JAMA | Review

Arteriovenous Access for Hemodialysis
A Review

Charmaine E. Lok, MD, MSc; Thomas S. Huber, MD, PhD; Ani Orchanian-Cheff, BA, MISt; Dheeraj K. Rajan, MD

IMPORTANCE Hemodialysis requires reliable vascular access to the patient's blood circulation, such as an arteriovenous access in the form of an autogenous arteriovenous fistula or nonautogenous arteriovenous graft. This Review addresses key issues associated with the construction and maintenance of hemodialysis arteriovenous access.

OBSERVATIONS All patients with kidney failure should have an individualized strategy (known as Patient Life-Plan, Access Needs, or PLAN) for kidney replacement therapy and dialysis access, including contingency plans for access failure. Patients should be referred for hemodialysis access when their estimated glomerular filtration rate progressively decreases to 15 to 20 mL/min, or when their peritoneal dialysis, kidney transplant, or current vascular access is failing. Patients with chronic kidney disease should limit or avoid vascular procedures that may complicate future arteriovenous access, such as antecubital venipuncture or peripheral insertion of central catheters. Autogenous arteriovenous fistulas require 3 to 6 months to mature, whereas standard arteriovenous grafts can be used 2 to 4 weeks after being established, and "early-cannulation" grafts can be used within 24 to 72 hours of creation. The prime pathologic lesion of flow-related complications of arteriovenous access is intimal hyperplasia within the arteriovenous access that can lead to stenosis, maturation failure (33%-62% at 6 months), or poor patency (60%-63% at 2 years) and suboptimal dialysis. Nonflow complications such as access-related hand ischemia ("steal syndrome"; 1%-8% of patients) and arteriovenous access infection require timely identification and treatment. An arteriovenous access at high risk of hemorrhaging is a surgical emergency.

CONCLUSIONS AND RELEVANCE The selection, creation, and maintenance of arteriovenous access for hemodialysis vascular access is critical for patients with kidney failure. Generalist clinicians play an important role in protecting current and future arteriovenous access; identifying arteriovenous access complications such as infection, steal syndrome, and high-output cardiac failure; and making timely referrals to facilitate arteriovenous access creation and treatment of arteriovenous access complications.

JAMA. 2024;331(15):1307-1317. doi:10.1001/jama.2024.0535
Published online March 18, 2024.

Multimedia

Supplemental content

CME at jamacmelookup.com

Author Affiliations: Department of Medicine, Division of Nephrology, University Health Network, Toronto, Ontario, Canada (Lok); Faculty of Medicine, University of Toronto, Toronto, Ontario, Canada (Lok, Rajan); Department of Surgery, University of Florida College of Medicine, Gainesville, Florida (Huber); Library and Information Services, University Health Network, Toronto, Ontario, Canada (Orchanian-Cheff); University Medical Imaging Toronto, University Health Network, Toronto, Ontario, Canada (Rajan).

Corresponding Author: Charmaine E. Lok, MD, MSc, University Health Network, 200 Elizabeth St, 8N-844, Toronto, ON M5G 2C4, Canada (charmaine.lok@uhn.ca).

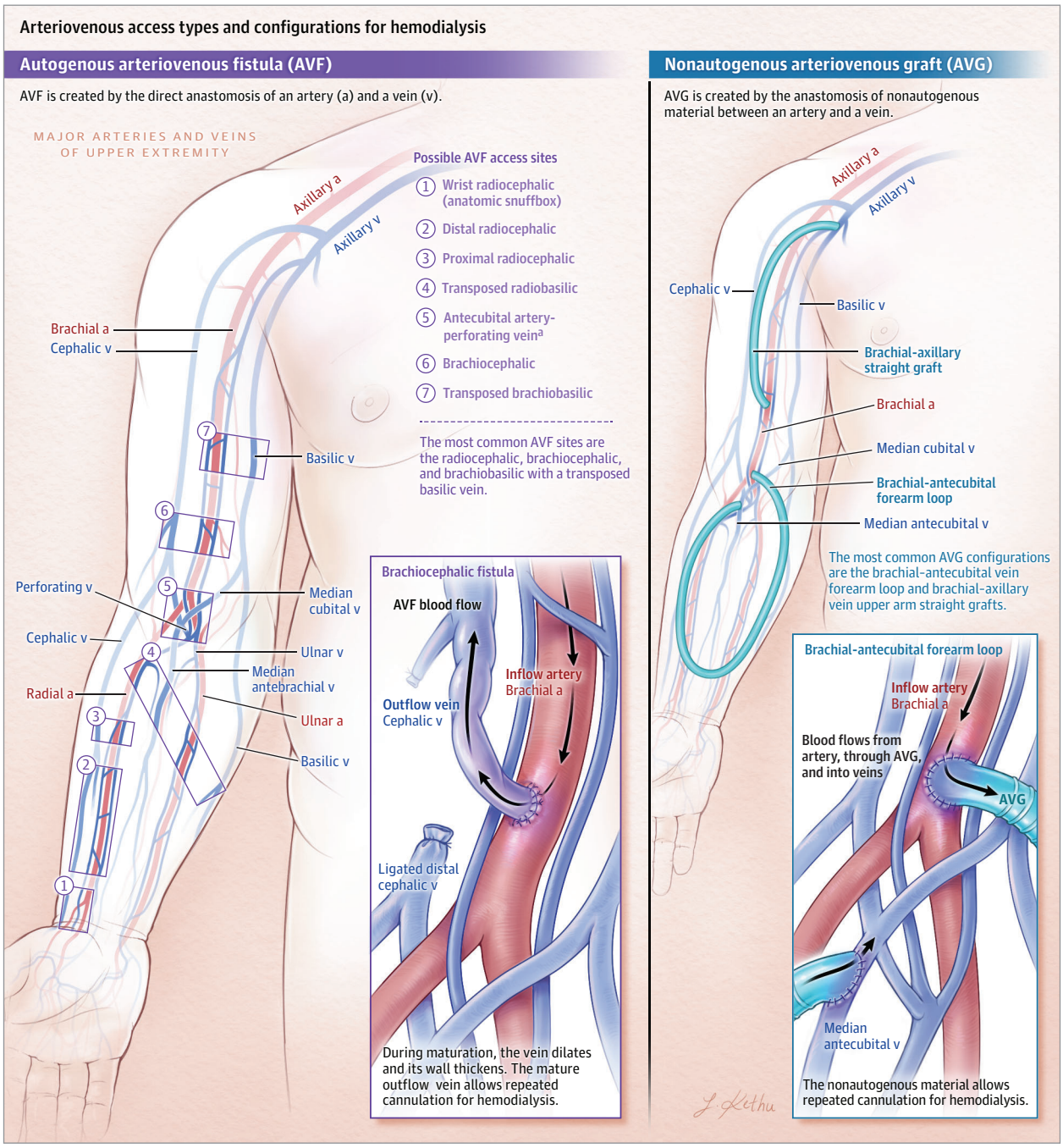
Section Editor: Kristin Walter, MD, Deputy Editor.

In 2021 in the United States,[1] there were 135 972 individuals with incident kidney failure requiring kidney replacement therapy (previously known as end-stage kidney disease) and 808 536 individuals with prevalent kidney failure requiring kidney replacement therapy.[2] Globally, the most common form of kidney replacement therapy is dialysis (78%), with the remaining 22% of patients living with a kidney transplant.[3] Approximately 90% of patients who undergo dialysis are treated with hemodialysis,[3] and they require vascular access to establish a connection between their circulation and the hemodialysis machine. The 2 main categories of vascular access are arteriovenous access and the central venous catheter (CVC). This Review will focus on arteriovenous access, which includes any conduit created involving a direct or indirect anastomosis between an artery and a vein for providing hemodialysis. Specifically, arteriovenous access will refer to an autogenous arteriovenous fistula (AVF) that is created by direct connection between an artery and a vein and in which the developed outflow vein is accessed for hemodialysis with needles; or arteriovenous graft (AVG), in which nonautologous material is placed between the artery and the vein, which is accessed for hemodialysis (**Figure 1**). We highlight information that is most important for generalist clinicians who, in cooperation with nephrologists and interventionalists, treat patients with chronic kidney disease (**Box**).

Methods

The comprehensive search from the National Kidney Foundation's Kidney Disease Outcomes Quality Initiative clinical practice guideline for vascular access 2019 (KDOQI guidelines) was updated from 2015 to 2023 and modified by removing CVCs in accordance with

Figure 1. Arteriovenous Access Types and Configurations



An acceptable cannulation zone should be straight, at least 8 to 10 cm long, close to the skin surface, and located on the extremity such that the extremity can be comfortably positioned during dialysis (ie, 3-6 hours per session). Upper extremity artery-vein conduit combinations include the radial, ulnar, brachial, and axillary arteries, and the cephalic, basilic, ulnar, and perforating veins.

[a] Perforating vein and antecubital artery (proximal radial, proximal ulnar, or antecubital brachial artery) combinations. These types of fistulas can be created by endovascular techniques.

the scope of this narrative Review to identify important studies on arteriovenous access with information that would be useful for generalist physicians. Searches were executed on March 1, 2023, in the following databases: Ovid MEDLINE, Ovid Embase, and Cochrane Central Register of Controlled Trials (Ovid). See the eAppendix in the Supplement for search strategies. We retrieved 4823 articles and retained 30 meta-analyses, 7 systematic reviews, 18 randomized clinical trials (RCTs), 14 observational cohort studies, and 17 retrospective studies. The most recent KDOQI vascular access guidelines are referenced in this narrative Review.[4]

End-Stage Kidney Disease Life Plan and Dialysis Access

Establishing an individualized plan (known as Patient Life-Plan, Access Needs [PLAN]) is a prerequisite to decision-making, planning, and management of hemodialysis vascular access.[4] The PLAN is composed of (1) the Patient end-stage kidney disease Life-Plan for kidney replacement modality choices (including conservative care); and (2) the Access Needs for the creation and management of respective dialysis access. Generalist clinicians are important partners who should be aware of, participate in, and support patients and specialists in implementing the PLAN as follows.

Planning and Preparation for Vascular Access

Planning and preparation for vascular access is required for patients with chronic kidney disease who are anticipated to need hemodialysis and those with kidney replacement therapy who are failing peritoneal dialysis or who have a failing transplant or arteriovenous access. Patients with chronic kidney disease should be referred to nephrologists to begin discussions about living with and treatments for chronic kidney disease, potential progression to kidney replacement therapy, and modality choices when the estimated glomerular filtration rate is less than or equal to 30 mL/min; nephrologists should refer patients to a surgeon or vascular interventionalist for vascular access assessment and creation when their estimated glomerular filtration rate is 15 to 20 mL/min with concurrent progressive decline in kidney function or earlier if they have a rapid decline in estimated glomerular filtration rate (>10 mL/min/y).[4]

Clinicians should be aware that vascular procedures (eg, peripheral insertion of a central catheterization line, cardiac catheterization performed via the radial artery), CVC placement or central venous instrumentation (eg, cardiac pacers, defibrillators), or even venipuncture in the antecubital fossa may impede the patient's future hemodialysis access options and procedures.[5-7] For example, peripherally inserted central catheters can damage the vein or cause stenosis or thrombosis of the median cubital, cephalic, axillary, brachiocephalic, and subclavian veins so that these vessels are not usable for arteriovenous access creation. Patients with chronic kidney disease who may need dialysis should be instructed to have venipuncture only on the back of their hands, if possible, rather than in the antecubital fossa to limit vessel damage and thus preserve veins for arteriovenous access creation. To avoid peripherally inserted central catheter placement, patients who are currently treated with hemodialysis and who need antibiotics may be provided these medications during hemodialysis in coordination with the dialysis team. The patient's primary care clinician and nephrologist should work together to individualize and optimize underlying medical conditions such as cardiovascular disease, glycemic control, and pulmonary comorbidities. Cardiovascular comorbidities are associated with greater mortality in dialysis patients,[8] and reduced left ventricular ejection fraction compared with a normal ejection fraction is also associated with AVF failures.[9] The KDOQI guidelines also support a team approach to identifying infection risks (eg, dental abscesses, osteomyelitis) that should be managed before proceeding with arteriovenous access creation.[4]

Box. Common Questions About Arteriovenous Access for Hemodialysis

When should a patient be referred for vascular access?
Patients should be referred for assessment for vascular access when their estimated glomerular filtration rate (eGFR) is 15-20 mL/min, including patients with a prior kidney transplant. However, patients with low-level kidney function that is stable during many years should be monitored but may not need vascular access creation. Patients undergoing peritoneal dialysis who are failing peritoneal dialysis modality, as well as patients undergoing hemodialysis who have nonfunctional or poorly functioning arteriovenous (AV) access (eg, needing ≥4 corrective interventions or surgeries in a year) or have a central venous catheter but are eligible for AV fistula (AVF) or AV graft (AVG), should also be referred for AV access creation.

How can a generalist physician participate in the patient's plan?
Generalist physicians should actively participate in the individualized strategy (known as Patient Life-Plan, Access Needs [PLAN]) in 2 key ways: (1) the patient's life plan, including appropriate referral to a nephrologist in a timely manner for clinical and urinary indications (acute kidney injury or abrupt sustained decline in GFR, chronic kidney disease [CKD] and hypertension refractory to treatment with 4 or more antihypertensive medications, progression of CKD, recurrent or extensive nephrolithiasis, hereditary kidney disease, persistent abnormalities of serum potassium level, eGFR less than 30 mL/min/1.73 m^2, consistent significant albuminuria [urinary albumin to creatinine ratio >300 mg/g or 30 mg/mmol], and urinary red blood cell [RBC] casts or RBC count greater than 20 per high-power field that is sustained or not easily explained); and (2) access needs: advocating and educating the patient and colleagues on protecting vessels if the patient has CKD or kidney failure, such as using the back of the hand for venipuncture and avoiding antecubital puncture, peripherally inserted central catheters, central venous catheters, and radial artery puncture for cardiac catheterizations, if possible.

What are the benefits of AVF?
An AVF that functionally matures and can be consistently cannulated with 2 needles to provide prescribed hemodialysis has superior longevity and reduced risk of infection compared with AVGs and central venous catheters.

Arteriovenous Access in Clinical Practice

The ideal arteriovenous access is easy to cannulate, provides adequate flow rate to sustain dialysis, has excellent long-term patency with minimal complications, is cost-effective compared with alternatives, and is acceptable to the patient. The risks of arteriovenous access surgery are comparable to those of any major surgical procedure, with the inherent risk owing to the patient's underlying comorbidities rather than the magnitude of the operation. Arteriovenous access creation, which is typically performed under local or regional anesthesia with use of conscious sedation, is usually an outpatient procedure. However, patients who need more complex proximal upper extremity procedures to establish arteriovenous access may require general anesthesia and an overnight hospitalization. Arteriovenous access can also be established with percutaneous endovascular techniques that do not require open surgery, incisions, or suture material (Figure 1).

The decision to place an AVF or AVG is made after consideration of the patency and complication rates of these arteriovenous access methods, a patient's comorbidities, personal preferences, and life expectancy. Both AVG and AVF work for only a finite period; the 2-year cumulative patency for AVF is 63% (95% CI, 59%-67%) and for AVG is 60% (95% CI, 55%-65%).[10] After creation, 20% to 60% of AVF may not be usable for dialysis and a CVC may be necessary. Arteriovenous grafts have low rates of primary failure, sparing the need for CVCs; however, if an AVF is usable (particularly if no intervention is required to facilitate use), AVFs typically have better long-term patency (>2 years) compared with AVG. A selective approach to AVF creation reduces arteriovenous access procedures and cost of arteriovenous access management.[11] Central venous catheters for hemodialysis should generally be used as short-term, temporary vascular access, including when an arteriovenous access is not usable or ready for dialysis; however, long-term CVCs may be used for patients undergoing hemodialysis who have valid reasons for their use, such as no other arteriovenous access options.[4]

Arteriovenous grafts can be constructed from a variety of nonautogenous materials (ie, synthetic, biological) and configurations (eg, typically loop and straight placements; tapered, swirl, and standard construction; bonded with heparin, other drug, or none), but none appear to be superior to another in terms of patency or complications.[12-15] Standard AVG cannot be used until after 2 to 4 weeks from creation to allow for proper incorporation of graft material into surrounding tissue and reduce the likelihood of hematoma formation with cannulation. A variety of commercially available "early-cannulation grafts" (eAVGs) that use different layering materials beyond the standard polytetrafluoroethylene are now available that can be used within 24 to 72 hours after implantation and are particularly useful for patients who urgently need to start dialysis, enabling CVC avoidance.[16,17] A study that randomized 236 patients to standard AVG and 241 to eAVG reported the median time to cannulation was 19.0 days (range, 15.0-22.0 days) for standard AVG vs 3.0 days (range, 1.0-9.0 days) for eAVG ($P < .001$).[17] Patency rates at 12 months were similar (67.8% in standard AVG and 69.7% in eAVGs; $P = .65$). Early-cannulation graft use has also been reported to result in lower CVC use. A study that randomized 60 patients to eAVG and 61 patients to CVC (all patients also had AVF creation) found that 18.3% of patients assigned to eAVG were undergoing dialysis via CVC at 12-month follow-up vs 41.0% of those assigned to CVC. In this study, culture-proven bacteremia developed in 10% of patients with eAVG vs 19% with CVC within 12 months (risk ratio, 0.55; 95% CI, 0.24-0.77; $P < .001$).[18] Two RCTs[17,18] and 2 systematic reviews[19,20] demonstrated that early-cannulation AVGs (available for use at <3 days after placement) were safe and had comparable longer-term patency rates compared with standard AVGs.[21]

An AVF requires maturation for approximately 4 months after creation before it can be used.[22] During this time, the cardiac output and arterial wall diameter increase, and the outflow vein wall dilates and thickens, which allows it to sustain the repeated trauma of needle cannulation. A systematic review of 62 unique cohorts (12 383 AVFs) found a primary failure rate of 23%.[23] A subsequent prospective multicenter study of 602 AVFs reported that by 6 months, 67% of AVFs created in patients with kidney failure who were already undergoing hemodialysis matured, whereas 38% of AVFs created in patients with chronic kidney disease before hemodialysis initiation matured.[24] Of AVFs that matured, 47.5% had further intervention to maintain patency or treat complications. The consequence of a nonmature or nonusable AVF is that it requires use of CVC, with its potential complications, and often the patient needs to undergo multiple facilitative procedures such as angioplasty or ligation or embolization of side branches before the AVF can be used. Duplex ultrasonography can help identify potential underlying causes of nonmaturing AVFs[25,26] such as stenosis or collateral or accessory vessels. A variety of techniques have been proposed to facilitate AVF maturation; however, only whole upper extremity and hand exercise[27] had sufficient evidence to be supported by the KDOQI guidelines.[4]

The KDOQI guidelines emphasize that AVFs and AVGs are preferred over CVCs, but the choice of an AVF or AVG requires the clinical judgment of the nephrologist and vascular access team. The choice of arteriovenous access is often a trade-off between short-term advantages that favor AVGs and longer-term advantages that favor AVFs[28] (**Figure 2**). Overall, the KDOQI guidelines consensus was that when compared with AVG, an AVF is preferable when feasible and appropriate[4] because if it matures successfully to provide prescribed dialysis, it is associated with fewer long-term vascular events such as thrombosis and fewer interventions to maintain functional patency.

Postoperative Symptoms

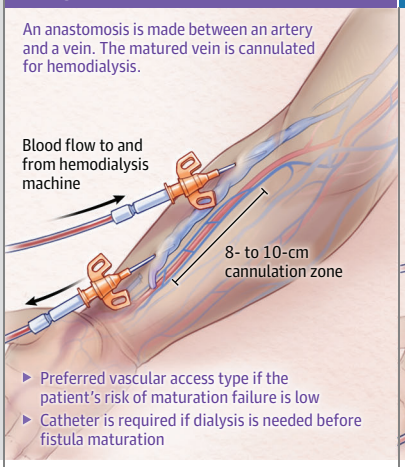
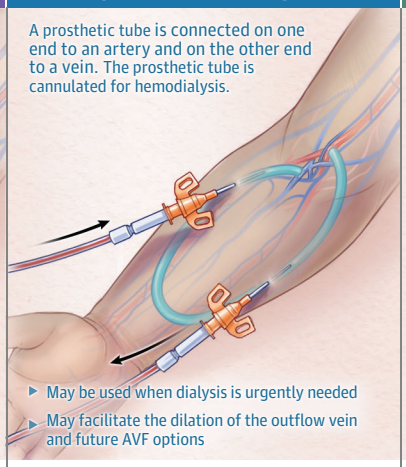
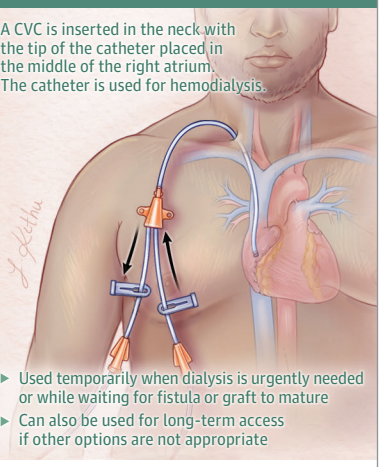
After creation of arteriovenous access, the patient's access extremity may be painful and swollen, which can be partially relieved with arm elevation. If the patient has residual kidney function, nonsteroidal anti-inflammatory drugs should be avoided for pain control to limit further decline in kidney function. Pain, erythema, and swelling may persist up to 2 to 3 weeks after AVG creation. The swelling with eAVGs may be reduced with early use (eg, within 24-72 hours). Any fever or persistently elevated white blood cell count 2 weeks after creation of arteriovenous access should prompt referral to the interventionalist who created the arteriovenous access for further evaluation. Both AVF and AVG may be associated with hand and finger tingling that may persist up to 4 to 6 weeks; beyond this, "steal syndrome" (discussed below) should be considered.

Monitoring and Surveillance

Generalist physicians and patients should be aware of the clinical findings determined by "look, listen, feel"[29,30] that suggest an arteriovenous access problem (**Figure 3**). Patients with an arteriovenous access that does not have a palpable pulse or thrill, or auscultated bruits, should have an urgent confirmatory evaluation by the nephrologist and undergo intervention immediately if there is any chance for arteriovenous access salvage. Salvage may not be possible after cessation of flow in an AVF after 72 hours and in an AVG after 5 days. The physical examination has 82% to 100% sensitivity and 67% to 88% specificity to detect inflow stenosis and 70% to 97% sensitivity and 67% to 93% specificity to detect outflow stenosis.[29] The physical examination can be supplemented by using surveillance technologies, such as ultrasound dilution or other dilution techniques or duplex ultrasonography.

Figure 2. Comparison of Pros and Cons of Vascular Access Types

A Comparison of arteriovenous access types

	Autogenous arteriovenous fistula (AVF)	Nonautogenous arteriovenous graft (AVG)	Central venous catheter (CVC)
Procedure and indications	An anastomosis is made between an artery and a vein. The matured vein is cannulated for hemodialysis.  ▸ Preferred vascular access type if the patient's risk of maturation failure is low ▸ Catheter is required if dialysis is needed before fistula maturation	A prosthetic tube is connected on one end to an artery and on the other end to a vein. The prosthetic tube is cannulated for hemodialysis.  ▸ May be used when dialysis is urgently needed ▸ May facilitate the dilation of the outflow vein and future AVF options	A CVC is inserted in the neck with the tip of the catheter placed in the middle of the right atrium. The catheter is used for hemodialysis.  ▸ Used temporarily when dialysis is urgently needed or while waiting for fistula or graft to mature ▸ Can also be used for long-term access if other options are not appropriate
Time to usage and duration	• 2- to 6-mo maturation time • 20%-60% Risk of maturation failure • Long term *May need multiple interventions to facilitate maturation*	• 2 to 4 wk to cannulation (if standard graft) • Can use within 72 h if using early-cannulation graft • Long term *May need multiple interventions to maintain patency*	• Immediately usable • Short or long term *May require multiple catheter changes*
Risks of possible complications	• **Stenosis** (11%-16% risk) and **thrombosis** • **Aneurysm** (risk worsened by poor cannulation, high flows, and stenosis) • **Steal syndrome** (greater in arm vs forearm) • **High-output heart failure** • **Infection** risk dependent on cannulation technique (lowest risk with rope ladder cannulation) *Fistulas that achieve unassisted maturation have fewest complications*	• **Stenosis** (35% risk) and **thrombosis** (3x greater risk than fistulas after first year) • **Pseudoaneurysm** (worsened by poor cannulation, high flows, and stenosis) • **Steal syndrome** (greater in arm vs forearm) • **High-output heart failure** risk typically less than with fistulas • **Infection** risk slightly greater than or similar to that with fistulas but less than that with catheters	• **Central venous stenosis** or **occlusion** (may prevent future fistula or graft creation) • **Greatest risk of infection** across all vascular access types • **Catheter displacement risk** (may fall out or become embedded in heart or blood vessels)
Patient satisfaction	• Can bathe, shower, and swim • High patient satisfaction	• Can bathe, shower, and swim • Moderate patient satisfaction	• Cannot shower without proper protection and cannot swim • Variable patient satisfaction • No cannulation pain

B Comparison of arteriovenous access characteristics

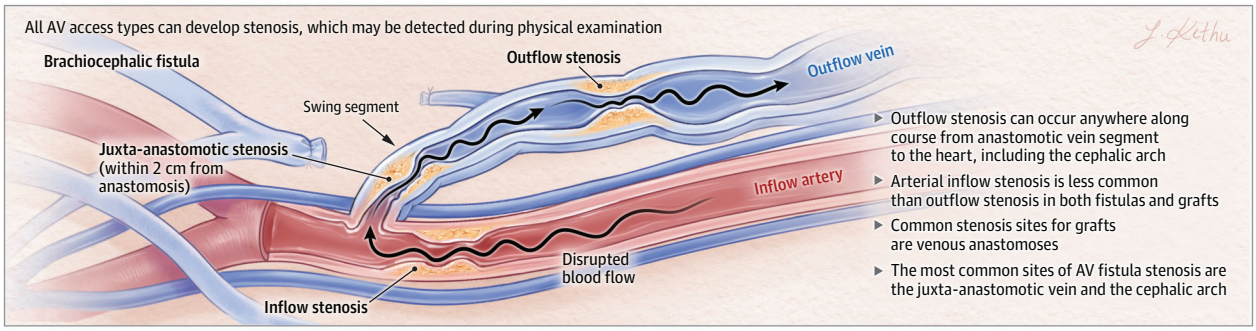
	Time to usage and durability			Risk of complications				Health care needs	
	Immediate use	Adequate blood flow for dialysis	Long lasting (>2 y)	Infection	Stenosis and thrombosis	Cardiac complications	Steal syndrome	Additional hospital visits	Additional remedial procedures
AVF	No	Yes	Yes	Low[a]-medium	Low-medium[b]	High	High	Reduced[c]	Reduced[d]
AVG	Yes[e]	Yes	Yes[f]	Low-medium	Low-medium[g]	Medium	Medium	Reduced	Reduced[f,h]
CVC	Yes	Yes[i]	Sometimes	High	High[j]	Low	Low	Increased	Increased

[a] With rope ladder cannulation.
[b] After successful maturation and use.
[c] Reduced complications requiring hospital admission.
[d] Needs procedure to start using AVF.
[e] With use of early-cannulation graft.
[f] Short-term patency improvement with acetylsalicylic acid/dipyridamole or fish oil.
[g] Low thrombosis risk short term, but higher risk long term.
[h] Autogenous arteriovenous graft needs procedures to maintain patency.
[i] Depends on prescription, including dialysis duration and blood pump speed of dialysis machine.
[j] Central vein stenosis and CVC lumen thrombosis.

Dialysis nurses and technicians, as well as patients, should monitor the arteriovenous access and various dialysis parameters to detect abnormalities before, during, and after dialysis that may indicate problems with the arteriovenous access and should involve the nephrologist and vascular access team for further investigation and management.

Figure 3. Common Clinical Indicators for Arteriovenous Access Problems Detectable on Clinical Monitoring

A Common sites of arteriovenous (AV) access stenosis



B Common signs and symptoms of AV access complications during procedures

SIGNS OF COMPLICATIONS	During physical examination or check	During dialysis
Outflow stenosis	• Hyperpulsatility at anastomosis • Failure of the fistula to collapse when the arm is elevated	• Elevated venous pressure during dialysis with no change in blood pump speeds
Inflow stenosis	• Lack of or decreased pulse augmentation • Excessive collapse of the venous segment on arm elevation	• Pressure monitor indicates elevated negative arterial pressure
General sign of stenosis	• Ipsilateral extremity edema • Pulse that is weak or difficult to compress in area of stenosis • Abnormal thrill (weak and/or discontinuous) with only a systolic component in area of stenosis • Abnormal bruit (high pitched with a systolic component in area of stenosis)	• New difficulty with cannulation • Aspiration of clots from the access • Inability to achieve the target dialysis blood flow • Prolonged bleeding beyond usual for that patient • Unexplained >0.2-unit decrease in the delivered dialysis dose (*Kt/V*) on a constant dialysis prescription without prolongation of dialysis duration

Kt/V indicates dialyzer clearance of urea in L/min (*K*), duration of treatment in minutes (*t*), and volume of urea distribution (*V*).

Arteriovenous Access Complications

Arteriovenous access complications can be broadly defined as flow-related dysfunction (eg, stenosis related, thrombotic related) or nonflow-related dysfunction (eg, infection, aneurysm, high-output cardiac failure).

Flow-Related Arteriovenous Access Dysfunction

Failing Arteriovenous Access

Stenosis is the most common cause (up to 90%) that limits flow within the arteriovenous access circuit and potentially leads to thrombosis and loss of the arteriovenous access.[31] The pathologic lesion is progressive neointimal hyperplasia, caused by intimal damage from arteriovenous access flow-related wall shear stress, surgical trauma, or both at arteriovenous access creation.[32]

The role of medications started perioperatively to prevent or improve flow-related arteriovenous access dysfunction remains unresolved despite a meta-analysis of 13 RCTs (1985 patients).[33] Older data of small short-term (<1 month) studies suggested ticlopidine may provide limited (<1 month) patency benefit for AVFs (10.5%-25.0% thrombosis in ticlopidine vs 47.1%-50.0% placebo)[33]; however, subsequent larger long-term RCTs have not been conducted to support this supposed advantage. For AVGs, aspirin-dipyridamole or fish oil may provide primary patency benefit[34,35] and reduce the need for interventions to maintain patency for AVGs.[34] The 1-year primary unassisted patency (ie, not needing intervention or salvage) in AVG with aspirin-dipyridamole was 28% vs 23% in placebo ($P = .03$)[36] and 48% with fish oil vs 32% in placebo ($P = .045$).[34] In the fish oil group, there were half as many thromboses (1.71 vs 3.41 per 1000 access-days; $P < .001$) and fewer corrective interventions (2.89 vs 4.92 per 1000 access-days; $P < .001$).[34]

Percutaneous balloon angioplasty (PTA) is recommended for flow-related arteriovenous access dysfunction and has a primary postintervention patency of 23% to 63% at 6 months, depending on the type of arteriovenous access. Preemptive (before thrombosis occurs) PTA of newly identified stenosis or known stenosis in a functional arteriovenous access does not increase arteriovenous access longevity.[37] Percutaneous balloon angioplasty can be performed with specialized balloons and supplemented with stents (ie, bare metal or preferably coated stents, also known as stent grafts).

Drug-eluting balloons are those used in PTA that act as a drug delivery platform (commonly paclitaxel or sirolimus) after standard PTA. The 2 largest RCTs that compared drug-eluting balloons with PTA outcomes, one including 285 patients and the other including 330 patients, demonstrated 6-month primary patency of 71% to 82% vs 63% to 60%, respectively, for AVFs[38,39]; a third large multicenter RCT of 212 patients reported no benefit of drug-eluting balloons vs PTA.[40] Many other smaller RCTs (which included

fewer than 40 arteriovenous accesses) have demonstrated contradictory results for both AVGs and AVFs. Arising from these studies are at least 14 meta-analyses (of 6-14 RCTs), most of which showed superiority of drug-eluting balloons compared with PTA at 6 and 12 months for target lesion primary patency in AVFs (72% vs 55% at 6 months), with no effect on mortality at 2 years.[41-54] There were too few studies to evaluate the potential effect of drug-eluting balloons on AVG outcomes.

Stent grafts, composed of a polytetrafluoroethylene covering that encases a nitinol stent, are used to bypass stenoses. For AVGs, 2 meta-analyses (of 4 and 7 RCTs) demonstrated superiority of stent grafts vs PTA for 6- and 12-month target lesion patency at the graft-vein anastomosis (6-month target, 64% vs 28%; and 12-month target, 45% vs 17%, respectively, with odds ratios of 4.48 and 4.07, respectively).[55,56] An RCT of stent grafts vs PTA in AVFs (280 patients) that had at least 50% stenosis and AVF dysfunction demonstrated superiority of stent grafts at both 6 and 12 months for target lesion primary patency (78.7% vs 55.8% at 6 months and 47.9% vs 21.2% at 12 months, respectively).[57]

Arteriovenous Access Thrombosis

Arteriovenous access thrombosis is 2 to 3 times more common with AVGs than AVFs.[58-60] Although contemporary primary comparative data are lacking, examples of thrombosis rates are 0.1 to 0.5 times per year for AVF and 0.5 to 2.0 times per year for AVG.[60] Arteriovenous access declotting with pharmacologic thrombolysis, endovascular mechanical or surgical thrombectomy, or both along with endovascular (typically balloon angioplasty with or without use of drug-coated balloons, stenting, or both) or surgical correction of potentially causative stenotic lesion(s) needs to be timely[58] and can be performed as outpatient procedures. Surgical thrombectomy is required for thrombosis of AVF created within 1 month and is an option for prior endovascular treatment failures or if endovascular expertise is unavailable. Thrombectomy should not be attempted if the patient has any active hemorrhage, has suspected infection within or surrounding the arteriovenous access, or has fever, leukocytosis, hypotension, or positive blood culture results. The risk of symptomatic pulmonary embolism related to corrective intervention is up to 5% and the risk of arterial embolism is 0.4% to 7%.[61] One meta-analysis (of 8 RCTs and 2 retrospective cohorts that included a total of 806 surgical and 466 endovascular treatments) found that in patients with thrombosed AVG, endovascular therapy was associated with patency rates similar to those of open surgery up to 90 days. However, the 1-year primary failure rate was higher with endovascular therapy (75%-92%) compared with open surgery (53%-77%), and there was a significantly higher technical failure rate with endovascular procedures compared with surgical thrombectomy (relative risk, 1.58; 95% CI, 1.06-2.37; $P = .03$).[62]

Central Vein Stenosis

Central vein stenosis may develop from the placement of intravenous foreign bodies, such as peripherally inserted central catheters, CVCs, and pacer leads into central veins, and may prohibit successful ipsilateral arteriovenous access creation or impair ipsilateral arteriovenous access function through increased venous pressures and reduced flow. Central vein stenosis can be easily detected on imaging, but its presence alone is not an indication for intervention. Studies have found that PTA performed on asymptomatic central vein stenosis accelerated the time to development of symptomatic central vein stenosis and was associated with a higher loss of central vein patency.[63,64] Interventions should not occur in asymptomatic central vein stenosis but should be performed for patients with symptomatic central vein stenosis, including those with swelling or pain (eg, in ipsilateral extremity, neck, head, chest, or breast), persistent difficulty with dialysis (eg, elevated venous pressures, diminished flow rates), or persistent prolonged bleeding with decannulation. For outflow stenosis, standard endovascular PTA or bare metal stenting of central vein stenosis was associated with limited (<60%) primary patency at 12 months[65]; specifically, such patency has been found to be 37% and 48%, respectively.[66]

Surgical options such as venous bypass and first rib resection can be attempted if symptomatic central vein stenosis persists despite endovascular approaches. The various options depend on the anatomic distribution of the stenosis. Arteriovenous access ligation typically eliminates arm edema but results in loss of the arteriovenous access.

Nonflow-Related Arteriovenous Access Dysfunction

Access-Related Hand Ischemia: Steal

The hemodynamic changes that accompany arteriovenous access creation result in decreased perfusion of tissues distal to the anastomosis, typically the hand for upper extremity arteriovenous access. This phenomenon, often referred to as the steal syndrome, can occur in up to 1% to 8% of patients with arteriovenous access. It can cause both acute and chronic ischemia, with the symptoms ranging from finger numbness and skin mottling to rest pain and tissue loss that can lead to amputation (**Figure 4**A and B).[67]

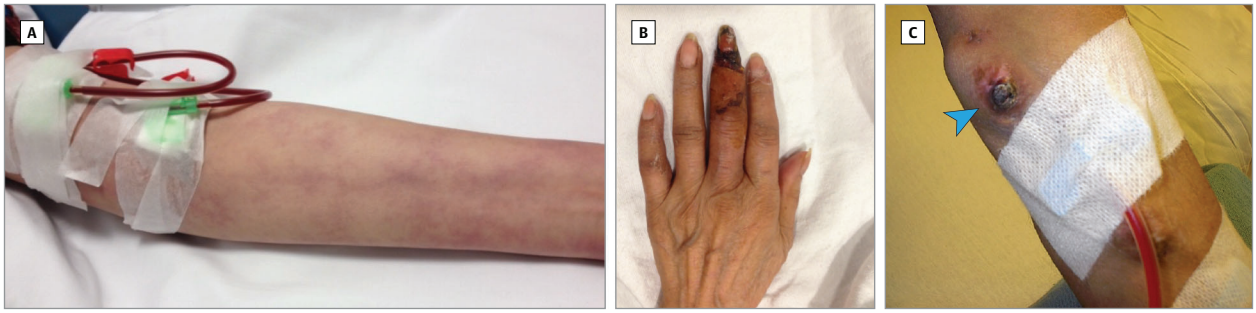
A decrease in distal perfusion occurs immediately after arteriovenous access creation and tends to plateau approximately a month later, as reflected by measurements of digital perfusion.[68] Forearm peripheral vascular disease, decreased blood pressure, or both can further reduce distal perfusion during hemodialysis and exacerbate steal syndrome symptoms. Although there are many proposed risk factors for steal syndrome, none absolutely preclude arteriovenous access creation. In a registry study of 35 236 vascular access creations in the Vascular Quality Improvement project, severe hand ischemia occurred in 2.75% of arteriovenous access.[69]

Steal syndrome is a clinical diagnosis based on the presence of symptoms such as cold skin, cyanosis, pain, or new-onset weakness or sensory deficit distal to the arteriovenous access that can be corroborated with noninvasive arterial testing demonstrating diminished brachial and radial arterial pressure measurements. Patients with mild intermittent symptoms can be treated conservatively (eg, by having them wear mittens to dilate and increase flow to distal vessels during dialysis). Patients with decreased motor function and substantial sensory deficits require referral to a surgeon for treatment to reverse symptoms and prevent any long-term sequelae.

Infection

Arteriovenous fistulae and AVGs become infected at a rate of 0.26 infections per 100 patient-months and 0.39 infections per 100 patient-months, respectively[70]; arteriovenous access infection is typically associated with lapses in infection control protocols or failure to adhere to aseptic cannulation technique. Infection can range from a localized infection near a cannulation site to the complete involvement of the arteriovenous access, including the anastomosis.

Figure 4. Arteriovenous Access Problems



Various manifestations of steal: cyanotic forearm during dialysis, suggesting steal syndrome (A); ischemic finger, leading to tissue loss (B); and eschar that may not appear concerning but is a danger sign for impending rupture (C). The arrowhead indicates the eschar. The clot is the only barrier between the blood circulation and the outside environment.

The 1-month infection rates are higher in patients with AVG[71] (1.8 infections/1000 patient access-days) than AVF (1.0 infection/1000 patient access-days); the 1-year bacteremia rates are similar (AVG vs AVF, 0.39/1000 patient access-days vs 0.37/1000 patient access-days).[72]

Localized AVG infections may be treated with systemic antibiotics alone or in combination with a partial graft resection that preserves AVG function. Infections involving the whole AVG should be treated as soon as possible and typically require resection of the graft material with reconstruction of the arterial anastomosis. Subtotal graft excision, which leaves a cuff of prosthetic material at the anastomosis site, is another option, but this procedure may be associated with worse outcomes compared with total resection. A meta-analysis (8 retrospective studies; N = 221 AVG infections) reported that compared with total graft excision, partial excision was associated with increased risk of persistent AVG infection (26.6% vs 4.8%; odds ratio = 0.23; 95% CI, 0.13-0.41; $P < .001$) and higher rates of reoperation to control infection (20.6% vs 3.3%; odds ratio = 0.14; 95% CI, 0.03-0.58; $P < .007$).[73]

In AVF, buttonhole cannulation uses a fibrous tissue tunnel tract developed by inserting sharp needles at the same site at the same angle and depth. Once the tract is established, blunt needles are used for dialysis. A scab forms over the tract after the needle is removed postdialysis, which is then picked off with tweezers, pickers, or needles before the next dialysis treatment, and a new needle is inserted into the same tract for dialysis. Compared with rope ladder cannulation, in which the needles are systematically rotated to different sites each dialysis session to resemble the pattern of the rungs of a rope ladder, buttonhole cannulation is associated with increased risk of infections. The National Healthcare Safety Network (NHSN), which collects and analyzes data for dialysis-associated infections reported by more than 6000 US outpatient hemodialysis facilities, found buttonhole cannulation was associated with significantly higher risk for access-related bloodstream infection (adjusted risk ratio, 2.6; 95% CI, 2.4-2.8) and local access-site infection (adjusted risk ratio, 1.5; 95% CI, 1.4-1.6) than rope ladder cannulation.[74] Three trials showed no difference in pain or patients' overall satisfaction between techniques.[75-77] The most common bacterium associated with buttonhole-related bacteremia is *Staphylococcus aureus* (>50%).[74] One RCT reported *S aureus* bacteremia to be more frequent with buttonhole cannulation (13%) vs rope ladder cannulation (0%) at 1 year (incident rate ratio, 63.3; 95% CI, 22.2-180.0; $P < .001$).[77] *S aureus* bacteremia may cause infection of the heart, lungs, bone, and brain. Patients may be evaluated by 2-dimensional echocardiography, magnetic resonance imaging, or joint aspirate to detect these infections. Prompt recognition and treatment of AVF and AVG infections is also important to avoid breakdown of the arteriovenous access and overlying skin, which may result in massive hemorrhage.

Pseudoaneurysms and Aneurysms

Arteriovenous fistulae and AVGs can develop pseudoaneurysms, which are areas of focal AVF wall or graft material degeneration that are contained by the surrounding soft tissue and are typically caused by repeated cannulation in the same spot (ie, "Swiss cheese" appearance). True aneurysms involve dilation of all 3 layers of the vessel wall in an AVF, have been reported to affect 0.04 patients per 1000 patient-days,[78] and range from 17% to 60% of AVFs[79,80]; a classification system estimated 43.5% of AVFs are aneurysmal.[81] Aneurysmal degeneration is likely due to local hemodynamic changes such as aberrant wall shear stress, although venous outflow stenosis is often present.[82] Arteriovenous access aneurysms or pseudoaneurysms can compromise dialysis efficiency, limit access to cannulation sites, and result in hemorrhage due to breakdown of the overlying skin. Important characteristic clinical manifestations suggestive of impending arteriovenous access rupture include erosion, persistent eschar (Figure 4), thin or shiny skin over the arteriovenous access site, exposed arteriovenous access prosthetic material, or visible pulsating vessel. These findings should prompt an urgent call to the vascular surgeon or referral to the emergency department. All arteriovenous access aneurysms or pseudoaneurysms with evidence of skin breakdown or ulceration should be evaluated urgently. The KDOQI guidelines indicate that the presence of an arteriovenous access aneurysm or pseudoaneurysm does not necessarily require treatment but should be closely monitored. Rapidly expanding aneurysms or pseudoaneurysms should be evaluated promptly by a nephrologist or surgeon.

Hemorrhage

Arteriovenous access hemorrhage is a medical emergency that can be fatal (<1%). Key contributing factors include the type, quality, and location of arteriovenous access; risk of infection; patient factors

(eg, cognitive impairment, with patients pulling out needles); and facility factors (eg, improper needle securement). Management depends on where the arteriovenous access ruptures (ie, in the dialysis facility or outside). Immediate pressure (manual pressure, tourniquet, blood pressure cuff, etc) must be placed proximal to the rupture site, with the patient calling for help to anyone nearby to call 911 or a code because hemorrhagic shock can occur within 1 to 2 minutes. Self-management should be taught as part of educational material after arteriovenous access creation.

High-Output Heart Failure

In creation of arteriovenous access, the connection between arterial and venous circuits results in structural and functional cardiovascular abnormalities such as decreased peripheral resistance, increased left ventricular end diastolic pressure, and increased cardiac contractility.[83-86] The increased cardiac output associated with arteriovenous access can cause high-output cardiac failure and pulmonary hypertension. Approximately 25% of cases of high-output heart failure are attributed to arteriovenous access,[87] more commonly with the higher-flow arm arteriovenous access compared with forearm arteriovenous access.[84,86,88] When a hemodialysis-dependent patient presents with heart failure that is not otherwise explained (such as volume overload), the arteriovenous access should be considered a potential contributing factor. Various 2-dimensional echocardiographic parameters can guide monitoring and management when the intra-access (within the arteriovenous access) blood flow is elevated (eg, >1.5- 2 L/min), such as the intra-access blood flow to cardiac output ratio or right ventricular longitudinal strain.[89,90] High-flow cardiac output failure has been associated with intra-access blood flow to cardiac output ratio greater than 20%.[4,85] Patients with high-output heart failure associated with arteriovenous access may be treated with surgical arteriovenous access banding and other revision techniques to decrease flow or arteriovenous access ligation,[91-93] which will result in loss of the arteriovenous access.

Conclusions

The selection, creation, and maintenance of arteriovenous access for hemodialysis is critical for patients with kidney failure. Generalist clinicians play an important role in protecting future and current arteriovenous access; identifying arteriovenous access complications such as infection, steal syndrome, and high-output cardiac failure; and making timely referrals to facilitate arteriovenous access creation and treatment of arteriovenous access complications.

ARTICLE INFORMATION

Accepted for Publication: January 14, 2024.

Published Online: March 18, 2024. doi:10.1001/jama.2024.0535

Author Contributions: Dr Lok had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Conflict of Interest Disclosures: Dr Lok reported receiving fees from BD, Gore, and Medtronic for providing talks or consultation on Kidney Disease Outcomes Quality Initiative guidelines and individualizing patient vascular access outside the submitted work. Dr Rajan reported receiving fees from Becton Dickinson and WL Gore for consultation services regarding commercially available devices outside the submitted work. No other disclosures were reported.

Submissions: We encourage authors to submit papers for consideration as a Review. Please contact Kristin Walter, MD, at kristin.walter@jamanetwork.org.

REFERENCES

1. United States Renal Data System. *2023 USRDS Annual Data Report: Epidemiology of Kidney Disease in the United States*. National Institutes of Health, National Institute of Diabetes and Digestive and Kidney Diseases; 2023.

2. Levey AS, Eckardt KU, Dorman NM, et al. Nomenclature for kidney function and disease: report of a Kidney Disease: Improving Global Outcomes (KDIGO) consensus conference. *Kidney Int*. 2020;97(6):1117-1129. doi:10.1016/j.kint.2020.02.010

3. Pecoits-Filho R, Okpechi IG, Donner JA, et al. Capturing and monitoring global differences in untreated and treated end-stage kidney disease, kidney replacement therapy modality, and outcomes. *Kidney Int Suppl (2011)*. 2020;10(1):e3-e9. doi:10.1016/j.kisu.2019.11.001

4. Lok CE, Huber TS, Lee T, et al; National Kidney Foundation. KDOQI clinical practice guideline for vascular access: 2019 update. *Am J Kidney Dis*. 2020;75(4)(suppl 2):S1-S164. doi:10.1053/j.ajkd.2019.12.001

5. McGill RL, Ruthazer R, Meyer KB, Miskulin DC, Weiner DE. Peripherally inserted central catheters and hemodialysis outcomes. *Clin J Am Soc Nephrol*. 2016;11(8):1434-1440. doi:10.2215/CJN.01980216

6. Otoya D, Simmonds A, Lavingia K, Amendola MF. Central line access for hemodialysis adversely affects ipsilateral arteriovenous graft outcomes. *Ann Vasc Surg*. 2022;86:236-241. doi:10.1016/j.avsg.2022.04.043

7. Czajkowski M, Jacheć W, Polewczyk A, et al. Severity and extent of lead-related venous obstruction in more than 3000 patients undergoing transvenous lead extraction. *Vasc Health Risk Manag*. 2022;18:629-642. doi:10.2147/VHRM.S369342

8. United States Renal Data System. US Department of Health and Human Services. 2023 Annual data report. Accessed February 7, 2024. https://adr.usrds.org/2022

9. Farrington CA, Robbin ML, Lee T, Barker-Finkel J, Allon M. Early predictors of arteriovenous fistula maturation: a novel perspective on an enduring problem. *J Am Soc Nephrol*. 2020;31(7):1617-1627. doi:10.1681/ASN.2019080848

10. Almasri J, Alsawas M, Mainou M, et al. Outcomes of vascular access for hemodialysis: a systematic review and meta-analysis. *J Vasc Surg*. 2016;64(1):236-243. doi:10.1016/j.jvs.2016.01.053

11. Allon M, Al-Balas A, Young CJ, Cutter GR, Lee T. Effects of a more selective arteriovenous fistula strategy on vascular access outcomes. *J Am Soc Nephrol*. 2023;34(9):1589-1600. doi:10.1681/ASN.0000000000000174

12. Kostakis ID, Loukopoulos I. Comparison between bovine carotid artery graft and polytetrafluoroethylene graft for haemodialysis vascular access: a systematic review and meta-analysis. *J Vasc Access*. 2021;22(1):26-33. doi:10.1177/1129729820926088

13. Shemesh D, Goldin I, Hijazi J, et al. A prospective randomized study of heparin-bonded graft (Propaten) versus standard graft in prosthetic arteriovenous access. *J Vasc Surg*. 2015;62(1):115-122. doi:10.1016/j.jvs.2015.01.056

14. Jasty VS, Haddad D, Mohan B, Zhou W, Siracuse JJ, Tan TW. Tapered and non-tapered prosthetic grafts in upper extremity dialysis access: a systematic review and meta-analysis. *J Vasc Access*. 2022;23(1):42-49. doi:10.1177/1129729820974177

15. Sawo P, Moufarrej A, Sloff M, et al. The effect of geometric graft modification on arteriovenous graft patency in haemodialysis patients: a systematic review and meta-analysis. *Eur J Vasc Endovasc Surg*. 2020;60(4):568-577. doi:10.1016/j.ejvs.2020.06.023

16. Aitken E, Thomson P, Bainbridge L, Kasthuri R, Mohr B, Kingsmore D. A randomized controlled trial and cost-effectiveness analysis of early cannulation arteriovenous grafts versus tunneled central venous catheters in patients requiring urgent vascular access for hemodialysis. *J Vasc Surg*. 2017;65(3):766-774.

17. Tawfik AM, Zidan MH, Salem A, Salem A. A randomized controlled study of early versus standard cannulation of arteriovenous grafts in hemodialysis patients. *J Vasc Surg*. 2022;75(3):1047-1053. doi:10.1016/j.jvs.2021.08.106

18. Aitken DEL, Thomson PC, Kingsmore D. A randomised controlled trial of early cannulation grafts (ECAVGS) versus tunneled central venous catheters in patients requiring urgent vascular access for haemodialysis: one year follow-up. *J Am Soc Nephrol*. 2017;28(48):2017-10.

19. Al Shakarchi J, Houston G, Inston N. Early cannulation grafts for haemodialysis: a systematic review. *J Vasc Access*. 2015;16(6):493-497. doi:10.5301/jva.5000412

20. Al Shakarchi J, Inston N. Early cannulation grafts for haemodialysis: an updated systematic review. *J Vasc Access*. 2019;20(2):123-127. doi:10.1177/1129729818776571

21. Xiao Z, Rotmans JI, Letachowicz K, Franchin M, D'Oria M. Outcomes of early cannulation arteriovenous graft versus PTFE arteriovenous graft in hemodialysis patients: a meta-analysis and systematic review. *J Vasc Access*. Published online November 7, 2023. doi:10.1177/11297298231205325

22. Woodside KJ, Bell S, Mukhopadhyay P, et al. Arteriovenous fistula maturation in prevalent hemodialysis patients in the United States: a national study. *Am J Kidney Dis*. 2018;71(6):793-801. doi:10.1053/j.ajkd.2017.11.020

23. Al-Jaishi AA, Oliver MJ, Thomas SM, et al. Patency rates of the arteriovenous fistula for hemodialysis: a systematic review and meta-analysis. *Am J Kidney Dis*. 2014;63(3):464-478. doi:10.1053/j.ajkd.2013.08.023

24. Huber TS, Berceli SA, Scali ST, et al. Arteriovenous fistula maturation, functional patency, and intervention rates. *JAMA Surg*. 2021;156(12):1111-1118. doi:10.1001/jamasurg.2021.4527

25. Han A, Min SK, Kim MS, et al. A prospective, randomized trial of routine duplex ultrasound surveillance on arteriovenous fistula maturation. *Clin J Am Soc Nephrol*. 2016;11(10):1817-1824. doi:10.2215/CJN.00620116

26. Robbin ML, Greene T, Allon M, et al; Hemodialysis Fistula Maturation Study Group. Prediction of arteriovenous fistula clinical maturation from postoperative ultrasound measurements: findings from the Hemodialysis Fistula Maturation Study. *J Am Soc Nephrol*. 2018;29(11):2735-2744. doi:10.1681/ASN.2017111225

27. Andrade FP, Benvenutti H, da Silva KC, Rovedder PME. Effects of upper limb exercise programs on the arteriovenous fistula in patients on hemodialysis: a systematic review and meta-analysis. *J Vasc Access*. 2022;23(5):770-777. doi:10.1177/11297298211001166

28. Voorzaat BM, Janmaat CJ, van der Bogt KEA, Dekker FW, Rotmans JI. Patency outcomes of arteriovenous fistulas and grafts for hemodialysis access: a trade-off between nonmaturation and long-term complications. *Kidney360*. 2020;1(9):916-924. doi:10.34067/KID.0000462020

29. Abreo K, Amin BM, Abreo AP. Physical examination of the hemodialysis arteriovenous fistula to detect early dysfunction. *J Vasc Access*. 2019;20(1):7-11. doi:10.1177/1129729818768183

30. End-Stage Renal Disease Network Coordinating Center. It only takes a minute to save your lifeline. Accessed December 7, 2023. https://www.kidney.org/sites/default/files/it_only_takes_a_minute_to_save_your_lifeline.pdf

31. Beathard GA. The treatment of vascular access graft dysfunction: a nephrologist's view and experience. *Adv Ren Replace Ther*. 1994;1(2):131-147. doi:10.1016/S1073-4449(12)80044-6

32. Roy-Chaudhury P, Sukhatme VP, Cheung AK. Hemodialysis vascular access dysfunction: a cellular and molecular viewpoint. *J Am Soc Nephrol*. 2006;17(4):1112-1127. doi:10.1681/ASN.2005050615

33. Ullah K, Bashir M, Ain NU, et al. Medical adjuvant therapy in reducing thrombosis with arteriovenous grafts and fistulae use: a meta-analysis of randomized controlled trials. *Clin Appl Thromb Hemost*. 2021;27:10760296211063882. doi:10.1177/10760296211063882

34. Lok CE, Moist L, Hemmelgarn BR, et al; Fish Oil Inhibition of Stenosis in Hemodialysis Grafts (FISH) Study Group. Effect of fish oil supplementation on graft patency and cardiovascular events among patients with new synthetic arteriovenous hemodialysis grafts: a randomized controlled trial. *JAMA*. 2012;307(17):1809-1816. doi:10.1001/jama.2012.3473

35. Dixon BS, Beck GJ, Vazquez MA, et al; DAC Study Group. Effect of dipyridamole plus aspirin on hemodialysis graft patency. *N Engl J Med*. 2009;360(21):2191-2201. doi:10.1056/NEJMoa0805840

36. Dixon BS, Beck GJ, Vazquez MA, et al; DAC Study Group. Effect of dipyridamole plus aspirin on hemodialysis graft patency. *N Engl J Med*. 2009;360(21):2191-2201. doi:10.1056/NEJMoa0805840

37. Ravani P, Quinn RR, Oliver MJ, et al. Pre-emptive correction for haemodialysis arteriovenous access stenosis. *Cochrane Database Syst Rev*. 2016;2016(1):CD010709. doi:10.1002/14651858.CD010709.pub2

38. Trerotola SO, Lawson J, Roy-Chaudhury P, Saad TF; Lutonix AV Clinical Trial Investigators. Drug coated balloon angioplasty in failing AV fistulas: a randomized controlled trial. *Clin J Am Soc Nephrol*. 2018;13(8):1215-1224. doi:10.2215/CJN.14231217

39. Lookstein RA, Haruguchi H, Ouriel K, et al. Drug-coated balloons for dysfunctional dialysis arteriovenous fistulas. *N Engl J Med*. 2020;383(8):733-742. doi:10.1056/NEJMoa1914617

40. Karunanithy N, Robinson EJ, Ahmad F, et al. A multicenter randomized controlled trial indicates that paclitaxel-coated balloons provide no benefit for arteriovenous fistulas. *Kidney Int*. 2021;100(2):447-456. doi:10.1016/j.kint.2021.02.040

41. Chen X, Liu Y, Wang J, Zhao J, Singh N, Zhang WW. A systematic review and meta-analysis of the risk of death and patency after application of paclitaxel-coated balloons in the hemodialysis access. *J Vasc Surg*. 2020;72(6):2186-2196.e3. doi:10.1016/j.jvs.2020.04.525

42. Abdul Salim S, Tran H, Thongprayoon C, Fülöp T, Cheungpasitporn W. Comparison of drug-coated balloon angioplasty versus conventional angioplasty for arteriovenous fistula stenosis: systematic review and meta-analysis. *J Vasc Access*. 2020;21(3):357-365. doi:10.1177/1129729819878612

43. Rokoszak V, Syed MH, Salata K, et al. A systematic review and meta-analysis of plain versus drug-eluting balloon angioplasty in the treatment of juxta-anastomotic hemodialysis arteriovenous fistula stenosis. *J Vasc Surg*. 2020;71(3):1046-1054.e1. doi:10.1016/j.jvs.2019.07.075

44. Yuan Y, Cheng W, Lu H. Drug-eluting balloon versus plain balloon angioplasty for the treatment of failing hemodialysis access: a systematic review and meta-analysis. *Ann Vasc Surg*. 2020;64:389-396. doi:10.1016/j.avsg.2019.10.062

45. Dinh K, Limmer AM, Paravastu SCV, et al. Mortality after paclitaxel-coated device use in dialysis access: a systematic review and meta-analysis. *J Endovasc Ther*. 2019;26(5):600-612. doi:10.1177/1526602819872154

46. Fong KY, Zhao JJ, Tan E, et al. Drug coated balloons for dysfunctional haemodialysis venous access: a patient level meta-analysis of randomised controlled trials. *Eur J Vasc Endovasc Surg*. 2021;62(4):610-621. doi:10.1016/j.ejvs.2021.06.006

47. Yan Wee IJ, Yap HY, Hsien Ts'ung LT, et al. A systematic review and meta-analysis of drug-coated balloon versus conventional balloon angioplasty for dialysis access stenosis. *J Vasc Surg*. 2019;70(3):970-979.e3. doi:10.1016/j.jvs.2019.01.082

48. Han A, Park T, Kim HJ, Min S, Ha J, Min SK. Editor's choice—paclitaxel coated balloon angioplasty vs plain balloon angioplasty for haemodialysis arteriovenous access stenosis: a systematic review and a time to event meta-analysis of randomised controlled trials. *Eur J Vasc Endovasc Surg*. 2021;62(4):597-609. doi:10.1016/j.ejvs.2021.05.043

49. Hu H, Tan Q, Wang J, Liu Y, Yang Y, Zhao J. Drug-coated balloon angioplasty for failing haemodialysis access: meta-analysis of randomized clinical trials. *Br J Surg*. 2021;108(11):1293-1303. doi:10.1093/bjs/znab301

50. Kennedy SA, Mafeld S, Baerlocher MO, Jaberi A, Rajan DK. Drug-coated balloon angioplasty in hemodialysis circuits: a systematic review and meta-analysis. *J Vasc Interv Radiol*. 2019;30(4):483-494.e1. doi:10.1016/j.jvir.2019.01.012

51. Khawaja AZ, Cassidy DB, Al Shakarchi J, McGrogan DG, Inston NG, Jones RG. Systematic review of drug eluting balloon angioplasty for arteriovenous haemodialysis access stenosis. *J Vasc Access*. 2016;17(2):103-110. doi:10.5301/jva.5000508

52. Cao Z, Li J, Zhang T, et al. Comparative effectiveness of drug-coated balloon vs balloon angioplasty for the treatment of arteriovenous fistula stenosis: a meta-analysis. *J Endovasc Ther*. 2020;27(2):266-275. doi:10.1177/1526602820902757

53. Liao MT, Chen MK, Hsieh MY, et al. Drug-coated balloon versus conventional balloon angioplasty of hemodialysis arteriovenous fistula or graft: a systematic review and meta-analysis of randomized controlled trials. *PLoS One*. 2020;15(4):e0231463. doi:10.1371/journal.pone.0231463

54. Luo C, Liang M, Liu Y, Zheng D, He Q, Jin J. Paclitaxel coated balloon versus conventional balloon angioplasty in dysfunctional dialysis arteriovenous fistula: a systematic review and meta-analysis of randomized controlled trials. *Ren Fail*. 2022;44(1):155-170. doi:10.1080/0886022X.2022.2029487

55. Ng B, Fugger M, Onakpoya IJ, MacDonald A, Heneghan C. Covered stents versus balloon angioplasty for failure of arteriovenous access: a systematic review and meta-analysis. *BMJ Open*. 2021;11(6):044256. doi:10.1136/bmjopen-2020-044356

56. Hu H, Wu Z, Zhao J, et al. Stent graft placement versus angioplasty for hemodialysis access failure: a meta-analysis. *J Surg Res*. 2018;226:82-88. doi:10.1016/j.jss.2018.01.030

57. Dolmatch B, Cabrera T, Pergola P, et al; AVeNEW Trial Investigators. Prospective, randomized, multicenter clinical study comparing a self-expanding covered stent to percutaneous transluminal angioplasty for treatment of upper extremity hemodialysis arteriovenous fistula stenosis. *Kidney Int*. 2023;104(1):189-200. doi:10.1016/j.kint.2023.03.015

58. Girerd S, Girerd N, Frimat L, et al. Arteriovenous fistula thrombosis is associated with increased all-cause and cardiovascular mortality in haemodialysis patients from the AURORA trial. *Clin Kidney J*. 2019;13(1):116-122. doi:10.1093/ckj/sfz048

59. Schild AF, Perez E, Gillaspie E, Seaver C, Livingstone J, Thibonnier A. Arteriovenous fistulae vs arteriovenous grafts: a retrospective review of 1,700 consecutive vascular access cases. *J Vasc Access*. 2008;9(4):231-235. doi:10.1177/112972980800900402

60. Quencer KB, Oklu R. Hemodialysis access thrombosis. *Cardiovasc Diagn Ther*. 2017;7(suppl 3):S299-S308. doi:10.21037/cdt.2017.09.08

61. Wu V, Kalva SP, Cui J. Thrombectomy approach for access maintenance in the end stage renal disease population: a narrative review. *Cardiovasc Diagn Ther*. 2023;13(1):265-280. doi:10.21037/cdt-21-523

62. Chan N, Wee I, Soong TK, Syn N, Choong AMTL. A systematic review and meta-analysis of surgical versus endovascular thrombectomy of thrombosed arteriovenous grafts in hemodialysis patients. *J Vasc Surg*. 2019;69(6):1976-1988.e7. doi:10.1016/j.jvs.2018.10.102

63. Levit RD, Cohen RM, Kwak A, et al. Asymptomatic central venous stenosis in hemodialysis patients. *Radiology*. 2006;238(3):1051-1056. doi:10.1148/radiol.2383050119

64. Renaud CJ, Francois M, Nony A, Fodil-Cherif M, Turmel-Rodrigues L. Comparative outcomes of treated symptomatic versus non-treated asymptomatic high-grade central vein stenoses in the outflow of predominantly dialysis fistulas. *Nephrol Dial Transplant*. 2012;27(4):1631-1638. doi:10.1093/ndt/gfr506

65. Wu TY, Wu CK, Chen YY, Lin CH. Comparison of percutaneous transluminal angioplasty with stenting for treatment of central venous stenosis or occlusion in hemodialysis patients: a systematic review and meta-analysis. *Cardiovasc Intervent Radiol*. 2020;43(4):525-540. doi:10.1007/s00270-019-02383-7

66. Razavi MK, Rajan DK, Nordhausen CT, Bounsanga J, Holden A. Objective performance goals based on a systematic review and meta-analysis of clinical outcomes for bare-metal stents and percutaneous transluminal angioplasty for hemodialysis-related central venous obstruction. *J Vasc Interv Radiol*. 2023;34(10):1664-1673.e3. doi:10.1016/j.jvir.2023.05.036

67. Stoecker JB, Li X, Clark TWI, Mantell MP, Trerotola SO, Vance AZ. Dialysis access–associated steal syndrome and management. *Cardiovasc Intervent Radiol*. 2023;46(9):1168-1181. doi:10.1007/s00270-023-03462-6

68. Oprea A, Molnar A, Scridon T, Mircea PA. Digital pressure in haemodialysis patients with brachial arteriovenous fistula. *Indian J Med Res*. 2019;149(3):376-383. doi:10.4103/ijmr.IJMR_415_17

69. Lee SR, Dardik A, Siracuse J, Ochoa Chaar CI. Risk factors and management of hemodialysis associated distal ischemia. *Ann Vasc Surg*. 2022;82:62-69.

70. Nguyen DB, Shugart A, Lines C, et al. National Healthcare Safety Network (NHSN) dialysis event surveillance report for 2014. *Clin J Am Soc Nephrol*. 2017;12(7):1139-1146. doi:10.2215/CJN.11411116

71. Ravani P, Gillespie BW, Quinn RR, et al. Temporal risk profile for infectious and noninfectious complications of hemodialysis access. *J Am Soc Nephrol*. 2013;24(10):1668-1677. doi:10.1681/ASN.2012121234

72. Xue H, Ix JH, Wang W, et al. Hemodialysis access usage patterns in the incident dialysis year and associated catheter-related complications. *Am J Kidney Dis*. 2013;61(1):123-130. doi:10.1053/j.ajkd.2012.09.006

73. Tullavardhana T, Chartkitchareon A. Meta-analysis of total versus partial graft excision: which is the better choice to manage arteriovenous dialysis graft infection? *Ann Saudi Med*. 2022;42(5):343-350. doi:10.5144/0256-4947.2022.343

74. Lyman M, Nguyen DB, Shugart A, Gruhler H, Lines C, Patel PR. Risk of vascular access infection associated with buttonhole cannulation of fistulas: data from the National Healthcare Safety Network. *Am J Kidney Dis*. 2020;76(1):82-89. doi:10.1053/j.ajkd.2019.11.006

75. Chow J, Rayment G, San Miguel S, Gilbert M. A randomised controlled trial of buttonhole cannulation for the prevention of fistula access complications. *J Ren Care*. 2011;37(2):85-93. doi:10.1111/j.1755-6686.2011.00211.x

76. MacRae JM, Ahmed SB, Atkar R, Hemmelgarn BR. A randomized trial comparing buttonhole with rope ladder needling in conventional hemodialysis patients. *Clin J Am Soc Nephrol*. 2012;7(10):1632-1638. doi:10.2215/CJN.02730312

77. Macrae JM, Ahmed SB, Hemmelgarn BR; Alberta Kidney Disease Network. Arteriovenous fistula survival and needling technique: long-term results from a randomized buttonhole trial. *Am J Kidney Dis*. 2014;63(4):636-642. doi:10.1053/j.ajkd.2013.09.015

78. Al-Jaishi AA, Liu AR, Lok CE, Zhang JC, Moist LM. Complications of the arteriovenous fistula: a systematic review. *J Am Soc Nephrol*. 2017;28(6):1839-1850. doi:10.1681/ASN.2016040412

79. Shahri J, Saberianpour S, Kazemzadeh G. Arteriovenous fistula aneurysm: bench to bedside. *Indian J Surg*. 2023;85(suppl 1):219-227.

80. Mudoni A, Cornacchiari M, Gallieni M, et al. Aneurysms and pseudoaneurysms in dialysis access. *Clin Kidney J*. 2015;8(4):363-367. doi:10.1093/ckj/sfv042

81. Valenti D, Mistry H, Stephenson M. A novel classification system for autogenous arteriovenous fistula aneurysms in renal access patients. *Vasc Endovascular Surg*. 2014;48(7-8):491-496. doi:10.1177/1538574414561229

82. Patel MS, Street T, Davies MG, Peden EK, Naoum JJ. Evaluating and treating venous outflow stenoses is necessary for the successful open surgical treatment of arteriovenous fistula aneurysms. *J Vasc Surg*. 2015;61(2):444-448. doi:10.1016/j.jvs.2014.07.033

83. Askary ZM, Abdelhady M, Yousef MA, Mohammed AK. Influence of native upper limb hemodialysis arteriovenous fistula on left ventricle. *Ital J Vasc Endovasc Surg*. 2022;29(2):70-73. doi:10.23736/S1824-4777.22.01532-7

84. Stoumpos S, Rankin A, Hall Barrientos P, et al. Interrogating the haemodynamic effects of haemodialysis arteriovenous fistula on cardiac structure and function. *Sci Rep*. 2021;11(1):18102. doi:10.1038/s41598-021-97625-5

85. Saleh MA, El Kilany WM, Keddis VW, El Said TW. Effect of high flow arteriovenous fistula on cardiac function in hemodialysis patients. *Egypt Heart J*. 2018;70(4):337-341. doi:10.1016/j.ehj.2018.10.007

86. Said K, Hassan M, Farouk M, Baligh E, Zayed B. Right ventricular function after creation of an atriovenous fistula in patients with end stage renal disease. *Heart Lung Circ*. 2019;28(6):884-892. doi:10.1016/j.hlc.2018.04.282

87. Reddy YNV, Melenovsky V, Redfield MM, Nishimura RA, Borlaug BA. High-output heart failure: a 15-year experience. *J Am Coll Cardiol*. 2016;68(5):473-482. doi:10.1016/j.jacc.2016.05.043

88. Roca-Tey R. Permanent arteriovenous fistula or catheter dialysis for heart failure patients. *J Vasc Access*. 2016;17(suppl 1):S23-S29. doi:10.5301/jva.5000511

89. Gumus F, Saricaoglu MC. Assessment of right heart functions in the patients with arteriovenous fistula for hemodialysis access: right ventricular free wall strain and tricuspid regurgitation jet velocity as the predictors of right heart failure. *Vascular*. 2020;28(1):96-103. doi:10.1177/1708538119866616

90. Elfekky EM, Lotfy AA, Diab OA, Ali AN. Optimal hemodialysis arteriovenous fistula flow volume for cardiovascular safety. *Vasc Dis Manage*. 2020;17(8):E170-E177.

91. Malik J, Valerianova A, Tuka V, et al. The effect of high-flow arteriovenous fistulas on systemic haemodynamics and brain oxygenation. *ESC Heart Fail*. 2021;8(3):2165-2171. doi:10.1002/ehf2.13305

92. Valerianova A, Malik J, Janeckova J, et al. Reduction of arteriovenous access blood flow leads to biventricular unloading in haemodialysis patients. *Int J Cardiol*. 2021;334:148-153. doi:10.1016/j.ijcard.2021.04.027

93. Maresca B, Filice FB, Orlando S, et al. Early echocardiographic modifications after flow reduction by proximal radial artery ligation in patients with high-output heart failure due to high-flow forearm arteriovenous fistula. *J Vasc Access*. 2020;21(5):753-759. doi:10.1177/1129729820907249