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Clinical Aspects of Dialysis Interventions: Physical and Sonographic Findings

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Abstract

Physical examination (PE) of arteriovenous access remains of high clinical value and continues to be recommended by leading societies and guidelines. PE is easy to learn and perform. Once learned, examiners can provide a comprehensive arteriovenous (AV) access examination in 20 to 30 seconds. Therefore, we continue to advocate that AV access PE should be part of the training for all dialysis care providers. Similarly, ultrasound can provide important AV access evaluation and provide key information. It is relatively cheap and can be readily available at the bed side. Additionally, it is well accepted by patients, as it is not expected to be associated with pain or discomfort during the examination. We present in this review the key components of PE, signs and symptoms of AV access dysfunction, and the role of ultrasound in AV access evaluation as a complementary tool to PE.

Keywords

- arteriovenous access
- arteriovenous fistula
- arteriovenous grant
- AV access dysfunction
- AV access physical examination
- interventional radiology

Hemodialysis (HD) was made possible in 1943 with the invention of hemodialyzer by Willem Kolff.[1] However, chronic HD was seriously limited by the lack of availability of technology to access arteries and veins repeatedly and consistently. Initial techniques to obtain access to the circulation involved repeated cutdowns, which resulted in running out of these vessels after a few treatments. Experimentation with glass shunts to connect arteries and veins was complicated by thrombosis and infection.[2] To overcome such limitations, there were several innovations over the next couple of decades, including creation of Scribner shunt, Brescia Cimino arteriovenous fistula (AVF), arteriovenous grafts (AVGs), and central venous catheters.[3–5]

An ideal vascular access for HD would be easy to create, be available for immediate use, provide sufficient blood flow for adequate dialysis, require no or few interventions to maintain long-term patency, and be free of complications including thrombosis, stenosis, infection, arterial steal, or aneurysm formation. Currently available vascular accesses do not have these attributes. Advent and frequent use of these multiple but imperfect HD accesses quickly resulted in emergence of complications relating to their use, often leading to their loss. Dialysis access thus became not just the lifeline but also the "Achilles Heel" of dialysis. Several types of complications are associated with the use of AVF and AVG. AVF frequently fail to mature after creation, while mature AVF and AVG may develop stenosis, aneurysm/pseudoaneurysm formation, bleeding, and limb ischemia. Management of these complications is associated with billions of dollars in cost to the health care system as a result of increased resource utilization, recurrent hospitalizations, and poor outcomes in dialysis patients.

The complications of HD access are unique not only in their need of urgent management but also in their almost predictable recurrence. Efficient management of these complications requires a well-defined process of monitoring, surveillance, and intervention to salvage these accesses. However, these processes are not always well-established. This leads to fragmented and disorganized care of dialysis vascular access. However, more recently, the importance of a multidisciplinary approach to manage the dialysis access has

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been recognized better. Multiple specialties—including surgeons, interventional radiologists, and interventional nephrologists—now work in a collaborative fashion with dialysis team to take care of dialysis access. Newer modalities of AVF creation are advancing the field further and have the potential to improve access outcomes for the complex population of patients with ESRD and multiple comorbidities.

Endovascular interventions are commonly required for the maintenance of dysfunctional HD access. These interventions include fistulogram or shuntogram, angioplasty, thrombectomy, stent placement, accessory vein coiling/ligation, and HD catheter placements, exchanges, and removals. However, it is important to have a comprehensive program of monitoring, surveillance, and referral to ensure timely and appropriate intervention that can salvage HD access.

Physical Exam of the AV Dialysis Access

AV access physical examination (PE) should be performed on at least a monthly basis by a trained dialysis provider.[6,7] PE accuracy and reliability has been well established and can be done in a relatively short time.[8] Therefore, it should be part of the monthly dialysis comprehensive evaluation. AV access PE consists of five main components: inspection, pulse, thrill, arm elevation, and augmentation test (►**Table 1**).

Inspection involves careful assessment of the ipsilateral extremity for visual anomalies, such as the presence of edema, side branches (accessory veins or collaterals), aneurysms, infections, ulcers, eschars, cannulation marks, the presence of buttonholes, and other abnormalities. Inspection should also involve the face, chest wall, and contralateral extremity for the presence of edema, old chest wall catheter marks, chest wall collateral veins, the presence of cardiac electronic implantable devices, or any other noticeable abnormality. Thus, a comprehensive evaluation of an upper extremity AV access should always include both upper extremities and the upper part of the body.

It is important to mention that the presence of edema in the ipsilateral extremity of the AV access almost always indicates the presence of central vein stenosis. The extent of the edema can reliably predict the location of a central vein stenosis.[8] Edema that involves the ipsilateral extremity indicates the presence of a subclavian vein stenosis; edema that involves ipsilateral extremity and ipsilateral part of the face indicates a brachiocephalic vein stenosis; and bilateral upper extremity (and facial) edema in patients with an upper extremity AV access indicates the presence of a superior vena cava stenosis.

Pulse evaluation can be performed by gently placing the palm side of the four fingers on the AV access. A normal pulse is easily compressible.[9] One method to assist in understanding a normal pulse is to mentally grade a pulse between 0 (zero) and 10 with 0 being no pulse and 10 being the strongest pulse you could feel. A normal pulse would be graded 3 to 4. In this scenario, grades 1 to 2 would indicate an inflow stenosis and grades 7 to 10 would indicate an outflow stenosis.[9]

Thrill can be evaluated at the same time you are evaluating pulse and by similarly placing the palmar side of the four fingers on the AV access. Thrill is the vibration or buzz you would feel once the fingers are on the AV access.[8,10] Normal thrill can be felt continuously during systolic and diastolic phases of the cardiac contraction. It is normal to have variation in intensity between the systolic and diastolic phases. The presence of systolic-only thrill indicates the presence of an AV access stenosis. An AV access stenosis will affect blood flow by changing its pattern.[6,7,11] The stenosis will eventually lead to a loss of the diastolic component of the thrill.

The arm elevation test is performed for the evaluation of the outflow venous system. This test is mainly used to evaluate AVFs and is less valuable for the evaluation of an AVG.[8] This test is performed by elevating the arm above the level of the patient's heart. The AVF should collapse indicating no significant outflow vein stenosis. A test is considered positive when the AVF remains visually prominent or distended by palpation indicating the presence of a clinically significant outflow stenosis. Occasionally, outflow vein stenosis can lead to distended AVF to the point of stenosis indicating the anatomical location of the stenotic lesion.

The augmentation test, on the other hand, evaluates the inflow components of the AV access. This test is performed by first placing the palmar side of the fingers of one hand on the cannulation portion of the AV access.[8] When this is done, the examiner will be able to feel the pulse and thrill. Next, the examiner completely occludes the outflow segment of the AV access proximal to the other hand. Making sure the first hand is still placed on the cannulation side of the AVF access, the

Table 1 Elements of AV access physical examination

	Normal	Abnormal
Inspection	No abnormality	Edema, collaterals, infections, aneurysms, ulcers, eschars, etc.
Pulse	Soft, easily compressible (3–4/10)	Weak pulse indicates inflow stenosis. Strong pulse indicates outflow stenosis
Thrill	Continuous (systolic–diastolic)	Systolic-only thrill indicates stenosis. Absent thrill and pulse indicate thromboses AV access
Arm elevation test	AVF collapses	No collapse indicates outflow vein stenosis
Augmentation test	Pulse intensifies Thrill disappears	Poor pulse intensification indicates inflow stenosis. Continuously present thrill indicates side branches

Abbreviations: AV, arteriovenous; AVF, arteriovenous fistula.

examiner will be able to sense the increase in intensity of the AV access pulse along with the disappearance of the thrill. An adequate increase in intensity of the pulse indicates no significant inflow stenosis. If the pulse does not augment or if it mildly augments, it indicates the presence of an inflow stenosis.[9] It may be helpful to grade the degree of the increase in pulse intensity using the scale of 0 to 10. For example, if the pulse intensity increases from 4 (normal) to 9, this indicates no significant inflow stenosis.[8]

The disappearance of the thrill during the augmentation test indicates the absence of any side branches (accessory vein or collateral vein) from the segment of the AV access distal to the occlusion area. And at the same time, if the thrill continues to be present, this indicates the presence of a side branch as described earlier.[8] If the test is positive (thrill does not disappear), the examiner can perform a sequential occlusion test to identify the location of the side branch. This is done by moving the occlusion point more distal at several increments while keeping the other hand on the AV access to feel the thrill. Once the thrill disappears, this indicates that the occluding fingers are now distal to the side branch. You can move the occlusion fingers slightly proximal and once the thrill appears again, this indicates that the fingers just passed the side branch. This way you can locate the anatomical location of the side branch with reasonable accuracy. It is important to distinguish between accessory veins (present without outflow stenosis) and collateral veins (present due to outflow stenosis). Accessory veins are problematic only if they originate from the cannulation site or originate distally to the cannulation site (closer to the arterial anastomosis). Proximal accessory veins to the cannulation site may play a beneficial role and should not be closed.

When a stethoscope is used in the evaluation of an AV access, the examiner is able to listen to the flow and the heard-auditory sound is called the “bruit.” A bruit has similar characteristics to a thrill which is felt by palpation. Both bruit and thrill are expected, in a normal AV access, to have systolic and diastolic components. Based on our experience, a bruit is more sensitive than a thrill. Therefore, if a thrill is not felt, the examiner can listen using a stethoscope to confirm the presence or absence of blood flow.

Recognizing AV Access Dysfunction

HD access is a closed circuit which requires continuous flow to enable adequate dialysis. Blood flow through an access starts with a blood pump in the form of left ventricle that propels blood into the circulation through the access to keep it free of stagnation and avoid thrombosis. Poor flow due to poor cardiac output can easily compromise the patency of access. Additionally, any issues with adequate size and patency of inflow, the presence of stenosis within access, and poor patency of the outflow will also result in access dysfunction. Outflow obstruction is especially common in the AVG at the site of venous graft anastomosis. Furthermore, obstruction beyond the cannulation site of the access can occur in the outflow veins at any point until venous return reaches back to the right atrium. Considering that HD access is always at risk of obstruction in this long circuit, it is important to recognize clinical clues early to be able to potentially intervene before adequate dialysis is compromised or access is lost due to thrombosis.

Good history and PE of dialysis access can indicate problems associated with inflow and outflow abnormalities (►**Tables 2** and **3**).[12] The symptoms of abnormal AV access function can be recognized by trained dialysis care providers. These symptoms are usually easy to recognize, and location of causative lesion ascertained by good PE. Having a working diagnosis and location of lesion can be very helpful in proper referral and planning of intervention as needed, which can prevent failure of access, missed HD, and poor outcomes.

Role of Ultrasound in Dialysis Access Evaluation

Sonographic evaluation of a dysfunctional access should include a thorough assessment of the entire circuit including the anastomosis, the inflow artery, and the peripheral outflow veins, though evaluation of the central veins remains technically challenging. A combination of B-Mode, Color Doppler, and Spectral Doppler is used for qualitative and quantitative assessments. A mature, functional fistula has depth, diameter, and flow measurements that have been

Table 2 Clinical symptoms of abnormal inflow in a hemodialysis AVF or AVG

A	Decreased access flow
B	Decreased hemodialysis adequacy (URR/Kt/V) in the absence of other causative factors
C	Systolic accentuation of bruit on auscultation over the site of AV anastomosis in AVF and arterial anastomosis in AVG
D	Poor filling and pulsations of the outflow vein distal to the site of manual occlusion of AVF with other signs of decreased access flow (normally expected to augment upon compression)
E	High negative arterial pressure during hemodialysis (below −200 mm Hg with 15-gauge needles and a blood flow of ≥400 mL/min
F	Difficult cannulation

Abbreviations: AVF, arteriovenous fistula; AVG, arteriovenous graft; URR, urea reduction ratio; K, dialyzer clearance of urea; t, dialysis time; V, volume of distribution of urea.
Source: Adapted from Haddad et al,[12] with permission.

Table 3 Clinical symptoms of abnormal outflow in a hemodialysis AVF or AVG

A	Decreased access flow
B	Decreased hemodialysis adequacy (URR/Kt/V) without change in dialysis prescription
C	Systolic accentuation of bruit over the outflow vein in AVF and venous anastomosis in AVG
D	Increased pulsation of AVG and the outflow vein distal to the stenotic area in AVF
E	Swelling of the distal limb and site of hemodialysis access because of increased venous pressure
F	Development of collateral veins
G	Prolonged bleeding after cannulation of both AVF and AVG in the absence of excessive/or change in anticoagulation
H	Drawing blood clots from AVG/AVF after cannulation
I	High venous pressure during hemodialysis (>125 mm Hg with the use of 15-gauge needles) at blood flow of 200 mL/min on three successive measurements
J	High negative arterial pressure during hemodialysis with juxta-anastomotic lesions (below −200 mm Hg with 15-gauge needles and a blood flow of ≥400 mL/min
K	Difficult cannulation and infiltration
L	Poorly collapsible AVF with arm elevation

Abbreviations: AVF, arteriovenous fistula; AVG, arteriovenous graft; URR, urea reduction ratio; K, dialyzer clearance of urea; t, dialysis time; V, volume of distribution of urea.
Source: Adapted from Haddad et al,[12] with permission.

previously described as the KDOQI "rule of 6s," which was based on a retrospective study that analyzed 69 patients, in whom adequacy for dialysis was known in 54 patients.[13,14] Fistula adequacy for dialysis doubled if the minimum venous diameter was 0.4 cm or greater, or if flow volume was 500 mL/min or greater. When these two parameters were combined, the predictive value of determining fistula adequacy was 95% as compared with 33% when neither of these criteria was met.

Normal flow through a fistula shows biphasic waveforms and a uniformly enlarged outflow. Abnormal enlargement of the outflow may be differentiated on ultrasound as pseudoaneurysms present with a typical "yin/yang" appearance on Doppler,[15] infections appear as heterogenous fluid collections, and seromas appear as homogeneous fluid collections without evidence of blood flow[16] and management may be adjusted accordingly, based on the pathology seen on ultrasound. Similarly, spectral analysis on ultrasound demonstrating flow reversal in the artery distal to the arterial anastomosis that normalizes to antegrade flow on access occlusion[15] is useful in confirming arterial steal. This is particularly important to recognize prior treatment of a suspected outflow lesion as it may worsen the arterial steal symptoms. Furthermore, a preprocedural ultrasound of a thrombosed access shows echogenic, luminal filling defects on B-Mode and Color Doppler confirms occlusion, though minimal flow can be detected by power Doppler. The extent of thrombus burden is useful in determining the safety of performing thrombectomies in the inpatient versus the outpatient setting.

In conjunction with PE, ultrasonography can also help identify early AVF failure that may be due to inadequate inflow from arterial or juxta-anastomotic stenosis, or late AVF failure secondary to outflow stenosis. Ultrasound characteristics of a stenotic area include a visual narrowing at the stenotic site, more than 50% decrease in luminal diameter, poststenotic dilatation of the draining vein, and an elevated peak systolic flow velocity.[17] In addition to diagnosis, sonography has also been used successfully in the management of these lesions, including intraoperative angioplasty under ultrasound guidance for arterial stenosis,[18] and in ambulatory practices for non-maturing and dysfunctional fistulae.[19,20] Ultrasound-guided interventions are also increasingly being used internationally with postintervention primary and secondary patency rates for these procedures comparable to those performed under fluoroscopic guidance.[21–23]

Accessory veins, another common etiology of early AVF failure, not only can be diagnosed by ultrasound but also may be ligated percutaneously under sonographic guidance.[24] More recently, a pilot study demonstrated that adding intravascular ultrasound to digital subtraction angiography changed management plans in 76% of the patients and increased the median time to reintervention or graft abandonment from 30 days in the control group to 61 days in the test group.[25] To evaluate the benefits and limitations of angioplasty using only ultrasound guidance, a recent prospective study evaluated 132 failing or non-maturing arteriovenous accesses that underwent 189 ultrasound-guided balloon angioplasties. The authors designated a procedure technically successful if the entire procedure was performed using ultrasound alone. 67% of the procedures were successfully completed without fluoroscopy, with failures largely due to difficulty in accessing deep, tortuous, or aneurysmal fistulae, as well as the inability to evaluate and treat central veins.[26]

Conclusion

AV access PE is extremely valuable when providing care to dialysis patients. It is simple and can be performed in short period of time. Therefore, PE should be part of all dialysis care providers' training.

PE is very well complemented by the use of ultrasonography. Advances in technology have led to its use for preprocedural assessment and to guide AV access interventions. The superficial position of the dialysis access coupled with the universal availability of this noninvasive, portable technology that minimizes the need for contrast or radiation has added a unique dimension to the management of HD vascular access.

Conflict of Interest
None declared.

References

1 Kolff WJ. Dialysis in treatment of uremia: artificial kidney and peritoneal lavage. AMA Arch Intern Med 1954;94(01): 142–160
2 Alwall N, Norvitt L, Steins AM. On the artificial kidney; some experiences during the study of dialytic treatment on animals with uremia caused by mercuric chloride poisoning. Acta Med Scand 1949;132(05):477–486
3 Scribner BH, Buri R, Caner JE, Hegstrom R, Burnell JM. The treatment of chronic uremia by means of intermittent hemodialysis: a preliminary report. Trans Am Soc Artif Intern Organs 1960; 6:114–122
4 Brescia MJ, Cimino JE, Appel K, Hurwich BJ. Chronic hemodialysis using venipuncture and a surgically created arteriovenous fistula. N Engl J Med 1966;275(20):1089–1092
5 Baker LD Jr, Johnson JM, Goldfarb D. Expanded polytetrafluoroethylene (PTFE) subcutaneous arteriovenous conduit: an improved vascular access for chronic hemodialysis. Trans Am Soc Artif Intern Organs 1976;22:382–387
6 Depner TA. Techniques for prospective detection of venous stenosis. Adv Ren Replace Ther 1994;1(02):119–130
7 Schwab SJ, Raymond JR, Saeed M, Newman GE, Dennis PA, Bollinger RR. Prevention of hemodialysis fistula thrombosis. Early detection of venous stenoses. Kidney Int 1989;36(04): 707–711
8 Salman L, Beathard G. Interventional nephrology: physical examination as a tool for surveillance for the hemodialysis arteriovenous access. Clin J Am Soc Nephrol 2013;8(07): 1220–1227
9 Asif A, Gadalean FN, Merrill D, et al. Inflow stenosis in arteriovenous fistulas and grafts: a multicenter, prospective study. Kidney Int 2005;67(05):1986–1992
10 Agarwal R, McDougal G. Buzz in the axilla: a new physical sign in hemodialysis forearm graft evaluation. Am J Kidney Dis 2001;38 (04):853–857
11 Leon C, Asif A. Physical examination of arteriovenous fistulae by a renal fellow: does it compare favorably to an experienced interventionalist? Semin Dial 2008;21(06):557–560
12 Haddad NJ, Winoto J, Shidham G, Agarwal AK. Hemodialysis access monitoring and surveillance, how and why? Front Biosci (Elite Ed) 2012;4:2396–2401
13 Robbin ML, Chamberlain NE, Lockhart ME, et al. Hemodialysis arteriovenous fistula maturity: US evaluation. Radiology 2002; 225(01):59–64
14 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
15 Lockhart ME, Robbin ML. Hemodialysis access ultrasound. Ultrasound Q 2001;17(03):157–167
16 Niyyar VD. Ultrasound in dialysis access: opportunities and challenges. J Vasc Access 2020;21(03):272–280
17 Teodorescu V, Gustavson S, Schanzer H. Duplex ultrasound evaluation of hemodialysis access: a detailed protocol. Int J Nephrol 2012;2012:508956
18 Napoli M, Montinaro A, Russo F, et al. Early experiences of intraoperative ultrasound guided angioplasty of the arterial stenosis during upper limb arteriovenous fistula creation. J Vasc Access 2007;8(02):97–102
19 Ascher E, Hingorani A, Marks N. Duplex-guided balloon angioplasty of failing or nonmaturing arterio-venous fistulae for hemodialysis: a new office-based procedure. J Vasc Surg 2009;50 (03):594–599
20 Gorin DR, Perrino L, Potter DM, Ali TZ. Ultrasound-guided angioplasty of autogenous arteriovenous fistulas in the office setting. J Vasc Surg 2012;55(06):1701–1705
21 Kumar S, Mahajan N, Patil SS, et al. Ultrasound-guided angioplasty for treatment of peripheral stenosis of arteriovenous fistula - a single-center experience. J Vasc Access 2017;18(01):52–56
22 Cho S, Lee YJ, Kim SR. Clinical experience with ultrasound guided angioplasty for vascular access. Kidney Res Clin Pract 2017;36 (01):79–85
23 Bojakowski K, Góra R, Szewczyk D, Andziak P. Ultrasound-guided angioplasty of dialysis fistula - technique description. Pol J Radiol 2013;78(04):56–61
24 Cui J, Freed R, Liu F, Irani Z. Interrupting rivaling access-flow with nonsurgical image-guided ligation: the "IRANI" procedure. Semin Dial 2015;28(06):E53–E57
25 Ross JR, Franga DL, Gallichio M, Patel AJ, Ouriel K. Role of intravascular ultrasound imaging during endovascular interventions of failing hemodialysis access grafts. J Vasc Surg 2017;65 (05):1383–1389
26 García-Medina J, García-Alfonso JJ. Ultrasound-guided angioplasty of dysfunctional vascular access for haemodialysis. The pros and cons. Cardiovasc Intervent Radiol 2017;40(05):750–754

