurate diagnostic modality with sensitivity of 95.4%, specificity of 96.1%, and diagnostic odds ratio of 211.47, in evaluating hemodialysis AV access.

The Li et al [11] meta-analysis of 500 patients with an autologous hemodialysis access, demonstrated that CTA and MRA supported accurate detection of stenoses and comparable diagnostic performance, suggesting that MDCT angiography and MRA may serve as diagnostic technical alternatives to DSA when assessing for stenoses in hemodialysis fistulas and grafts. Both CTA and MRA demonstrated high specificity, sensitivity, diagnostic odds ratio, positive likelihood ratio, and negative likelihood ratio with no significant difference in stenosis detection between CTA and MRA.

Planken et al [34] use of MRA resulted in reports of low specificity of 20% for the detection of

hemodynamically significant stenoses. The considerable number of false-positive lesions detected with contrast-enhanced (CE)-MRA may be secondary to restricted spatial resolution, precipitating stenosis overestimation. In a study of inflow stenoses, Duijm et al [12] used CE-MRA to image 66 dysfunctional AVFs and 35 AVGs. A complete examination of the inflow from the subclavian artery through to the region of the shunt, and complete outflow to the level of the subclavian vein were demonstrated effectively on CE-MRA. CE-MRA demonstrated 19 arterial stenoses in 14 patients (14%) with DSA confirming 18 of such flagged lesions in 13 patients and with no other inflow lesions noted. Low-flow access improved from 477 ± 74 mL/min to 825 ± 199 mL/min after angioplasty.

Variant 1: Suspected dysfunction of upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Initial imaging to guide interventional radiologic therapy options.

F. MRA Extremity Area of Interest Without IV Contrast

There is no identified relevant literature to support the use of MRA of the extremity without IV contrast in evaluation of suspected dysfunction of a hemodialysis access.

Variant 1: Suspected dysfunction of upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Initial imaging to guide interventional radiologic therapy options.

G. MRV Extremity Area of Interest Without and With IV Contrast

There is no identified relevant literature to support the use of MR venography (MRV) of the extremity without and with IV contrast in evaluation of suspected dysfunction of a hemodialysis access.

Variant 1: Suspected dysfunction of upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Initial imaging to guide interventional radiologic therapy options.

H. MRV Extremity Area of Interest Without IV Contrast

There is no identified relevant literature to support the use of MRV of the extremity without IV contrast in evaluation of suspected dysfunction of a hemodialysis access.

Variant 2: Suspected dysfunction of the upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Treatment and procedures.

Variant 2: Suspected dysfunction of the upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Treatment and procedures.

A. Fluoroscopy Fistulography Hemodialysis Access with Intervention

Over 90% of dialysis access dysfunction is caused by an anatomic stenosis, which can be identified during diagnostic fistulography [7]. In the setting of a dysfunctional dialysis access, endovascular treatment of a stenosis found during diagnostic fistulography may be warranted. Numerous studies have shown that percutaneous endovascular interventions extend patency rates and reduce

the need for surgical revision or abandonment of the dialysis access [22,35-42]. Endovascular interventions have the advantages of being minimally invasive, allowing the procedure to be performed in an outpatient setting. Endovascular interventions are associated with short procedure time, use of moderate sedation as opposed to general anesthesia, and allow for hemodialysis immediately after the procedure. In addition, they can be performed repeatedly without the need for adding graft material or shortening the access [35,38].

The endovascular treatments of dysfunctional dialysis access with a stenotic lesion seen during diagnostic fistulography typically include percutaneous transluminal angioplasty (PTA) using a balloon and stent placement. The 2006 KDOQI guidelines established that PTA represents the first-line treatment for a stenosis in the dialysis access circuit [4]. Technical success for the treatment of a stenosis is defined by the SIR as <30% residual narrowing of the lumen in a treated segment. Clinical success is defined as at least 1 successful session of hemodialysis following treatment [7]. PTA is the first-line endovascular treatment of a hemodynamically significant stenosis [3,7]. Repeated PTA on stenotic lesions can be performed on dialysis access to maintain patency [43]. Technical failure of PTA on a stenotic lesion is associated with loss of AVF patency [44]. An untreated anatomic stenosis within the dialysis access circuit is the leading cause of a thrombosed access. The SIR guidelines suggest that surgical revision should be considered if 2 to 3 interventions are required within a 1-to-3-month period [7].

Clinical success of restoring patency in grafts with hemodynamically significant stenoses without thrombosis that are treated primarily with balloon angioplasty is 85% to 98%. Reported cumulative patency at 6-month (primary), 12-month (primary), and 12-month (secondary) interval was 38% to 63%, 23% to 44%, and 81% to 82%, respectively [45]. In addition to the use of conventional balloons for PTA, high-pressure balloons (>20 atm), cutting balloons, and drug-eluting balloons have been used typically for stenoses resistant to conventional PTA. There has been mixed evidence to support the use of cutting balloons. One prospective randomized study found higher patency rates with cutting balloon angioplasty of venous anastomotic stenoses in a graft compared to conventional angioplasty [46]. However, another prospective randomized study showed no significant change in patency between cutting and high-pressure balloon angioplasty, which conflicted with a study by Aftab et al that did show significantly improved patency using cutting balloons compared to high-pressure balloons [47,48].

Drug-eluting balloons coated with paclitaxel have been shown in multiple prospective randomized trials to have significantly improved patency when compared to conventional balloon angioplasty except for a study by Maleux et al that demonstrated higher patency rates but without significance [49-52]. On January 17, 2019, the FDA issued a warning letter about a possible increase in long-term mortality rates among patients with peripheral artery disease treated with paclitaxel-coated balloons and paclitaxel-eluting stents when compared to patients treated with control devices such as noncoated balloons or bare metal stents. The FDA allowed for the continued use of paclitaxel-coated balloons and paclitaxel-eluting stents per the current standard of care with recommendations for continued surveillance and discussion of the risks and benefits with patients, including a possible increased risk of long-term mortality [53].

Indications for placement of an endoluminal stent (bare metal stent or stent graft) as defined by the SIR and KDOQI guidelines, include technical failure of PTA of a culprit lesion, recurrence of the same stenotic lesion within a 3-month period after a prior successful balloon angioplasty, and in

the event of a complication during treatment such as venous rupture [3,7]. When indicated, a stent or stent graft can be placed over the stenotic lesion typically following angioplasty. While early studies, such as Quinn et al, did not show significant improvement in patency rates of stents versus PTA, follow-up prospective randomized studies demonstrated a significant improvement in dialysis access patency after bare stent placement [54-57]. Stent grafts have shown superior patency rates when comparing bare stents and angioplasty alone [58-63]. In one multicenter prospective randomized study, Haskal et al [63] demonstrated superior patency rates following the treatment of a stenosis in an AVG using a stent graft versus PTA with patency rates at 12 months of 47.6% versus 24.8% and at 24 months of 26.9% versus 13.5%, respectively.

Variant 2: Suspected dysfunction of the upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Treatment and procedures.

B. Surgical Consultation

Multidisciplinary care in support of the maintenance of hemodialysis access are critical in achieving optimal patient outcomes [64]. According to SIR Quality Improvement Guidelines, endovascular management has emerged as the preferred alternative to open surgery as first-line therapy for dialysis access dysfunction or thrombosis [7]. However, vascular surgery consultation for possible revision or creation of a new fistula should be considered if >2 interventions for dialysis access dysfunction occur within a 3-month period or after a clinical failure of an endovascular treatment [7]. Vascular surgery consultation for access revision may be performed if thrombosis of the access occurs >2 times within a single month, or if recurrence of a correctable stenosis is delineated in the circuit. In patients with recurrent occlusions of their vascular access, hypercoagulability testing ought to be considered [65].

While endovascular interventions are often performed in the setting of suspected stenosis of the vascular access, surgical revision remains a viable option. Multiple nonrandomized prospective and retrospective studies have shown that while surgical revision has significantly higher postintervention primary patency rates when compared to endovascular intervention, repeat endovascular interventions can extend the life of the AVF or AVG [66-71].

Various open surgical techniques exist for managing peripheral venous lesions and include patch angioplasty and interposition grafting, with the selection of a given technique dictated by the lesion's extent. Romann et al [72] noted failure of balloon angioplasty for stenoses in AVF were correlated with a lesion's length. As such, lesions >2 cm demonstrated a higher failure rate, suggesting a possible relative benefit for their treatment by an open approach. Two series reports that cephalic arch stenoses managed surgically have favorable outcomes [73,74]. However, a systematic review failed to demonstrate relative superiority between endovascular and open options [75].

Variant 2: Suspected dysfunction of the upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Treatment and procedures.

C. Placement of a New Tunneled Dialysis Catheter

The KDOQI guidelines suggest that it is preferable for patients requiring hemodialysis to utilize an AV access (AVF or AVG) as opposed to a CVC, whenever possible. This is secondary to the

association of AV access with reduced vascular access-related events such as infection, thrombotic, and nonthrombotic complications [5]. In special circumstances, a temporary CVC may be required to manage a vascular access complication (<2 weeks). In such cases, a nontunneled CVC or nontunneled dialysis catheter may be used.

The KDOQI guidelines considers it reasonable to use a nontunneled internal jugular CVC strictly for temporary purposes for a defined period of time such as <2 weeks or per institutional policy in order to reduce the risk of infection [5]. It is considered prudent to limit the use of such noncuffed, nontunneled dialysis catheters, with special consideration for patients requiring emergent access. As such, given the lower infection risk, tunneled CVCs are often used in preference to nontunneled CVCs.

In the case of a tunneled dialysis catheter, there is no maximum time limit to CVC use. However, regular evaluation is needed to determine if the CVC offers the most appropriate means for dialysis access. Indications for placement of a cuffed, tunneled dialysis catheter include the following: exhaustion of other AV access site options; temporary transition from another form of dialysis (eg, renal transplant-acute rejection, peritoneal dialysis-related complications such as pleural leak); waiting for a live-donor kidney transplant with a scheduled surgical date in <90 days; notably limited life expectancy, <6 to 12 months; medical conditions that are exacerbated by the presence of an AV access such as nontreatable skin lesions at the site of cannulation high-flow with ejection factor <15%, patient scratching the skin over the AV access that is deemed to appreciably increase the risk of infection or access rupture risk; selection by patient after appropriate informed consent such as in the case of competent, >85-year-old elderly patient with needle phobia, high risk for AV access failure, and indeterminate life expectancy [5].

Variant 2: Suspected dysfunction of the upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Treatment and procedures.

D. Continued Hemodialysis Access Use with Surveillance

Continuing to use an AV access in settings where a patient's electrolytes are within normal limits and a scheduled dialysis access intervention to remedy the cause of the suspected dysfunction is acceptable. However, it is important to note that all hemodialysis accesses ultimately fail in time, and particularly those with evidence of suspected dysfunction. A positive correlation exists between the frequency and duration of hemodialysis and patient morbidity and mortality [4,6]. As high as 90% of patients with abnormal physical examination findings demonstrate a hemodynamically significant abnormality on imaging that warrants intervention. In addition, dialysis circuit blood flow measurements provide accurate hemodynamic data on lesions that warrant dialysis access maintenance [76,77].

For example, Qa correlates closely with inflow stenoses in AVFs [73]. The KDOQI guidelines recommend AVF intervention when Qa is <450 to 500 mL/min [4]. Also, when the ratio of venous access pressure to the mean arterial pressure is >0.55, this has reflected a reliable predictor for the presence of an outflow stenosis in an AVG [78,79]. The core principle for performing routine vascular access monitoring and surveillance is to detect and treat the stenosis to preempt a reduction in dialysis clearance, to reduce the rate of thrombosis, and to improve AV access function [5].

In one prospective randomized control trial study, 58 AVFs were assessed for subclinical stenosis (>50% reduction in vessel diameter compared with the adjacent segment) and Qa >500 (<900) mL/min but with abnormal physical examination result, and elevated static venous pressure in groups that underwent prophylactic repair by surgery or PTA (pre-emptive intervention group) versus observation. The loss of AVF was decreased in the group preemptively treated with PTA when compared to the observation alone group, 5 (18%) versus 13 (43%). These correlated to AVF loss rates [event/AVF-year] of 0.066 and 0.186; *P* = .041 [5].

Variant 2: Suspected dysfunction of the upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). Treatment and procedures.

E. US Duplex Doppler Hemodialysis Access Area of Interest

Recent evidence supports the safety and efficacy of US-guided interventions for dysfunctional hemodialysis access. Stenotic lesions within the dialysis vascular access circuit can be treated with US-guided balloon angioplasty. In one retrospective study, Wakabayashi et al [80] reported a 97.1% technical and clinical success rate in the US-guided treatment of 4,414 cases of stenosis causing dysfunctional dialysis access. Additional studies report success rates of 92% to 98% for US-guided percutaneous balloon angioplasty of stenoses within the dialysis vascular access circuit [29,30,81]. US-guided interventions allow for such procedures to be performed in an office-based outpatient setting. Major limitations include the difficulty in evaluating for and treating central venous stenoses, lower sensitivity, and specificity of US for the detection of stenotic lesions compared to angiography. While Wakabayashi et al [80] reported identifying and treating central venous stenoses by using a smaller US probe in the intercostal space, the other studies exclude central venous stenosis (CVS).

Variant 3: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Initial imaging to guide interventional radiologic therapy options.

The presence of an occlusive thrombosis reflects a terminal event in the life of a failing AV access. It represents 65% to 85% of all cases of access abandonments. While the precipitating cause of the provocative terminal is often clear, such as venous outflow stenoses or low flow in the case of an AVG, a patient may present with a thrombosis without any obvious mechanism [5,82].

Variant 3: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Initial imaging to guide interventional radiologic therapy options.

A. Fluoroscopy Fistulography Hemodialysis Access Area of Interest

Thrombosis of a hemodialysis vascular access (fistula or graft) connotes lack of blood flow and is a diagnosis that is readily made by physical examination [7]. Diagnostic fistulography is suggested for suspected thrombosis if there is an intention to perform an endovascular intervention on significant findings or if it is needed for surgical planning, according to the SIR Quality Improvement Guidelines [7]. The European Best Practice Guidelines Expert Group on Hemodialysis recommends against performing diagnostic fistulography without intention to intervene on significant findings [19]. Given that up to 90% of dialysis access thrombosis is caused by an underlying stenosis, fistulography performed before or after thrombolysis or thrombectomy can help detect and treat any anatomic stenosis within the dialysis access circuit [7].

Variant 3: Suspected thrombosis of the upper or lower extremity hemodialysis access,

marked by absent pulse and thrill on physical examination. Initial imaging to guide interventional radiologic therapy options.
B. US Duplex Doppler Hemodialysis Access Area of Interest

There is no known evidence to support the use of diagnostic US once an AVF or AVG is suspected to be thrombosed on physical examination [5,7].The role of US duplex Doppler has mainly been shown to be beneficial in the identification of stenoses and risk factors for hemodialysis access thrombosis [83]. To prevent adverse outcomes, the KDOQI guidelines suggest routine performance of diagnostic imaging, which includes Doppler US and fistulography when an abnormality is detected [5].

Variant 3: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Initial imaging to guide interventional radiologic therapy options.
C. CTA Extremity area of Interest With IV Contrast

MDCT angiography has been shown to correlate well with DSA in evaluation of stenoses in hemodialysis patients with native AVF [17]. MDCT angiography has also been demonstrated to accurately diagnose stenoses in a dysfunctional AVF and AVG with a sensitivity of 95% [84]. In a more recent feasibility study, time-resolved dynamic CTA utilizing 3-phase imaging was compared to Doppler US in the evaluation of AVF and AVG. In conclusion, dynamic CTA was found to detect multiple pathologic findings not detected by US [85]. While no large studies exist, CTA is frequently performed in practice as a complementary imaging modality to diagnostic US and fistulography.

Variant 3: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Initial imaging to guide interventional radiologic therapy options.
D. CTV Extremity Area of Interest With IV Contrast

There is no relevant literature to support the use of CTV with IV contrast in evaluation of suspected dysfunction of a hemodialysis access.

Variant 3: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Initial imaging to guide interventional radiologic therapy options.
E. MRA Extremity Area of Interest Area of Interest Without and With IV Contrast

There is no relevant literature to support the use of MRA without and with IV contrast in evaluation of suspected dysfunction of a hemodialysis access.

Variant 3: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Initial imaging to guide interventional radiologic therapy options.
F. MRA Extremity Area of Interest Without IV Contrast

Multiple publications provide support for specific noncontrast MRA sequences to evaluate hemodialysis access, for example time-of-flight imaging, black-blood imaging, and quiescent-interval single-shot imaging. However, there is no significant literature to support or recommend its wide-spread usage [86,87]. MRA carries additional disadvantages of flow-related artifacts, as well as artifacts from endoprostheses.

Variant 3: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Initial imaging to guide interventional radiologic therapy options.

G. MRV Extremity Area of Interest Without and With IV Contrast

There is no relevant literature to support the use of MRV without and with IV contrast in evaluation of suspected dysfunction of a hemodialysis access.

Variant 3: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Initial imaging to guide interventional radiologic therapy options.

H. MRV Extremity Area of Interest Without IV Contrast

There is no relevant literature to support the use of MRV without IV contrast in evaluation of suspected dysfunction of a hemodialysis access.

Variant 4: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Treatment and procedures.

Variant 4: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Treatment and procedures.

A. Fluoroscopy Fistulography Hemodialysis Access with Intervention

Roughly 30% to 60% of AVFs experience thrombosis. Their restoration may be readily achieved using a combination of image-guided percutaneous interventional procedures, surgery, or some permutation of these therapeutic techniques [4]. However, the endovascular therapeutic options have largely superseded open surgical techniques for the restoration of a thrombosed dialysis access [88]. The SIR Standards and Practice Committee guidelines suggest that a stenosis with an associated thrombosis that occurs in a dialysis circuit ought to be managed with endovascular techniques when a perianastomotic stenosis is present and when a concomitant venous stenosis is present. In the former case, when a graft thromboses, such perianastomotic lesions should be managed first with combined thrombolysis and/or thrombectomy as well as balloon angioplasty [7].

Early diagnosis with the requisite intervention on the thrombosed hemodialysis access to restore its patency within 24 to 48 hours should be employed whenever achievable [7]. Every intervention employed in hemodialysis access maintenance should be coordinated and executed with the intention of preserving and optimizing the usable arterial and venous segments within a given patient's access. Various supportive percutaneous therapies have been effectively employed to manage AVGs and AVFs, including mechanical thrombectomy (eg, suction thrombectomy, balloon thrombectomy, or clot maceration), pharmacologic thrombolysis, balloon angioplasty, stent graft or stent placement, or any assortment of these combined techniques [5,7]. The clinical success for thrombolysis and/or thrombectomy is 75% to 94%. At 3-month, 6-month (primary), 6-month (secondary), and 12-month (secondary) cumulative patency has been reported at 37% to 58%, 18% to 39%, 62% to 80%, and 57% to 69%, respectively, with the latter 2 outcomes reflecting the results of thrombolysis only [45].

Variant 4: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Treatment and procedures.

B. Surgical Consultation

According to the SIR Quality Improvement Guidelines, endovascular management is the preferred alternative to open surgery as a first-line therapy for dialysis accesses thrombosis [7]. However, vascular surgery consultation for possible revision for creation of a new fistula may be considered in the setting of clinical failure of endovascular treatment [7]. Vascular surgery consultation for

access revision may be performed if thrombosis of the access occurs >2 times within a single month, or if recurrence of a correctable stenosis is delineated in the circuit. In patients with frequent or recurrent thrombotic occlusions of the hemodialysis access, hypercoagulability testing for associated thrombophilia may also be explored [7,89]. While some 90% of access thromboses are secondary to an anatomic stenosis, it should be noted that alternative precipitating processes exist and include hypotension post hemodialysis, hypercoagulable states, decreased cardiac output, and access site infection [7].

AV access aneurysms or pseudoaneurysms may contribute to AV access thrombosis and confound the efficacy of a successful endovascular thrombectomy. This is in part secondary to the presence of chronic intraluminal thrombus and difficult to access clot in the aneurysmal regions. Cull et al [90] reported a helpful technique that involves making an incision regional to the arterial anastomosis to facilitate removal of the arterial plug followed by a thorough manual thrombectomy of the circuit by physically "milking" the thrombus from the access lumen. In their series, complete extraction of both acute and chronic thrombus from the autogenous access was accomplished in 140 of 146 cases (95%).

Variant 4: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Treatment and procedures.
C. Placement of a New Tunneled Dialysis Catheter

In the case of a failed declot of an AVF or AVG, a tunneled dialysis catheter may be performed as an interval means for hemodialysis. The KDOQI 2019 guidelines suggest that placement of a tunneled (cuffed) dialysis catheter is a valid option, supported by the goal of hemodialysis access use for limited duration (eg, <3 months) [5]. In such cases, when AV access is expected to be ready for use in the short term, it is preferred to place tunneled dialysis catheters in the extremity opposite to the extremity that is anticipated for AV access creation or revision. The KDOQI experts tout that in urgent dialysis initiation (eg, <1 month), a tunneled cuffed femoral CVC may be acceptable until the AV access is created and usable. The option to use the femoral vein allows for preservation of upper extremity vasculature for the pending AV access creation.

The KDOQI 2019 guidelines regards it as reasonable to place a tunneled dialysis catheter for a long term or indefinite duration in those with limited life expectancy, patients in whom there are multiple prior failed AV accesses with no available options due to a combination of inflow artery and outflow vein problems (eg, severe arterial occlusive disease, noncorrectable central venous outflow occlusion) or in pediatric patients with vessels of prohibitively diminutive caliber [5]. In addition, tunneled dialysis catheters may be placed for long-term use in patients with a valid preference, whereby use of an AV access would considerably restrict quality of life or attainment of life goals. This is advocated only after the patient has been properly informed of patient-specific risks and benefits of other potential and reasonable access options that specifically apply to them [5]. Under valid indications for tunneled dialysis catheter placement, the KDOQI guidelines suggests that when the duration of catheter use is anticipated to be prolonged (>3 months) without the anticipated use of AV access, a tunneled dialysis catheter may be placed in order of preference in the following vein, namely internal jugular, external jugular, femoral, subclavian, and lumbar veins, respectively [5]. In the absence of pathologic findings such as a CVS or devices such as pacemakers, tunneled dialysis catheter placement on the right side is preferred to the left side secondary to a more direct venous anatomy. If a single side demonstrates findings that restrict AV access creation but not catheter placement, that laterality ought to be utilized to preserve the contralateral side for creation of the intended AV access.

Variant 4: Suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. Treatment and procedures. D. US Duplex Doppler Hemodialysis Access Area of Interest

There is minimal data to support US-guided endovascular thrombectomy or thrombolysis [80]. Fluoroscopically-guided endovascular interventions performed during fistulography are routine techniques employed to facilitate endovascular thrombectomy or thrombolysis. Several retrospective studies have shown the feasibility of performing US-guided endovascular thrombectomy or thrombolysis [80,91]. The largest series by Wakabayashi et al [80] reported a 97.4% technical success rate and a 91.9% primary patency rate in 455 cases of US-guided thrombectomy at 1-month. Major limitations include the lower sensitivity and specificity of US for the detection of underlying stenotic lesions compared to angiography.

Variant 5: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Initial imaging to guide interventional radiologic therapy options.

Optimal hemodialysis is dependent on the presence of a mature, functioning AVF. A mature fistula may be defined as functionally mature or physiologically mature. The KDOQI guidelines defines a mature fistula as one that dependably provides the prescribed dialysis using 2 needles for greater than two-thirds of the dialysis sessions over a 4 consecutive week period [5].

Before initiation of use of the AVF, a waiting time is warranted to allow for structural evolutions to the circuit, the core being "arterialization" of the vein wall secondary to turbulent flow. The KDOQI guidelines suggest that an access may be defined as functional when its flow exceeds 600 mL/min, the vein is measured at a minimal diameter of 6 mm, dialysis access is not located at a depth >0.6 cm, and its margins are readily identifiable. While depth, vein diameter, and blood flow have been demonstrated to be important when utilizing criteria of fistula blood flow of 600 mL/min, a vein diameter of 6 mm, as well as a depth of 2 mm below the skin, the likelihood of maturation success was approximately 50%. Greater depths were thought to be associated with worse maturation outcomes. Considering that maturation was 50% for accesses at a depth of 2 mm, a depth of 6 mm was deemed to be less successful [5]. The adequacy of blood flow and an appropriate needle access segment represent the 2 most critical aspects of an AVF. The time needed to achieve such maturation characteristics ranges from 1 to 3 months after surgical creation of the AVF. An AV access that is marked by a failure to mature is one that in spite of radiologic or surgical intervention including open procedural management or endovascular management may be utilized successfully for hemodialysis by 6 months postcreation [92]. A venous stenosis, which is frequently caused by neointimal hyperplasia results in sequelae in both AVGs and AVFs. The presence of a stenosis may precipitate nonmaturation of the AVF with subsequent reliance on a central venous dialysis catheter. AVF maturation failure occurs in observational studies in 20% to 60% of cases [93].

Variant 5: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Initial imaging to guide interventional radiologic therapy options. A. Fluoroscopy Fistulography Hemodialysis Access Area of Interest

Given that early detection and intervention of a nonmaturing AVF can mitigate early access failure, prompt identification is critical. While various noninvasive imaging strategies such as US remain helpful imaging tools for evaluation of a nonmaturing native AVF, fistulography has been often used with other authors citing it as the next step after an initial duplex Doppler US evaluation for suspected nonmaturation [94,95]. Diagnosis of an AVF may be performed via the traditional retrograde venous fistulography or via direct retrograde access of the perfusing brachial artery

using a 3F micropuncture access [94]. One of the core benefits of using early fistulography in assessing a native AVF that has been deemed to be nonmaturing is that transvenous angioplasty may be in turn used to correct and achieve functional patency in most cases [96,97].

While the problems in maturation may often be predicted at the time of fistula creation (eg, efferent vein is small, <3 mm), the anatomic location of the principal lesion on angiography has been clearly demonstrated in the anastomosis segment, and juxta-anastomotic segments, with inflow arterial lesions ranging from 4% to 7% of cited studies [95,98]. Multiple reports have cited the benefits of using the percutaneous technique of fistulography to aid early identification of fistulas that are deemed as failing to mature followed by subsequent early treatment of the underlying causes. These subsequent endovascular techniques that may be warranted are readily facilitated and ultimately result in a functional fistula in most patients when this percutaneous imaging and treatment strategy is employed [96,97,99].

Variant 5: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Initial imaging to guide interventional radiologic therapy options.

B. US Duplex Doppler Hemodialysis Access Area of Interest

Duplex Doppler US reflects a unique ability to reliably evaluate the functional and structural characteristics of the peripheral vasculature. As such, it has become a well-established imaging modality for vascular access follow-up. Duplex Doppler US reflects a reliable means of assessing the velocity of the flow. KDOQI 2019 guidelines recognize the presence of established minimum US criteria for AVF maturity at 4 weeks that includes evaluation of the vessel diameter and flow parameters. Sonographic demonstration of a vessel diameter of 4 to 5 mm and blood flow of 400 to 500 mL/min has been associated with high reliability of the access in providing adequate dialysis [5]. For example, this includes a vein diameter of 6 mm, which is considered adequate. Given the need for a long enough access segment capable of supporting 2 dialysis access needles, a straight segment 10 cm or longer is needed. Finally, demonstration of the depth of the access <6 mm from the skin can also be demonstrated on duplex Doppler US [32]. Doppler US is particularly helpful in assessing the causes of nonmaturation of an AVF, such as the presence of stenoses in the access circuit or competing venous tributaries, and thus can be used to prospectively inform the needed percutaneous or surgical therapy [7]. A vein diameter of at least 5 mm and a palpable thrill are deemed sensitive predictors (83% and 96%, respectively) for successful future dialysis use [100].

Mufty et al [101] suggested that when physical examination, consisting of inspection, palpation, and auscultation was deemed insufficient to support a definitive diagnosis, subsequent diagnostic evaluations first by duplex US followed by angiography may be performed. In the report of their dedicated surveillance program aimed at optimizing the functional access rate at first dialysis, a functional outcome rate of 94.2% (145/154 patients) at the time of first dialysis or at the end of the studied period was noted. Forty reinterventions were needed secondary to failure to mature in 31 patients (31/40; 77.5%). Thus, an average of 1.29 interventions for every nonmaturing AVF was reported. Reinterventions were required in 9 of 40 (22.5%) of these cases (n = 20) due to dysfunction after there was deemed to be an initial successful maturation. In this cohort, 41.4% of reported reinterventions were required prior to duplex US investigation [101]. Along with flow measurements, direct or derived static pressure, duplex US provides effective surveillance techniques for detection of a nonmaturing AVF in the predialysis stage [102]. Singh et al [103] reported a systematic use of US in triaging immature AVFs and reported an increase in 47% of AVFs that successfully matured to usability by dialysis.

Variant 5: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Initial imaging to guide interventional radiologic therapy options. C. CTA Extremity area of Interest With IV Contrast

Contrast-enhanced MDCT angiography may be used to evaluate for anastomotic or juxta-anastomotic strictures, outflow vein stenosis, or dispersal of flow due to an accessory vein in patients with failure of maturation [17,85,104].

Variant 5: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Initial imaging to guide interventional radiologic therapy options. D. CTV Extremity Area of Interest With IV Contrast

There is no identified relevant literature to support the use of CTV extremity in evaluating a failure of an AVF to mature.

Variant 5: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Initial imaging to guide interventional radiologic therapy options. E. MRA Extremity Area of Interest Without and With IV Contrast

There is no identified relevant literature to support the use of MRA extremity without and with IV contrast in evaluating a failure of an AVF to mature.

Variant 5: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Initial imaging to guide interventional radiologic therapy options. F. MRA Extremity Area of Interest Without IV Contrast

There is no identified relevant literature to support the use of MRA extremity without IV contrast in evaluating a failure of an AVF to mature.

Variant 5: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Initial imaging to guide interventional radiologic therapy options. G. MRV Extremity Area of Interest Without and With IV Contrast

There is no identified relevant literature to support the use of MRV extremity without and with IV contrast in evaluating a failure of an AVF to mature.

Variant 5: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Initial imaging to guide interventional radiologic therapy options. H. MRV Extremity Area of Interest Without IV Contrast

There is no identified relevant literature to support the use MRV extremity without IV contrast in evaluating a failure of an AVF to mature.

Variant 6: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Treatment and procedures.

Variant 6: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Treatment and procedures.
A. Fluoroscopy Fistulography Hemodialysis Access with Intervention

The SIR Standards and Practice Committee suggests that AVFs that have not met criteria for maturity after 2 months since their creation are candidates for endovascular therapies. These include 3 distinct techniques. Firstly, balloon angioplasty of any afferent preanastomotic stenoses inhibiting arterialization of the AVF may be performed. Secondly, balloon angioplasty of the arterial anastomosis may be performed to augment inflow to the maturing venous segment. Thirdly, any small venous tributaries competing with the main venous outflow by shunting blood

flow away from it and thus compromising its maturation may be embolized percutaneously [7].

When performing angioplasty of stenoses within the access circuit that are inhibiting AVF maturation, the maximum acceptable residual stenosis is <30%. Restoration of a palpable thrill posttreatment is the goal in each case and is the best predictor of optimal long-term outcomes [105]. Reported clinical success for treatment of nonmaturing AVFs is 92%. In studies using angioplasty as the principal therapeutic percutaneous technique, cumulative patency at 3-month (primary), 6-month (primary), 12-month (primary), 6-month (secondary), and 12-month (secondary) are 71%, 54%, 54%, 82%, and 77%, respectively [7]. While the long-term viability of fistulas that have been flagged as nonmaturing has been called into question, the early identification of suboptimal maturation and thus the treatment of the AVF may result in a functional fistula in the vast maturity of patients. Two prospective studies demonstrate that immature AVFs may be salvaged by endovascular management in 83% to 87% of cases [95,99].

A study by Clark et al [106] reported a paradigm where native fistulas were assessed with physical examination at 4 to 6 weeks by a surgical or nephrology team member. A single attempt at cannulation was then performed. If the fistula was clearly visible and easily cannulated, no further evaluation was performed, and the fistula continued its subsequent maturation until deemed suitable for use, routinely at 3 months postcreation. If a native fistula was not deemed to have matured sufficiently at 3 months, the patient was referred to interventional radiology for diagnostic fistulography with an attempt at percutaneous salvage. Clark et al [106] reported that percutaneous angioplasty facilitated the salvage of 75 of 85 (88%) of the studied native fistulas that were flagged as failing to mature. They achieved primary patency rates of 45% (6 months) and 34% (12 months). Of note, their reported secondary interventions included angioplasty, stent placement, as well as thrombectomy, which were reported to help augment the patency rate up to 79% at 6 months with long-term rates at 12 months of 75%, and at 18 months to 63% [106].

Variant 6: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Treatment and procedures.

B. Surgical Consultation

Opinions and research diverge on the causes of nonmaturation. Turmel-Rodrigues et al [97] purports that an AVF that fails to mature is precipitated by a coexisting venous stenosis in 100% of patients assessed with diagnostic fistulography. Conversely, Beathard et al [96] touts that a lack of maturation is routinely due to a competing venous collateral. Small venous tributaries or accessory veins are thought to shunt blood flow away from the venous outflow, thus impairing maturation.

However, the accepted range of etiologies for nonmaturation of an AVF include a stenosis, lack of vein and artery dilation secondary to intimal hyperplasia, the presence of scarring in the outflow vein, and atherosclerotic disease, large accessory veins, an AVF vein that is too deep to cannulate, among other factors [107]. A hemodynamically significant stenosis results in smaller diameters and thus reduced blood flows, a finding which was significant in the Hemodialysis Fistula Maturation (HFM) in their initial studied model [107]. Of note, in this prospective study, there was no significant relationship of fistula nonmaturation with the presence of an accessory vein. However, authors note that a large accessory vein may divert blood flow to a degree that warrants embolization by an interventional radiologist or ligation by a vascular surgeon [103].

In a study by Mufty et al [101] a proactive surveillance program was developed to identify and preemptively manage nonmaturing AVFs. In this study, 164 patients were seen at an outpatient

clinic at 2 weeks, 6 weeks, 3 months, 6 months, and 12 months postoperatively, by a dialysis nurse and vascular surgeon. AVF maturation marked in part by patency and functionality were assessed by physical examination as well as US. When there was clinical suspicion for a stenosis, further diagnostic duplex US and/or fistulography was performed. When indicated, a salvage intervention was then performed. Similarly, when a percutaneous salvage procedure was not deemed feasible, creation of a new AVF by the vascular surgeon ensued.

Mufty et al [101] also reported that in follow-up, 40 patients (24.4%) required 1 or more subsequent interventions, for a total of 60 reinterventions. In the study, 30% of the aforementioned interventions included endovascular techniques (eg, angioplasty, thrombectomy, and angioplasty) and 70% included surgical techniques, with the latter interventions including open thrombectomy, superficializing and lateralization, branch ligation, reanastomosis, creation of a new AVF, and creation of a polytetrafluoroethylene AV-loop graft. At the completion of the study period, dialysis had been initiated in 85 patients. In 66 patients, dialysis was initiated via a functional AVF after a creation of the AVF at a mean of 305 days (median: 243 days; range 40–979 days). Primary patency, assisted primary patency (defined as thrombosis free as well as the time interval between initial AVF creation and thrombosis of the access, or the time of measurement of patency measurement, which includes any needed treatments intended to preserve the functionality of a patent AVF), and secondary patency (defined as the time interval between AVF initial creation and thrombosis, abandonment of the access or the time of patency measurement which includes intervening treatments intended to reestablish the functionality of a thrombosed access) rates at 1 year were reported as 67.7% ± 4.2, 82.9% ± 3.4 and 84.6% ± 3.3, respectively. The KDOQI guidelines cite that there is inconclusive data to make a recommendation on the preferred use of endovascular vs surgical techniques to facilitate postoperative maturation. They cite that it is reasonable to make an appropriate decision in the setting of a careful individualized approach to a given patient on the use of either endovascular or surgical techniques when the need to intervene on an AV access to promote its maturation postoperatively arises [5].

Variant 6: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Treatment and procedures.

C. Placement of a New Tunneled Dialysis Catheter

The KDOQI 2019 guidelines regards it as reasonable to place a tunneled dialysis catheter for a short-term duration for patients in whom an AVF or AVG was created but not ready for use and in whom hemodialysis is required [5]. Among the indications for a long-term tunneled dialysis catheter, the KDOQI guidelines considers the following: multiple prior failed AV accesses with no feasible options, a valid patient preference, whereby the use of an AV access may considerably limit quality of life or achievement of stated life goals, after appropriate informed consent of the patient-specific risks and other reasonable and practical access solutions may be afforded to the patient. In addition, the KDOQI guidelines consider it reasonable to place a CVC in patients without any given access creation options due to outflow vein problems, such as a noncorrectable central venous outflow occlusion and/or inflow artery problems such as severe arterial occlusive disease, or in infants/children with prohibitively diminutive vessels.

In a study by Mufty et al [101] where a multidisciplinary surveillance protocol assessed fistulas postcreation and monitored and supported their readiness for use, 10 of 164 patients in the study required dialysis within the minimal anticipated maturation period after AVF creation (~4 weeks). A tunneled (cuffed) central venous hemodialysis catheter was provided to these patients, although ultimately excluded for further follow-up in their study. A study by Arhuidese et al [108] assessed

vascular access outcomes for long-term hemodialysis in the United States and the associated impact of utilizing a temporizing catheter. Temporizing with a catheter was associated with a 51% increase in mortality (adjusted hazard ratio [aHR], 1.51; 95% confidence interval [CI]; 1.48–1.53; *P* < .001), 69% decrease in primary patency (aHR, 0.31; 95% CI; 0.31–0.32; *P* < .001), and 130% increase in severe infection (aHR, 2.3; 95% CI; 2.2–2.5; *P* < .001) compared to initiation with autogenous fistulas or prosthetic grafts. Mortality was 2.2 times higher for patients who remained using hemodialysis catheters compared to those who initiated hemodialysis with autogenous fistulas (aHR, 2.25; 95% CI; 2.21–2.28; *P* < .001).

Absolute all-cause mortality during the study period was 29.5% for autogenous fistulas, 36.7% for prosthetic grafts, and 42.2% for patients persistently dialyzing through a catheter (*P* < .001). This corresponds to an incidence death rate of 161 per 1,000 person-years for autogenous fistulas, 218 per 1,000 person-years for prosthetic grafts, and 262 per 1,000 person-years for the catheter persistent group (*P* < .001). Kaplan-Meier estimates of patient survival comparing autogenous fistulas, prosthetic grafts, and persistent hemodialysis with catheters were 84.0%, 78.2%, and 69.6% at 1 year; 72.3%, 64.4%, and 58.8% at 2 years; 62.0%, 53.6%, and 51.2% at 3 years; 53.5%, 44.9%, and 45.2% at 4 years; and 50.0%, 41.2%, and 42.9% at 5 years (*P* < .001). Prosthetic grafts were associated with 29% increase in mortality compared to autogenous fistulas (aHR, 1.29; 95% CI; 1.27–1.31; *P* < .001) [108].

Variant 6: Failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. Treatment and procedures.

D. US Duplex Doppler Hemodialysis Access Area of Interest

Along with blood flow measurements, direct or derived static pressure, duplex US is among the limited effective surveillance techniques for detection of a nonmaturing AVF in the predialysis stage [102]. Singh et al [103] systematic use of US in triaging immature AVFs resulted in an increase in 47% of AVFs that successfully matured to usability by dialysis. Mufty et al [101] reported the results of a strict but successful surveillance program using a 3-month maturation period required before needling the AVF. Adjuvant duplex US and/or phlebography was offered when physical examination was equivocal. AVF maturation was also confirmed by US and physical examination of the AVF. If indicated; however, a salvage intervention was performed or when a salvage procedure was not possible, a new AVF was created. Duplex US evaluation was also performed to support triaging and screening in 41.4% of reinterventions. Ultimately, with duplex US at the core of the surveillance program, a functional success rate of 94.2% was accomplished [101]. The evidence suggests that the critical role of US is centered in surveillance and flagging of the immature at-risk AVF, diagnostic in determining the cause of failed maturity, or in determining the need for reintervention [100,107,109].

Variant 7: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Initial imaging to guide interventional radiologic therapy options.

The presence of an occlusion or hemodynamically significant stenoses in any of the major central or intrathoracic veins, including the internal jugular, subclavian, brachiocephalic veins, or SVC can degrade the function of an AV access, resulting in ineffective hemodialysis. These may occur in 5% to 50% of cases. Such lesions may also precipitate high venous pressures secondary to an increase in flow within the AVF, with associated broad symptom severity including chest wall and central ipsilateral extremity venous collaterals, dermatosclerosis, arm edema, ulceration, and SVC

syndrome. The presence of such stenoses in the central venous outflow may result in prolonged bleeding after decannulation post dialysis, with or without an increase in venous pressures noted during monitoring of the access or increased AV access recirculation [5]. Causes and exacerbating processes include intravascular CVC, deep venous thromboses, pacemakers and other cardiac rhythm devices, as well as the presence of the hemodialysis AV access itself [4,5].

Variant 7: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Initial imaging to guide interventional radiologic therapy options.

A. Fluoroscopy Fistulography Hemodialysis Access Area of Interest

There is consensus that central vein occlusions and stenoses that develop in the outflow track of a dialysis access ought to be treated in the setting of handicapping extremity edema [110]. A high index of suspicion, particularly in patients with a history of multiple prior catheter placements or chronic dialysis catheter use, may lead to a clinical diagnosis of CVS. While meticulous physical examination may demonstrate limb or breast swelling and neck or chest wall collaterals, the definitive diagnosis of CVS is made on angiography [111].

Diagnostic fistulography allows for angiographic visualization of a culprit lesion resulting in the noted swelling of the ipsilateral extremity. However, given that a symptomatic CVS is primarily treated with PTA, a single intervention may facilitate both definitive diagnosis of the suspected CVS and its treatment [112].

Variant 7: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Initial imaging to guide interventional radiologic therapy options.

B. US Duplex Doppler Hemodialysis Access Area of Interest

Duplex US has been cited as suboptimal for the diagnostic assessment of the central veins in part secondary to interference by the enveloping bony thorax as well as due to overlapping soft tissue in obese individuals [111]. However, color flow duplex US negates the need for use of radiocontrast and can also suggest the presence of CVS when there is absent respiratory variation in vessel diameter, a lack of polyphasic atrial waves, and depiction of regional venous collaterals. Data also suggests that duplex US may be used in select patients to identify a culprit CVS requiring an intervention, but also as a means of monitoring the durability of success posttreatment [113]. For example, in a study comparing duplex US in symptomatic patients with venography as the reference standard, a significant yield with duplex US in addition to 90% agreement with venography was noted. The preferred threshold to detect a >50% stenosis by duplex US was suggested by a poststenotic to prestenotic peak vein velocity ratio of 2.5 [113]. Given the limitations of US in reliably assessing the culprit lesion in the thoracic cavity, there is no relevant literature to support the practical use of duplex Doppler US of the hemodialysis access in evaluation of a suspected CVS or occlusion, suggested by swelling of the extremity ipsilateral to the hemodialysis access.

Variant 7: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Initial imaging to guide interventional radiologic therapy options.

C. CTA Extremity area of Interest With IV Contrast

MDCT angiography can depict the anatomy of the entire vascular tree extending from the fistula to the heart. A study by Wasinrat et al [17] compared MDCT angiography with conventional DSA in the assessment of stenoses within vascular accesses in hemodialysis patients. In a subgroup analysis assessing the proximal regions of the access, which include the subclavian veins, brachiocephalic veins, and SVC, which are located deep and are thus routinely difficult to visualize on the color Doppler US (CDUS), the overall accuracy for MDCT was 98.4%. This affirms MDCT angiography's advantage over CDUS in imaging the proximal hemodialysis access as well as its helpful correlation with DSA. MDCT angiography was found to provide helpful correlation with DSA and good visualization of central venous anatomy [17].

In a study by Doelman et al [114] comparing CE-MRA and CDUS with DSA for the detection of significant (≥50%) stenoses in dysfunctional dialysis accesses, MDCT angiography was able to reliably image the subclavian and other central venous vasculatures that were limited in visualization on CDUS. In the detection of subclavian stenoses, Wasinrat et al [17] reported high specificity (94.7%) with a single false-positive stenosis on CT imaging when compared with DSA. Given that stenoses of the subclavian vein represent a high frequency of central venous stenoses within hemodialysis patients, their reliable detection is essential [114].

MDCT angiography has been reported to accurately detect stenoses compared to DSA with a sensitivity of 95% (including all segments). However, in a study by Dimopoulou et al [84], the usefulness of MDCT angiography with 3-D image reconstruction was evaluated in the long-term assessment of hemodialysis patients with dysfunctional AVF and AVG. Poor quality of contrast enhancement was noted in 5 (5.5%) of the 92 imaged segments, which were all central in location. This phenomenon was noted in patients with multiple and/or severe stenoses in the AVF or AVG. A pseudostenosis was depicted in the MDCT angiography images in 3 patients secondary to venous compression regional to the thoracic inlet. While this likely occurred due to prone patient positioning with the AVF or AVG arm in extended position above the head, similar observations have been made by Heye et al [18] who described 3 pseudostenosis artifacts secondary to venous compression. Conversely, Ko et al [115] reported 100% sensitivity and specificity of MDCT angiography of central venous stenoses with no report of any detected pseudostenosis artifacts regional to the thoracic inlet, nor suboptimal contrast opacification in the central vessels. It may be concluded that in cases where MDCT angiography is utilized with inadequate contrast opacification of the central vessels or suspicion for pseudostenosis artifacts, thorough examination of the vascular tree with diagnostic fistulography would be indicated [84]. Additionally, prior review articles support the usage of MDCT for detection of central stenoses [104].

Variant 7: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Initial imaging to guide interventional radiologic therapy options.

D. CTV Extremity Area of Interest With IV Contrast

The KDOQI 2019 guidelines state that CTV provides the advantage of offering a noninvasive imaging option that allows for concomitant assessment of the four extremities, noting that the relative timing of the IV contrast bolus and the corresponding image acquisition may be challenging [5]. However, there is no identified literature to support the widespread use of CTV extremity with IV contrast in evaluation of suspected central stenosis or occlusion suggested by swelling of the extremity ipsilateral to the hemodialysis access.

Variant 7: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Initial imaging to guide interventional radiologic therapy options.

E. MRA Extremity Area of Interest Without and With IV Contrast

In a meta-analysis by Li et al [11] it was noted that the number of included studies of noncontrast enhanced MRA was not sufficient to support a reliable subgroup analysis. Contrasting to conventional MRA techniques such as time-of-flight and phase-contrast, which depend on phase shift effects or velocity-dependent inflow, the use of gadolinium-enhanced MRA does not rely upon the movement of blood. Unfortunately, in this meta-analysis, the effect could not be explored. Li et al [11] cited that another limitation in MRA lies in the differences in field-of-view between CE-MRA and noncontrast enhanced MRA. The field-of-view of CE-MRA is cited as similar to that of CTA, which includes the complete fistula circuit, namely the inflow artery, arterial anastomosis, draining vein, and central venous outflow to the SVC. However, the field-of-view in noncontrast-enhanced MRA has been reported to exclude imaging of the central venous outflow [11]. Depiction of the central venous outflow is critical as subclavian vein stenoses are not uncommon in patients on hemodialysis. As such, there is no identified relevant literature to support the use of MRA extremity without and with IV contrast in evaluation of suspected central stenosis or occlusion suggested by swelling of the extremity ipsilateral to the hemodialysis access.

Variant 7: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Initial imaging to guide interventional radiologic therapy options.

F. MRA Extremity Area of Interest Without IV Contrast

There is no relevant literature to support the use of MRA extremity without IV contrast in evaluation of suspected central stenosis or occlusion suggested by swelling of the extremity ipsilateral to the hemodialysis access.

Variant 7: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Initial imaging to guide interventional radiologic therapy options.

G. MRV Extremity Area of Interest Without IV Contrast

As the initial imaging to guide interventional radiologic therapy options, there is no identified relevant literature to support the use of MRV extremity without IV contrast in evaluating a patient with clinical suspicion of CVS or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals.

Variant 7: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Initial imaging to guide interventional radiologic therapy options.

H. MRV Extremity Area of Interest Without and With IV Contrast

As the initial imaging to guide interventional radiologic therapy options, there is no identified relevant literature to support the use of MRV extremity without and with IV contrast in evaluating a patient with clinical suspicion of CVS or occlusion suggested by swelling (ie, soft tissue edema) of

the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals.

Variant 8: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Treatment and procedures.

Variant 8: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Treatment and procedures. A. Fluoroscopy Fistulography Hemodialysis Access with Intervention

Employing diagnostic fistulography to support endovascular treatment of a CVS is indicated when a stenosis >50% of the endoluminal diameter is detected, when there is hemodynamic compromise in the dialysis vascular access circuit or when the AVF is nonmaturing. A determination to perform endovascular treatment of central venous stenoses is based on the presence of compelling clinical parameters, which include debilitating arm swelling or the presence of increased frequency of failing accesses [7,116].

Angioplasty for asymptomatic stenoses is not ideal as it is associated with increased progression to symptomatic stenosis [5,110,117]. The KDOQI guidelines 2019 state that an endovascular approach with transluminal balloon angioplasty is the first-line treatment of a symptomatic CVS [5,116]. The SIR Standards and Practice Committee guidelines and the KDOQI 2019 guidelines suggest that the use of a stent or stent graft should be considered in the setting of failed angioplasty after employing high-pressure balloons, marked by the presence of a refractory or persistent stenosis, abnormal hemodynamic findings that persist postangioplasty, or elastic venous recoil after angioplasty resulting in a reduction in the normal vessel caliber >50%, or stenosis recurrence within 3 months postangioplasty [5,7].

Yan et al [112] noted that balloon angioplasty of the central venous stenoses were seen to yield little benefit on AV access blood flow but resulted in effective relief of associated symptoms. One retrospective study by Bakken et al [118] reports a primary patency of 76% as equivalent between angioplasty versus angioplasty with stenting at 30 days. 12-month rates of 29% versus 21% for angioplasty and stenting, respectively, were noted. In a second retrospective study by Ozyer et al in patients undergoing hemodialysis without CVCs, primary patency, marked by time from intervention to the subsequent intervention, was 24.5 months and 13.4 months, in the angioplasty and stent group, respectively [5,119]. Stents ought to be used cautiously or avoided regional to the thoracic outlet because of the associated risks for extrinsic compression and resultant stent fracture. In addition, the placement of stents over indwelling pacer or defibrillator wires may confound their removal. As such, consideration for their removal or for creation of a new AV access on the contralateral extremity when possible, may be given [5]

Variant 8: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Treatment and procedures. B. Surgical Consultation

An array of open surgical options exists for a patient with CVS or occlusion that is related to their AV access. Of note, however, these options are regarded as alternative options and are determined by the patient's vascular anatomy, namely the availability of patent inflow and outflow veins. Such

options include an axillary-axillary bypass, axillary-jugular bypass, axillary-atrial bypass, axillary-femoral bypass, or the jugular vein turndown procedure [120,121]. Conversely, the related venous hypertension may be diminished by reducing the blood flow through AV access using some form of flow limiting procedure or banding [5].

The Hemoaccess Reliable Outflow (HeRO) Vascular Access Device (Hemosphere, Inc) may be used as a hybrid alternative. Upon bypass of the occlusion, it employs a combined endovascular and open surgical access approach [122]. The HeRO graft itself has a 6 mm inner diameter polytetrafluoroethylene graft that is paired with a CVC with an outer diameter of 19F. While it may commonly be used as a new access option, the HeRO graft may be integrated in the setting of an existing AVF or AVG to support augmented "central vein runoff". The aforementioned is dictated by whether passage of the delivery sheath for the CVC through the lesion is feasible [5].

Variant 8: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Treatment and procedures. C. Placement of a New Tunneled Dialysis Catheter

The presence of an appropriately positioned CVC in the internal jugular vein can result in a CVS even when the duration of placement is brief. Even peripherally inserted central catheters (ie, PICCs) are reported to precipitate a CVS or occlusion in as a high as 7% of cases with subclavian catheters provoking such stenotic lesions in up to 50% of cases [111]. Given that central venous stenoses or occlusions may represent the worst of the CVC-related complications, the KDOQI 2019 guidelines underscore the importance of limiting their use [5].

Considering the limitations of CVCs in precipitating or exacerbating central venous stenoses, there is no relevant literature to support the use of new tunneled dialysis catheter placement in the setting of a suspected CVS or occlusion, suggested by swelling of the extremity ipsilateral to the hemodialysis access.

Variant 8: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Treatment and procedures. D. Continued Hemodialysis Access Use with Surveillance

Mild symptoms associated with central venous stenoses, or occlusions may improve in time through the development of venous collaterals. As such, the presence of a central venous occlusion or stenosis may be marked by a functional AV access without associated arm edema in some patients [5]. In such cases, intervention is unindicated for these asymptomatic lesions or those with minimal associated symptoms [110]. Of note, it is common for a degree of arm edema to occur in patients after AV access construction, possibly related to operative trauma and/or mild venous hypertension. Its postoperative resolution usually occurs in 2 to 6 weeks as the peri-surgical inflammation subsides, and venous collaterals develop.

Variant 8: Clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. Treatment and procedures. E. US Duplex Doppler Hemodialysis Access Area of Interest

CDUS represents a noninvasive method to evaluate CVS. Limitations include its inadequate use when used to conduct central venous assessments in the absence of an angiographic map. The

subclavian and brachiocephalic veins, as well as the SVC are located deep and are thus routinely difficult to visualize on CDUS [17]. Given the limitations of US in reliably assessing the culprit lesion in the thoracic cavity, there is no relevant literature to support the use of duplex Doppler US of the hemodialysis access in evaluation of a suspected CVS or occlusion, suggested by swelling of the extremity ipsilateral to the hemodialysis access.

Variant 9: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Initial imaging to guide interventional radiologic therapy options.

Variant 9: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Initial imaging to guide interventional radiologic therapy options.
A. Fluoroscopy Fistulography Hemodialysis Access Area of Interest

In the absence of vascular access site infection, fluoroscopic fistulography of the hemodialysis access may have been considered as an option prior to surgical repair of an aneurysm or pseudoaneurysm to evaluate and treat an underlying venous outflow stenosis that may be a precipitator of the associated aneurysm or pseudoaneurysm [123]. Given that the presence of skin erosion or active or impending hemorrhage from an AV access in the setting of a pseudoaneurysm is a surgical emergency, there is no relevant identified literature to support the use of fluoroscopy fistulography in the evaluation of abnormal skin changes associated with the hemodialysis access cannulation site.

Variant 9: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Initial imaging to guide interventional radiologic therapy options.
B. US Duplex Doppler Hemodialysis Access Area of Interest

In the setting of skin changes overlying the hemodialysis access site, KDOQI touts that physical examination remains the hallmark for assessing for infection. However, considering the possibility for other differential diagnoses, KDOQI considers it reasonable for radiologic imaging such as duplex US ± CT scan, PET, and nuclear medicine scans (eg, indium scan) to be utilized as an adjunctive diagnostic technique [5]. In addition, the use of duplex US can corroborate a suspected diagnosis such as infection and confirm the extent of involvement of the AV access. Duplex US reliably confirms access patency. It assesses the integrity of the wall of the AV access, which may be degenerated, and excludes the presence of a pseudoaneurysm, namely a contained rupture in the access circuit. Moreover, US is adept at identifying the presence of fluid regional to the access which may represent an abscess, hematoma or seroma [5].

Variant 9: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Initial imaging to guide interventional radiologic therapy options.
C. CTA Extremity area of Interest With IV Contrast

There is no relevant identified literature to support the use of CTA extremity with IV contrast in the evaluation of abnormal skin changes associated with the hemodialysis access cannulation site.

Variant 9: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Initial imaging to guide interventional radiologic therapy options.
D. CTV Extremity Area of Interest With IV Contrast

There is no relevant identified literature to support the use of CTV extremity with IV contrast in the evaluation of abnormal skin changes associated with the hemodialysis access cannulation site.

Variant 9: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Initial imaging to guide interventional radiologic therapy options.
E. MRA Extremity Area of Interest Without and With IV Contrast

There is no relevant identified literature to support the use of MRA extremity without and with IV contrast in the evaluation of abnormal skin changes associated with the hemodialysis access cannulation site.

Variant 9: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Initial imaging to guide interventional radiologic therapy options.
F. MRA Extremity Area of Interest Without IV Contrast

There is no relevant identified literature to support the use of MRA extremity without IV contrast in the evaluation of abnormal skin changes associated with the hemodialysis access cannulation site.

Variant 9: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Initial imaging to guide interventional radiologic therapy options.
G. MRV Extremity Area of Interest Without and With IV Contrast

There is no relevant identified literature to support the use of MRV extremity without and with IV contrast in the evaluation of abnormal skin changes associated with the hemodialysis access cannulation site.

Variant 9: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Initial imaging to guide interventional radiologic therapy options.
H. MRV Extremity Area of Interest Without IV Contrast

There is no relevant literature to support the use of MRV extremity without IV contrast in the evaluation of abnormal skin changes associated with the hemodialysis access cannulation site.

Variant 10: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Treatment and procedures.

Variant 10: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar

formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Treatment and procedures.

A. Fluoroscopy Fistulography Hemodialysis Access with Intervention

In cases of suspected superficial or deep infection, there is no evidence to support fluoroscopic fistulography of the hemodialysis access with endovascular intervention. Vascular surgical consultation is supported to evaluate the need for surgical revision.

In the setting of pseudoaneurysm formation at the hemodialysis access cannulation site without suspicion for infection, fluoroscopic fistulography with endovascular intervention may have a limited role in treatment. There have been several small retrospective and prospective nonrandomized studies suggesting the viability of endovascular treatment of the cannulation site pseudoaneurysms using endovascular stent grafts [124-126]. In a retrospective study of 24 patients with a pseudoaneurysm treated with endovascular stent grafts, Shah et al [124] reported an overall patency rate of 81.5% with a mean follow up of 268.9 days and a treatment failure rate of 18.5%. Of the 5 patients with treatment failure, 3 underwent surgical repair due to graft infection. A retrospective review of 38 endovascular stent placements for treatment of a pseudoaneurysm and stenosis found a complication rate of 28.9%, with a relative risk ratio of 5 for stent graft placement for the treatment of a pseudoaneurysm compared to for a stenosis alone [127].

Fluoroscopic fistulography of the hemodialysis access with endovascular intervention has been considered as an option prior to surgical repair of an aneurysm or pseudoaneurysm to evaluate and treat an underlying venous outflow stenosis that may be a precipitator of the associated aneurysm or pseudoaneurysm [123]. In the absence of concomitant infection, this may support an initial diagnostic assessment followed by treatment of any underlying venous outflow or central venous stenoses that may have caused the aneurysm or pseudoaneurysm [123]. Endovascular occlusion of the hemodialysis access using vascular plugs has also been suggested as a potential treatment for patients with aneurysm or pseudoaneurysm formation who are at-risk for rupture and who are poor surgical candidates [128].

Variant 10: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Treatment and procedures.

B. Surgical Consultation

Surgical management may be helpful in the setting of abnormal skin changes associated with the hemodialysis access cannulation site. Significant risk of life-threatening infection, rupture, and bleeding exists when abnormal skin changes are seen, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial, or deep infection [129-132]. The presence of skin erosion or active hemorrhage from an AV access in the setting of a pseudoaneurysm is a surgical emergency that necessitates prompt recognition and definitive management. The treatment of an AVG pseudoaneurysm routinely involves placement of an interposition prosthetic graft which is tunneled in situ or extra-anatomically depending on the presence of a vascular access site infection [5].

Variant 10: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Treatment and procedures.

C. Placement of a New Tunneled Dialysis Catheter

In the setting of abnormal skin changes associated with the hemodialysis access cannulation site, the placement of a new tunneled dialysis catheter may be indicated as a bridging therapy, allowing for hemodialysis access while the patient undergoes surgical evaluation. If there is clinical concern for a systemic infection or bacteremia, treatment of the underlying infection should be initiated prior to the placement of a new tunneled dialysis catheter. A temporary nontunneled dialysis catheter can be placed for immediate hemodialysis access, while treatment of the infection is initiated. Given associated increased risks for catheter-associated infection, higher mortality, and lower patency when compared to AVF and AVG, tunneled dialysis catheters should be avoided if possible or considered a temporizing measure until other hemodialysis access is available [108].

Variant 10: Abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. Treatment and procedures.

D. Continued Hemodialysis Access Use with Surveillance

There is no evidence to support the continued hemodialysis access use with surveillance in the setting of abnormal skin changes associated with the hemodialysis access cannulation site. Surgical evaluation is prompted before continued use of the hemodialysis access, as significant risk of life-threatening infection, rupture, and bleeding exists [129,130].

Variant 11: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Initial imaging to guide interventional radiologic therapy options.

Steal syndrome refers to compromised perfusion and ischemia of tissue that results after the construction of an AV access. The presence of hand (or pedal) ischemia in a patient with an AV access is a critical complication in a patient receiving long-term hemodialysis. Many terms have been used to refer to this entity including "arterial steal syndrome", "ischemic steal syndrome" and dialysis associated-steal syndrome (DASS) [133,134]. Most AV accesses demonstrate characteristics of arterial steal, while a fraction of those patients manifest symptoms. As such, peripheral hypoperfusion and ischemia represents a more central role than the arterial steal itself, thus prompting some to use the term digital hypoperfusion ischemic syndrome (DHIS).

The prevalence of this entity ranges from 1% to 20% and it occurs secondary to the shunting of arterial blood flow through the AV access and away from the peripheral system [133]. This results in a constellation of signs and symptoms, ranging from mild digital (pedal or hand) numbness to severe motor impairment. It may progress to skin ulceration or gangrene necessitating a digit or limb amputation. The physiologic compensatory response to such a phenomenon is augmentation in cardiac output, arterial vasodilation, as well as formation of arterial collaterals. The presence of an arterial inflow stenosis (eg, subclavian artery stenosis) as well as an outflow stenosis (eg, forearm occlusive disease) will worsen these hemodynamics [135]. The syndrome presents more frequently in patients with proximal accesses supported by brachial artery inflow as opposed to distal accesses, such as those with radial artery inflow. It usually manifests as hand pain during as well as while off dialysis and less commonly as loss of function or tissue death.

Hemodialysis access dysfunction may provoke DHIS due to the occurrence of an atherosclerotic stenosis within the arterial inflow to the distal extremity. Such lesions may occur at any point along the course of the inflow artery of the upper extremity, including proximal arteries [133]. In such

cases, it may result in ischemia of the extremity harboring the access or heart failure. In such cases, a decision to treat is based on the degree of the patient's symptoms. Angioplasty or stenting of the culprit lesion may offer therapeutic benefit and thus relief of the patient's ischemic symptoms [133].

The central objective in treating a patient with hemodialysis presenting with hand ischemia is to preserve the digits and hand without sacrificing the vascular access. Given that distal hypoperfusion may develop in the absence or presence of arterial stenoses, diagnostic arteriography of the extremity and the entirety of its inflow is a foundational part of the diagnostic evaluation prior to determining management. The subsequent choice of management may only be made after considering this diagnostic study. For example, a concomitant arterial stenosis may have a deleterious effect on a surgical procedure performed to treat the distal ischemia. Failure to recognize such stenoses may prove detrimental postsurgery. For example, in the presence of a hemodynamically significant arterial stenosis that is proximal to the arterial anastomosis of the access, a banding procedure employed to reverse the arterial steal may result in a perilous decline in blood flow through the access, possibly resulting in access thrombosis [133].

Variant 11: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Initial imaging to guide interventional radiologic therapy options.

A. Fluoroscopy Fistulography Hemodialysis Access Area of Interest

Leon et al [133] describes optimized arteriography as the most critical tool needed to facilitate the diagnosis of DASS or DHIS and support an appropriate treatment strategy. DSA supports effective visualization from the aortic arch to the palmar arch, allowing for detection of lesions in the more proximal arteries. Since steal from the distal vessels may be expected, DSA is performed with and without occlusion of the AV access. While the femoral artery has been used to perform diagnostic fluoroscopic arteriography in this setting, this evaluation may be performed simply by retrograde cannulation of the access with diagnostic catheter advancement into the aortic arch [133].

Given that an arterial stenosis may be an important contributor to distal ischemia, diagnostic fistulography via a percutaneous access has gained popularity in supporting management of DHIS. Valji et al [136] used arteriography to assess patients presenting with clinical findings of hand ischemia. They were able to image the entire arterial tree (ie, aortic arch to the palmar arch). Of those presenting with hand pain, 7 out of 10 patients were found to accurately depict the presence of arterial stenoses. Imaging revealed 3 cases of excessive flow into the access via the arterial anastomosis.

To assess for the presence of arterial stenosis in patients with a hemodialysis access who have presented with clinical concern for peripheral ischemia, one study (n = 13) reports using complete arteriography to image from the aortic arch to the palmar arch [136]. They concluded that 62% of the 13 patients who underwent referrals for assessment for steal syndrome were found to have a hemodynamically significant (>50%) arterial stenosis. Another study (n = 5) reveals that a culprit stenosis in the inflow arterial circulation was imaged in 100% of the patients undergoing complete arteriography [137].

Lazarides et al [138] touts that arteriography is not a prerequisite for the diagnosis and management of DHIS. They consider the return of radial or ulnar pulses with associated manual compression of the graft as the sole requisite factor required to confirm the diagnosis. They

utilized an empiric threshold level of systolic pressure index <0.5 to denote abnormal nerve conduction studies, marked by a positive predictive value of 75%. In 94% of their studied patients, distal ischemia was detected by a systolic pressure index <0.8 to some degree. In patients with systolic pressure index <0.5, these were most likely to have impaired nerve conduction studies.

Variant 11: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Initial imaging to guide interventional radiologic therapy options.

B. US Duplex Doppler Hemodialysis Access Area of Interest

The changes noted on US examination are not diagnostic of a clinical steal syndrome. However, they can illustrate the presence of a steal phenomenon in settings where DASS or DHIS is clinically suspected. For example, there may be reversal of the blood flow distal to the arterial anastomosis (flow towards the fistula) or it may be bidirectional with or without evidence of DASS [139]. Of note, the demonstration of retrograde flow on CDUS evaluation of an AV access does not reliably predict or provide the presence of a clinical steal syndrome. While hemodynamic findings of arterial steal can be illustrated in most patients with forearm as well as proximal AV accesses, development of ischemic symptoms occurs in a small fraction of cases. An array of noninvasive investigations along with duplex US such as digital/brachial index measurements, transcutaneous oxygen saturation, and digital plethysmography may assist in helping to evaluate patients that demonstrate symptoms suggestive of arterial steal [133].

Variant 11: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Initial imaging to guide interventional radiologic therapy options.

C. CTA Extremity area of Interest With IV Contrast

While not associated with widespread use in the evaluation of DASS or DHIS, CTA represents a less invasive imaging option for the extremity arteries [133]. MDCT technology has allowed CTA to reliably assess the peripheral arteries in the upper and lower extremities [133]. MDCT is associated with the advantages of high spatial resolution, fast scan times, augmented anatomic coverage, and the capacity for generation of high-quality multiplanar reformats and 3-D renderings from raw data that can be expeditiously reprocessed.

Variant 11: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Initial imaging to guide interventional radiologic therapy options.

D. CTV Extremity Area of Interest With IV Contrast

There is no identifiable relevant literature to support the use of CTV extremity in evaluation of suspected vascular steal.

Variant 11: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Initial imaging to guide interventional radiologic therapy options.

E. MRA Extremity Area of Interest Without and With IV Contrast

Dujim et al [12] reported a study assessing the role of CE-MRA in the evaluation of inflow lesions, where 13 patients were evaluated, of which 2 were referred due to symptoms of steal. In this study, 7 of the 13 patients revealed arterial stenoses while 6 patients demonstrate additional stenoses regional to the shunt and/or outflow. Aside from standard DSA of the shunt and outflow, inflow DSA evaluation was accomplished by catheterization in every case where the CE-MRA exhibited a stenotic inflow lesion. Endovascular treatment of the culprit stenoses was accomplished after

obtaining a confirmatory DSA. In 1 of 2 patients with symptoms of steal, the reported symptoms resolved postangioplasty [12].

Variant 11: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Initial imaging to guide interventional radiologic therapy options.
F. MRA Extremity Area of Interest Without IV Contrast

There is no identifiable relevant literature to support the use of MRA extremity without IV contrast in evaluation of suspected vascular steal.

Variant 11: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Initial imaging to guide interventional radiologic therapy options.
G. MRV Extremity Area of Interest Without and With IV Contrast

There is no identifiable relevant literature to support the use of MRV extremity without and with IV contrast in evaluation of suspected vascular steal.

Variant 11: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Initial imaging to guide interventional radiologic therapy options.
H. MRV Extremity Area of Interest Without IV Contrast

There is no identifiable relevant literature to support the use of MRV extremity without IV contrast in evaluation of suspected vascular steal.

Variant 12: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Treatment and procedures.

Variant 12: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Treatment and procedures.
A. Fluoroscopy Fistulography Hemodialysis Access with Intervention

While surgical management for vascular steal syndrome is often considered, fluoroscopic fistulography of the hemodialysis access with endovascular intervention may have a limited role in treatment, including elimination of a culprit arterial stenosis by angioplasty or stenting. In cases of DASS with stenosis of the inflow artery supplying the hemodialysis access and the extremity, endovascular angioplasty with or without stent placement has been proposed as a potential treatment [140]. Endovascular occlusion of hemodialysis access using vascular plugs has also been suggested as a potential treatment for patients with DASS as an alternative to surgical ligation [128].

In cases where surgical ligation may be challenging due to ulcerations or marked edema or swelling of the extremity, surgery may be delayed due to challenging patient comorbidities [128]. In such cases, an endovascular approach may be necessary to manage the problem. Gumus et al [128] reported 21 patients who underwent endovascular occlusion of their native fistulas. Of the studied patients, 2 patients had hyperdynamic heart failure, 2 exhibited DASS and 5 patients had findings of critical hand ischemia with a nonhealing ulcer or necrosis. Successful embolization of all fistulas using AMPLATZER vascular plugs were performed with no immediate or delayed complications with a mean follow-up of 13.5 months.

In forearm and wrist fistulae, cases of DASS occur at a rate of 1%, and is referred to as palmar arch

steal syndrome. While digital revascularization with interval ligation (DRIL) is the most accepted technique with the highest success of correcting signs of steal phenomenon while preserving access patency, it is technically difficult and has a small chance of success when employed in wrist fistulae. This is due to the notably reduced diameter of the associated arteries that may also contain calcific disease in at-risk persons [134]. As such, in forearm AVF, surgical ligation or endovascular embolization of the radial artery distal to the anastomosis are helpful treatment options. Miller et al reported endovascular coil embolization in 10 patients while surgical ligation was conducted in 5 patients. Improvement in symptoms was noted in each of the patients in the endovascular group versus 3 patients in the group which underwent ligation [141].

Advantages of endovascular management include its minimally invasive nature, its ability to be performed concomitantly with diagnostic angiography, and the capacity for performing occlusion of both the distal radial artery as well as any other culprit branches. The ability to perform angioplasty on additional stenoses augments blood flow to the fistula and hand. Endovascular dilation is achievable in the palmar arch arteries and distal forearm where surgical revascularization is routinely not possible.

Distal radial artery embolization combined with recanalization and angioplasty of any present ulnar artery stenoses and occlusions may provide equivalent results with the DRIL operation, which is regarded as the most efficient and effective treatment option for correcting the hemodynamics in DASS. While coil occlusion of the distal radial artery preempts the steal phenomenon in a manner comparable to that of interval ligation, the presence of a normal or effectively angioplastied ulnar artery will offer distal blood flow with superior flows [134].

Variant 12: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Treatment and procedures.
B. Surgical Consultation

Surgical management in the setting of DASS or ischemic steal syndrome is a useful treatment option [142-146]. Surgical management of moderate-to-severe ischemic steal syndrome may be divided into 3 general categories which includes ligation (banding and plication), rerouting of arterial inflow, and restriction of flow. Surgical techniques for the treatment of DASS include DRIL, which involves ligation of the brachial artery and placement of a vein bypass to the distal brachial artery, revision using distal inflow, distal radial artery ligation, proximalization of arterial inflow, and banding [144,145].

Leake et al [145] evaluation of surgical management of DASS in 175 AV fistulas (80%), 41 upper extremity prosthetic grafts (19%), and 2 thigh grafts (1%) demonstrated that DRIL and ligation were offered to patients with the highest severity of symptoms. When compared to ligation, DRIL is equivalent in symptom resolution, with no associated increase in complications, and offers fistula preservation. When compared to banding, DRIL achieved a higher degree of fistula preservation and with a lower incidence of complications. They concluded that DRIL ought to be the preferred surgical management of DASS in patients with a functioning autologous fistula who are surgical candidates. Gupta et al [147] similarly reported their analysis of the outcomes of management of patients with ischemic steal syndrome. They reported that DRIL was the most frequently selected option for late interventions (41%). Banding was reported to have a high failure rate (62%) and was associated with the most common cause for reintervention (8 of 11, 73%), DRIL boasted superior success rates to banding ($P < .05$).

While surgical treatment options are preferred in upper arm fistulae, endovascular treatment options may be more suited for revascularization of fistulae in the forearm secondary to the diminutive caliber of target vessels, the often-severe calcifications in at-risk persons, and thus the low chance of success [134]. However, surgery consultation is still recommended when vascular steal syndrome is suspected.

Variant 12: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Treatment and procedures.
C. Placement of a New Tunneled Dialysis Catheter

The placement of a new tunneled dialysis catheter may be a bridging therapy, allowing for hemodialysis access while a patient undergoes surgical or radiologic evaluation, in the setting of suspected vascular steal syndrome, suggested by cardiac failure or ischemic symptoms. Given associated increased risks of infection, higher mortality, and lower patency when compared to AVF and AVG, tunneled dialysis catheters should be avoided if possible or considered a temporizing measure until other hemodialysis access is available [108].

Variant 12: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Treatment and procedures.
D. Continued Hemodialysis Access Use with Surveillance

In settings of mild ischemic symptoms such as paresthesia's, it is deemed acceptable to continue interval hemodialysis while awaiting surgical consultation and evaluation. Otherwise, there is no identifiable evidence to support continued hemodialysis access use with long term surveillance in the setting of suspected vascular steal syndrome, suggested by cardiac failure or lifestyle-limiting ischemic symptoms.

Variant 12: Suspected vascular steal syndrome (upper or lower extremity), suggested by cardiac failure or ischemic symptoms. Treatment and procedures.
E. US Duplex Doppler Hemodialysis Access Area of Interest

There is no identifiable evidence to support the use of US duplex Doppler with interventions in the setting of suspected vascular steal syndrome, suggested by cardiac failure or ischemic symptoms.

Summary of Recommendations

- **Variant 1**: Fluoroscopy fistulography of the hemodialysis access or US duplex Doppler of the hemodialysis access is usually appropriate for a patient with suspected dysfunction of the upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). This initial imaging will guide interventional radiologic therapy options. These imaging procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).
- **Variant 2**: Fluoroscopy fistulography of the hemodialysis access with intervention or US duplex Doppler of the hemodialysis access is usually appropriate to treat a patient with suspected dysfunction of the upper or lower extremity hemodialysis access (ie, arteriovenous fistula or graft) suggested by an abnormal clinical indicator or hemodynamic indicator (ie, reduction in dialysis vascular access blood flow rate or kinetics). These therapeutic procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the

clinical information to effectively manage the patient's care).

- **Variant 3**: Fluoroscopy fistulography of the hemodialysis access is usually appropriate for a patient with suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. This initial imaging will guide interventional radiologic therapy options.
- **Variant 4**: Fluoroscopy fistulography of the hemodialysis access with intervention or surgical consultation is usually appropriate to treat a patient with suspected thrombosis of the upper or lower extremity hemodialysis access, marked by absent pulse and thrill on physical examination. These therapeutic procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).
- **Variant 5**: Fluoroscopy fistulography of the hemodialysis access or US duplex Doppler of the hemodialysis access is usually appropriate for a patient with failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. This initial imaging will guide interventional radiologic therapy options. These imaging procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).
- **Variant 6**: Fluoroscopy fistulography of the hemodialysis access, and US duplex Doppler of the hemodialysis access, and surgical consultation are usually appropriate to treat a patient with failure of an upper or lower extremity arteriovenous fistula to mature within 2 months after creation. These therapeutic procedures are complementary alternatives (ie more than one procedure will be ordered to provide the clinical information to effectively manage the patient's care).
- **Variant 7**: Fluoroscopy fistulography of the hemodialysis access is usually appropriate for a patient with a clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals. This initial imaging will guide interventional radiologic therapy options.
- **Variant 8**: Fluoroscopy fistulography of the hemodialysis access with intervention is usually appropriate to treat a patient with a clinical suspicion of central venous stenosis or occlusion suggested by swelling (ie, soft tissue edema) of the extremity ipsilateral to the upper or lower extremity hemodialysis access, with or without the development of venous collaterals.
- **Variant 9**: US duplex Doppler of the hemodialysis access is usually appropriate for a patient with abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. This initial imaging will guide interventional radiologic therapy options.
- **Variant 10**: Placement of a new tunneled dialysis catheter and surgical consultation are usually appropriate to treat a patient with abnormal skin changes associated with the upper or lower extremity hemodialysis access cannulation site, including marked thinning, ulceration, eschar formation, spontaneous bleeding, pseudoaneurysm formation, superficial or deep infection. These therapeutic procedures are complementary alternatives (ie more than one procedure will be ordered to provide the clinical information to effectively manage the patient's care).
- **Variant 11**: Fluoroscopy fistulography of the hemodialysis access and US duplex Doppler of the hemodialysis access are usually appropriate for a patient with suspected vascular steal

syndrome in the upper or lower extremity, suggested by cardiac failure or ischemic symptoms. This initial imaging will guide interventional radiologic therapy options. These therapeutic procedures are complementary alternatives (ie more than one procedure will be ordered to provide the clinical information to effectively manage the patient's care).

- **Variant 12**: Surgical consultation is usually appropriate to treat a patient with suspected vascular steal syndrome in the upper or lower extremity, suggested by cardiac failure or ischemic symptoms.

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at https://acsearch.acr.org/list. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents, please go to the ACR website at https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria.

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ

sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® Radiation Dose Assessment Introduction document.

Relative Radiation Level Designations

Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
O	0 mSv	0 mSv
☢	<0.1 mSv	<0.03 mSv
☢☢	0.1-1 mSv	0.03-0.3 mSv
☢☢☢	1-10 mSv	0.3-3 mSv
☢☢☢☢	10-30 mSv	3-10 mSv
☢☢☢☢☢	30-100 mSv	10-30 mSv

*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (e.g., region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."

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The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical

condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.

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