# Dialysis Fistulas

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## Overview

### Introduction

Hemodialysis fistulas are surgically created communications between the native artery and vein in an extremity. Direct communications are called native arteriovenous fistulas (AVFs). Polytetrafluoroethylene (PTFE) and other materials (Dacron, polyurethane, bovine vessels, saphenous veins) are used or have been used as a communication medium between the artery and the vein and are termed prosthetic hemodialysis access arteriovenous grafts (AVGs). The access that is created is routinely used for hemodialysis 2-5 times per week.[1, 2]

Many patients who are not candidates for renal transplantation or those for whom a compatible donor cannot be secured are dependent on hemodialysis for their lifetime. This situation results in the long-term need for and use of dialysis access. The preservation of patent, well-functioning dialysis fistulas is one of the most difficult clinical problems in the long-term treatment of patients undergoing dialysis. As many as 25% of hospital admissions in the dialysis population have been attributed to vascular access problems, including fistula malfunction and thrombosis.

### History of the management of dialysis access

Historically, native fistula or graft malfunction and thrombosis were treated by using surgical thrombectomy and revision, resulting in the eventual exhaustion of the veins and the need to create a new access. Initially applied in the 1980s, percutaneous techniques such as balloon angioplasty (percutaneous transluminal angioplasty [PTA]), thrombolysis, and mechanical thrombectomy allowed the treatment of stenosis and fistula thrombosis without surgery.

In the past 2 decades, interventional radiologists have increasingly been involved in angiographic evaluation and treatment of malfunctioning and occluded hemodialysis access. The multidisciplinary management of dialysis access coordinated among interventional radiologists, vascular surgeons, and nephrologists has proven extremely effective in prolonging the patency of the vascular access and decreasing the morbidity and mortality of patients with chronic renal failure.[3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14]

Examples of a vessel with long-segment stenosis before and after treatment are provided below.

Long-segment outflow vein stenosis before percutaneous transluminal angioplasty.

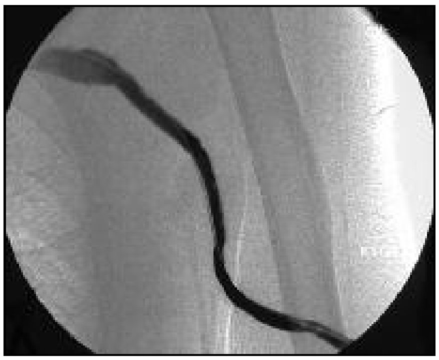


Image obtained after percutaneous transluminal angioplasty in a long-segment stenosis (same patient as in Image above).

## Indications

Less than 15% of dialysis fistulas remain patent and can function without problems during the entire period of a patient's dependence on hemodialysis. The mean problem-free patency period after creation of native fistulas is approximately 3 years, whereas prosthetic polytetrafluoroethylene (PTFE) grafts last 1-2 years before indications of failure or thrombosis are noted. After multiple interventions to treat underlying stenosis and thrombosis, the long-term secondary patency rates for native fistulas are reportedly 7 years for fistulas in the forearm and 3-5 years for fistulas in the upper arm; prosthetic grafts remain patent for up to 2 years.

## Causes of dialysis fistula failures

To the authors' knowledge, all observations and publications reported to date indicate that for prosthetic grafts, fistula failure and eventual occlusion occur most commonly as a result of the progressive narrowing of the venous anastomosis; for native fistulas, failure occurs most commonly as a result of the narrowing of the outflow vein. In some reports, venous anastomosis is identified in more than 90% of grafts. The primary underlying pathophysiologic mechanism responsible for causing the failure is intimal hyperplasia at the anastomotic site. Additional causes include surgical and iatrogenic trauma, such as repeated venipunctures. Stenoses along the venous outflow and in intragraft locations (for prosthetic PTFE grafts) are also common and require appropriate treatment.

## When to consult with an interventional radiologist

The following are indications for consultation with an interventional radiologist:

- Abnormal findings on clinical examination, such as weak thrill or pulsatility
- Direct palpation of stenosis
- Insufficient inflow, such as stenosis in the supplying native artery or proximally in the subclavian or brachiocephalic artery
- Vacuum phenomenon
- Identification of high venous pressures in accordance with the protocol appropriate for the specific type of hemodialysis machine
- Suboptimal blood flow (according to the National Kidney Foundation's Kidney Disease Outcomes Quality

Initiative 1997 guidelines: 700-800 mL/min for prosthetic grafts and 500 mL/min for native fistulas) or recirculation while the patient receives hemodialysis[15]
- Demonstration of stenoses in a previous Doppler ultrasonographic examination
- Ipsilateral arm edema and/or collateral venous pathways suggestive of a central venous stenosis

### Contraindications

The presence of an infection is the only absolute contraindication to angiography and percutaneous treatment of a dysfunctional or thrombosed dialysis access.

## Preparation

### Angiography

Angiographic examination of the entire arteriovenous access from the inflow native artery to the right atrium is undertaken to evaluate a failing hemodialysis access. It is important that all underlying lesions be identified and treated. Even in cases in which a stenosis has been identified on ultrasonograms, additional lesions should be searched for and treated to prevent occlusion and recurrence of access malfunction.

Angiography is performed under sterile conditions after (1) a direct puncture is made in the arterial limb of the graft with the needle pointing toward the venous outflow or (2) a puncture is made in the native vein of the arteriovenous fistula (AVF) just distally to the anastomosis.

This imaging study may be performed by using the outer plastic sheath of a 19-gauge angiocatheter or by using a 4-French (4-F) sheath of a micropuncture set. Arterial anastomosis must always be evaluated, and it is achieved by injecting contrast material via the same access site as described above during a temporary occlusion of the outflow with the use of manual compression or a pressure cuff to allow reflux of contrast agent via the anastomosis into the native artery.

In addition to venous lesions, the arteriovenous anastomosis and the nearby portion of the native artery also should be evaluated. In patients with native AVFs, a direct arterial puncture may be performed to evaluate inflow problems. In certain instances, evaluation to the level of the subclavian and innominate arteries is performed to identify the underlying stenosis.

## Technique

### Percutaneous Transluminal Angioplasty

Percutaneous transluminal angioplasty (PTA) should be performed to treat hemodynamically significant anastomotic and outflow venous lesions and purely arterial inflow stenoses after the fistula is accessed toward the venous and arterial limbs or, in native fistulas, the arteriovenous anastomosis. A hemodynamically significant lesion is usually identified on angiography, because a stenosis causing a decrease in luminal diameter of more than 30% may be accompanied by the formation of collateral blood vessels (see the image below).

Long-segment outflow vein stenosis before percutaneous transluminal angioplasty.

Once identified, most venous lesions can be treated with the use of PTA (see the following image). Results from centers that implemented aggressive surveillance programs and PTA treatment in identified stenoses demonstrated a significant decrease in access graft thrombosis and replacement rates. Patency rates can be prolonged by repeating PTA procedures as required without sacrificing the outflow vein.

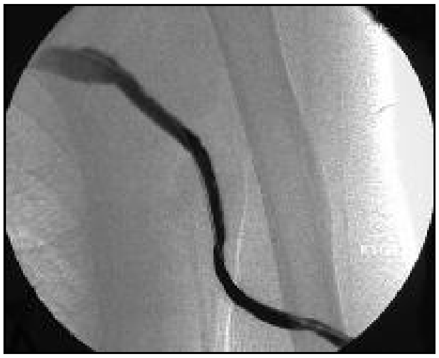


Image obtained after percutaneous transluminal angioplasty in a long-segment stenosis (same patient as in Image above).

## PTA versus surgical intervention

Direct comparisons between PTA and surgical revisions are not easy and are rarely undertaken. The percutaneous approach allows detailed angiographic evaluation of the entire fistula to the right atrium, as well as PTA of identified lesions, during the same session. PTA and stent deployment can be performed in most patients via the initial angiography puncture site of the access and after appropriate dilatation and vascular sheath placement, without surgical incision (see Stent Deployment). A second retrograde puncture (ie, a puncture toward the arteriovenous anastomosis) may be needed to treat stenoses close to the anastomosis of native fistulas.

Treatment may be performed in an outpatient setting; the access may be used for hemodialysis immediately after the procedure.

## Stent Deployment

Although a variety of stents are available, self-expanding stents are generally preferred for the treatment of dialysis access stenosis because of their flexibility and radial force. Most interventional radiologists agree that a stent is indicated to treat PTA-related flow-limiting ruptures or dissections that persist after prolonged local balloon inflation. Relative indications, such as recoil of a previously successfully treated stenosis by PTA, should be treated after a discussion with the vascular surgeon and after the surgical options and possible future access sites are evaluated.

Stent placement is contraindicated in patients with PTA-resistant stenoses.[16, 17]

## Central vein occlusion

The discrepancy between the reported results after stent deployment in the central veins and the observed stenosis recurrence in the stent or at its edges makes the systematic use of stents in the central vein questionable. The patency of a given vascular access is thus prolonged significantly, although most published reports indicate that this is the result of multiple procedures that are required after stent deployment to maintain good fistula function.

## Catheter-Directed Thrombolysis

Thrombosis of dialysis access is an unfortunate but common event in patients with grafts who undergo long-term dialysis; in native fistulas, this complication occurs more rarely. Thrombosis is the result of progressive narrowing in one of multiple sites in the arteriovenous shunt and its pathway to the right atrium.

Historically, temporary hemodialysis catheter placement and/or surgical thrombectomy with hospital admission were the only available treatments. Typically, with surgical treatment, a portion of the outflow vein is sacrificed. Repeated surgical revisions soon exhaust the available sites for peripheral access, exasperating patients and physicians alike. In more recent years, a growing number of institutions provide percutaneous treatment on an outpatient basis, generally within 24 hours of the event.

The consequences of thrombosis of hemodialysis access with regard to patients' quality of life, public health concerns, and society in general are well known. The advantages of percutaneous radiologic interventions for the surveillance and treatment of the failing access also apply to clotted grafts and fistulas.

Angiography is performed to evaluate the condition of the outflow to the right atrium (and, for native fistulas, inflow) before any attempt is made to recanalize an occluded access. The entire recanalization procedure is completed within hours, after which the patient can be discharged and the access used immediately for dialysis. Perhaps the most valuable benefit of percutaneous declotting is the preservation of the entire outflow vein. Repeated procedures can be performed to preserve access patency.

## Pulsed-spray thrombolysis

Many percutaneous techniques with comparable results have been described in the treatment of hemodialysis access occlusion. One of the first and most commonly performed techniques is pulsed-spray thrombolysis (PST) with urokinase (UK) and PTA. The technique underwent several modifications, which mostly shortened the initial procedure time to less than 2 hours and decreased the overall amount of thrombolytic agent needed. However, since the disappearance of UK from the US market in 1999, different forms of tissue plasminogen activator (t-PA) have been used in PST, with similar results.[18, 19, 20, 21, 22, 23, 24, 25, 26]

Additional recanalization techniques include balloon thrombectomy and thromboaspiration, PST with sodium chloride solution and heparin, and the use of a series of mechanical thrombectomy devices.[27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44]

## Procedure

The graft is accessed in a crisscross manner.

Using a micropuncture 21-gauge needle, the graft in the arterial limb is initially entered, pointing toward the venous outflow. Over a 0.018-inch (in) Cope Mandril wire, the needle is exchanged for the introducer sheath of a micropuncture set. Initially, venous outflow is evaluated to confirm patency. If outflow is occluded, an attempt is made to pass a wire and, subsequently, a catheter to evaluate outflow. When adequate outflow is documented, PST or mechanical thrombectomy is initiated.

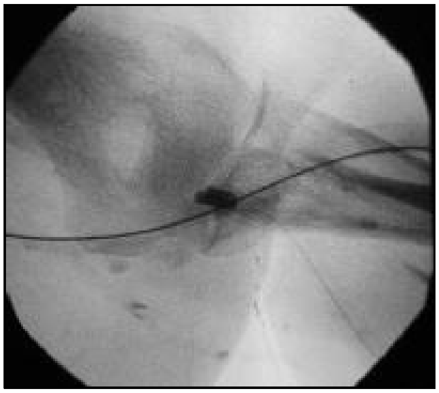
Thrombolysis can be performed before evaluating the outflow. One method for evaluating outflow is the lyse-and-wait technique, in which the thrombolytic agent is administered while the patient waits for the angiography suite to become available.[45] At least in theory, outflow patency reduces the risk of arterial emboli during the thrombolysis or thrombectomy procedure, which is performed within the graft, because outflow patency allows the thrombus to enter the venous outflow rather than move via reflux into the native artery.

Using a micropuncture set as described above, a second puncture is then made in the venous limb of the graft, pointing toward the arterial anastomosis. A 0.035-in wire is advanced in the arterial limb. Care is taken to avoid forcing the wires and catheters via the arterial anastomosis into the native artery, so as to prevent inadvertent arterial embolization.

A 5-French (5-F) multiside-slit pulse-spray infusion catheter of appropriate length for the graft (5-20 cm available) is placed over the 0.035-in wires in a crisscross manner. The tip of the venous catheter is advanced just past the venous anastomosis in the outflow vein. The second infusion catheter is placed over the 0.035-in wire in the arterial limb, with the tip positioned near but not across the arterial anastomosis. In cases involving straight and short grafts, thrombolysis via only the venous catheter is effective.

When thrombolysis or thrombectomy has been completed in both limbs of the graft, contrast-enhanced venography of the entire venous outflow to the right atrium is performed. At this point, all sites of stenosis can be identified in a pattern of distribution similar to that for stenoses associated with patent failing grafts. In more than 85% of reported cases, a venous anastomotic lesion requiring PTA is present. As a rule, such lesions are the result of intimal hyperplasia; therefore, these lesions are particularly firm and resistant. A high-pressure balloon is used routinely, with good results.

At the end of thrombolysis and mechanical thrombectomy and after the confirmation of venous outflow patency, the arterial anastomosis is addressed. Typically, a residual arterial plug is present and must be dislodged. This plug is resistant to thrombolysis, because it consists of impacted erythrocytes and fibrin (white clot). Dislodgement is usually achieved by performing a Fogarty-type balloon embolectomy, during which the balloon is advanced into the native artery via the arterial-limb directed access in the graft. Subsequently, the balloon is retracted from the graft in a retrograde manner. Some use thromboaspiration or a percutaneous thrombectomy device (PTD) to treat the arterial plug. See the following images.


Dislodgement of arterial plug w ith the use of a Fogarty balloon.


Patent loop of arteriovenous graft after successful thrombolysis, w hich included percutaneous transluminal angioplasty of venous anastomosis and dislodgement of arterial plug.

At this point, inflow to the graft is established; a palpable thrill is usually present over the graft as a result of fast blood flow. The recanalization procedure is usually complete at this point. The procedure requires 60-120 minutes to perform.

If no thrill is present, inflow is reevaluated, and the Fogarty balloon embolectomy or another maneuver is repeated as needed. Rarely, a lesion is present in the native artery or in the arterial anastomosis; in such cases, PTA with an appropriate-sized balloon is effective.

If arterial inflow demonstrates no disease at this point and if flow via the graft remains inadequate, the venous track is reevaluated to identify recurrent stenoses.

The presence of stenosis at the same location as a lesion that was previously treated with PTA is an indication for endovascular stent placement after PTA. Stent deployment is performed on an individual basis after conferring with the referring vascular surgeon, bearing in mind the best interest of each particular patient.[46]

# Post-Procedure

## Results

Most series define success as complete recanalization of the thrombosed graft such as to allow at least 1 successful dialysis session within 24 hours of the procedure. Success rates reported in the literature have been similar, ranging from 71% to 100%. Long-term results of graft recanalization are usually evaluated by calculating primary and secondary patency rates from Kaplan-Meier life tables.

## Patency rates

The primary patency rate is defined as the time between the initial procedure and a second procedure that is needed to preserve graft patency. Overall results show primary patency rates of more than 32% at 30 days, more than 30% at 6 months, and less than 25% at 1 year.

Secondary patency rate refers to the cumulative time from the initial procedure to the abandonment of the graft or a surgical revision. Reported secondary patency rates have been significantly higher than primary rates, reaching more than 90% at 30 days, more than 80% at 6 months, as high as 80% at 1 year, and slowly decreasing thereafter.

It is noteworthy that success rates are similar for prosthetic polytetrafluoroethylene (PTFE) grafts and forearm native fistulas, although most interventional radiologists agree that declotting a native fistula is technically more challenging than declotting a graft. In addition, the results clearly appear to be more durable after recanalization of a forearm native fistula, although repeat intervention is much more common for prosthetic grafts and upper-arm fistulas.

## Nonsurgical versus surgical interventions

Technologic progress in the field of interventional radiology and device manufacturing has allowed a large number of procedures to be performed without open surgery. One of the fields in which this approach has flourished is the treatment of failing and thrombosed dialysis access. Direct comparison with the surgical treatment of graft thrombosis is not easy, and when patency rates are involved, the comparison is meaningless, because the surgical literature determines patency from the time of graft placement or fistula creation, whereas assessment of nonsurgical interventional procedures begins from the point of failure or thrombosis. Very few small, randomized trials have been conducted comparing the results and failures of nonsurgical interventions and surgical procedures.

With the exception of certain stent locations, most nonsurgical interventional procedures do not prohibit future surgical revision if and when needed. Nonsurgical procedures can also be used to recanalize the access site without sacrificing any fragment of the venous outflow, thereby prolonging the use and overall life of the access.

Several percutaneous techniques have been studied, with comparable results. In the literature, sufficient evidence has proven that nonsurgical interventional treatment of hemodialysis access failure and thrombosis provides good and durable results when performed by experienced operators. This assessment has been supported by the US National Kidney Foundation's Kidney Disease Outcomes Quality Initiative guidelines for graft maintenance.

## Complications

Overall complication rates are low—typically, 0-16%. Complications include arterial emboli (1-7%); post–percutaneous transluminal angioplasty (PTA) flow-compromising ruptures (2-5%; the rate can be higher in native fistulas of upper arm [15%]); fluid overload or pulmonary edema; reactions to the contrast agent; extravasation hematomas at puncture sites of previous dialysis procedures; infection; and death (very rare). Death may result from cardiac arrhythmia, pulmonary edema, or a reaction to the contrast medium.[47]

Although clots may migrate into pulmonary circulation, clinically evident pulmonary embolism has been reported in only 6 cases; however, pulmonary embolism may occur with native fistulas. This complication is extremely rare during thrombolysis of hemodialysis access grafts.

## Management of complications

Most complications are treated by the interventional radiologist during the procedure. Arterial emboli are retrieved with an embolectomy or with the use of a Fogarty balloon thromboaspiration, or they are treated with local infusion of a thrombolytic agent (urokinase [UK] or tissue plasminogen activator [t-PA]). Although there is a theoretical risk of serious complications during thrombolysis with any of the thrombolytic agents (UK, streptokinase, t-PA), life-threatening bleeding complications are extremely rare.

Post-PTA ruptures have been treated successfully with prolonged balloon inflation and the deployment of uncovered and, more recently, covered stents, as needed. If needed, stent deployment may be used to keep the pathway toward the right atrium patent. These options usually allow completion of the procedure and salvage of the arteriovenous graft or native fistula.

Fluid overload and pulmonary edema can be avoided by providing hemodialysis via a temporary catheter in all patients who do not undergo dialysis for more than 72 hours before the recanalization procedure. When fluid overload occurs during or after the procedure, it can be treated medically with appropriate methods, including oxygen therapy and the administration of diuretics.[48]

## Conclusion

With the advent of new devices and the continuous improvement of existing devices, the percutaneous treatment of failing and occluded dialysis access will continue to improve in the future. The role of the interventional radiologist is changing. The radiologist's role has changed from that of an angiographer who makes the diagnosis into that of a physician who treats patients with chronic renal failure in coordination with the nephrologist and the vascular surgeon.

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## References

1. Maya ID, Oser R, Saddekni S, Barker J, Allon M. Vascular access stenosis: comparison of arteriovenous grafts and fistulas. *Am J Kidney Dis*. Nov 2004;44(5):859-65. [Medline].
2. Gomes A, Schmidt R, Wish J. Re-envisioning Fistula First in a Patient-Centered Culture. *Clin J Am Soc Nephrol*. Jun 6 2013;[Medline].
3. Burger H, Kootstra G, de Charro F, Leffers P. A survey of vascular access for haemodialysis in The Netherlands. *Nephrol Dial Transplant*. 1991;6(1):5-10. [Medline].
4. Sharafuddin MJ, Kadir S, Joshi SJ, Parr D. Percutaneous balloon-assisted aspiration thrombectomy of clotted hemodialysis access grafts. *J Vasc Interv Radiol*. Mar-Apr 1996;7(2):177-83. [Medline].
5. Himmelfarb J, Saad T. Hemodialysis vascular access: emerging concepts. *Curr Opin Nephrol Hypertens*. Nov 1996;5(6):485-91. [Medline].
6. Rodriguez JA, Armadans L, Ferrer E, Olmos A, Codina S, Bartolomé J, et al. The function of permanent vascular access. *Nephrol Dial Transplant*. Mar 2000;15(3):402-8. [Medline].
7. Turmel-Rodrigues L, Pengloan J, Rodrigue H, Brillet G, Lataste A, Pierre D, et al. Treatment of failed native arteriovenous fistulae for hemodialysis by interventional radiology. *Kidney Int*. Mar 2000;57(3):1124-40. [Medline].
8. Turmel-Rodrigues L, Pengloan J, Baudin S, Testou D, Abaza M, Dahdah G, et al. Treatment of stenosis and thrombosis in haemodialysis fistulas and grafts by interventional radiology. *Nephrol Dial Transplant*. Dec 2000;15(12):2029-36. [Medline].
9. Overbosch EH, Pattynama PM, Aarts HJ, Schultze Kool LJ, Hermans J, Reekers JA. Occluded hemodialysis shunts: Dutch multicenter experience with the hydrolyser catheter. *Radiology*. Nov 1996;201(2):485-8. [Medline].
10. Windus DW. Permanent vascular access: a nephrologist's view. *Am J Kidney Dis*. May 1993;21(5):457-71. [Medline].
11. Winkler TA, Trerotola SO, Davidson DD, Milgrom ML. Study of thrombus from thrombosed hemodialysis

access grafts. *Radiology*. Nov 1995;197(2):461-5. [Medline].

12. Ethier J, Mendelssohn DC, Elder SJ, Hasegawa T, Akizawa T, Akiba T, et al. Vascular access use and outcomes: an international perspective from the Dialysis Outcomes and Practice Patterns Study. *Nephrol Dial Transplant*. Oct 2008;23(10):3219-26. [Medline]. [Full Text].
13. Besarab A. Resolved: Fistulas are preferred to grafts as initial vascular access for dialysis. Pro. *J Am Soc Nephrol*. Sep 2008;19(9):1629-31. [Medline].
14. Galic G, Kvesic A, Tomic M, Rebac Z, Brekalo Z, Martinovic V, et al. The advantages of end-to-side arteriovenous anastomosis over the other two types of arteriovenous anastomosis in dialysis patients. *Coll Antropol*. Mar 2008;32(1):109-14. [Medline].
15. Aruny JE, Lewis CA, Cardella JF, Cole PE, Davis A, Drooz AT, et al. Quality improvement guidelines for percutaneous management of the thrombosed or dysfunctional dialysis access. Standards of Practice Committee of the Society of Cardiovascular & Interventional Radiology. *J Vasc Interv Radiol*. Apr 1999;10(4):491-8. [Medline].
16. Pan HB, Liang HL, Lin YH, Chung HM, Wu TH, Chen CY, et al. Metallic stent placement for treating peripheral outflow lesions in native arteriovenous fistula hemodialysis patients after insufficient balloon dilatation. *AJR Am J Roentgenol*. Feb 2005;184(2):403-9. [Medline].
17. Patel RI, Peck SH, Cooper SG, Epstein DM, Sofocleous CT, Schur I, et al. Patency of Wallstents placed across the venous anastomosis of hemodialysis grafts after percutaneous recanalization. *Radiology*. Nov 1998;209(2):365-70. [Medline].
18. Falk A, Mitty H, Guller J, Teodorescu V, Uribarri J, Vassalotti J. Thrombolysis of clotted hemodialysis grafts with tissue-type plasminogen activator. *J Vasc Interv Radiol*. Mar 2001;12(3):305-11. [Medline].
19. Cooper SG, Falk A, Sofocleous CT, Schur I, Patel RI, Peck SH. Vascular Access for Hemodialysis. In: Henry ML, Ferguson RM, eds. *Modified pulse-spray pharmacomechanical thrombolysis technique: review of 278 procedures*. Chicago, Ill: Precept Press; 1997:172-7.
20. Kinney TB, Valji K, Rose SC, Yeung DD, Oglevie SB, Roberts AC, et al. Pulmonary embolism from pulse-spray pharmacomechanical thrombolysis of clotted hemodialysis grafts: urokinase versus heparinized saline. *J Vasc Interv Radiol*. Oct 2000;11(9):1143-52. [Medline].
21. Polak JF, Berger MF, Pagan-Marin H, Aruny JE, Meyerovitz MF. Comparative efficacy of pulse-spray thrombolysis and angioplasty versus surgical salvage procedures for treatment of recurrent occlusion of PTFE dialysis access grafts. *Cardiovasc Intervent Radiol*. Jul-Aug 1998;21(4):314-8. [Medline].
22. Roberts AC, Valji K, Bookstein JJ, Hye RJ. Pulse-spray pharmacomechanical thrombolysis for treatment of thrombosed dialysis access grafts. *Am J Surg*. Aug 1993;166(2):221-5; discussion 225-6. [Medline].
23. Sofocleous CT, Cooper SG, Schur I, Patel RI, Iqbal A, Walker S. Retrospective comparison of the Amplatz thrombectomy device with modified pulse-spray pharmacomechanical thrombolysis in the treatment of thrombosed hemodialysis access grafts. *Radiology*. Nov 1999;213(2):561-7. [Medline].
24. Trerotola SO. Pulse-spray thrombolysis of hemodialysis grafts: not the final word. *AJR Am J Roentgenol*. 1995;164:1501-3.
25. Trerotola SO, Vesely TM, Lund GB, Soulen MC, Ehrman KO, Cardella JF. Treatment of thrombosed hemodialysis access grafts: Arrow-Trerotola percutaneous thrombolytic device versus pulse-spray thrombolysis. Arrow-Trerotola Percutaneous Thrombolytic Device Clinical Trial. *Radiology*. Feb 1998;206(2):403-14. [Medline].
26. Valji K, Bookstein JJ, Roberts AC, Oglevie SB, Pittman C, O'Neill MP. Pulse-spray pharmacomechanical thrombolysis of thrombosed hemodialysis access grafts: long-term experience and comparison of original and current techniques. *AJR Am J Roentgenol*. Jun 1995;164(6):1495-500; discussion 1501-3. [Medline].
27. Beathard GA, Welch BR, Maidment HJ. Mechanical thrombolysis for the treatment of thrombosed

hemodialysis access grafts. *Radiology*. Sep 1996;200(3):711-6. [Medline].

28. Middlebrook MR, Amygdalos MA, Soulen MC, Haskal ZJ, Shlansky-Goldberg RD, Cope C, et al. Thrombosed hemodialysis grafts: percutaneous mechanical balloon declotting versus thrombolysis. *Radiology*. Jul 1995;196(1):73-7. [Medline].

29. Soulen MC, Zaetta JM, Amygdalos MA, Baum RA, Haskal ZJ, Shlansky-Goldberg RD. Mechanical declotting of thrombosed dialysis grafts: experience in 86 cases. *J Vasc Interv Radiol*. Jul-Aug 1997;8(4):563-7. [Medline].

30. Swan TL, Smyth SH, Ruffenach SJ, Berman SS, Pond GD. Pulmonary embolism following hemodialysis access thrombolysis/thrombectomy. *J Vasc Interv Radiol*. Sep-Oct 1995;6(5):683-6. [Medline].

31. Trerotola SO, Lund GB, Scheel PJ Jr, Savader SJ, Venbrux AC, Osterman FA Jr. Thrombosed dialysis access grafts: percutaneous mechanical declotting without urokinase. *Radiology*. Jun 1994;191(3):721-6. [Medline].

32. Turmel-Rodrigues L, Sapoval M, Pengloan J, Billaux L, Testou D, Hauss S, et al. Manual thromboaspiration and dilation of thrombosed dialysis access: mid-term results of a simple concept. *J Vasc Interv Radiol*. Sep-Oct 1997;8(5):813-24. [Medline].

33. Uflacker R, Rajagopalan PR, Vujic I, Stutley JE. Treatment of thrombosed dialysis access grafts: randomized trial of surgical thrombectomy versus mechanical thrombectomy with the Amplatz device. *J Vasc Interv Radiol*. Mar-Apr 1996;7(2):185-92. [Medline].

34. Valji K, Bookstein JJ, Roberts AC, Davis GB. Pharmacomechanical thrombolysis and angioplasty in the management of clotted hemodialysis grafts: early and late clinical results. *Radiology*. Jan 1991;178(1):243-7. [Medline].

35. Zaetta JM, Baum RA, Haskal ZJ, Shlansky-Goldberg RD, Soulen MC. Thrombosed dialysis grafts: percutaneous mechanical declotting using a central venous approach. *J Vasc Interv Radiol*. Sep-Oct 1998;9(5):833-6. [Medline].

36. Dougherty MJ, Calligaro KD, Schindler N, Raviola CA, Ntoso A. Endovascular versus surgical treatment for thrombosed hemodialysis grafts: A prospective, randomized study. *J Vasc Surg*. Dec 1999;30(6):1016-23. [Medline].

37. Falk A, Guller J, Nowakowski FS, Mitty H, Teodorescu V, Uribarri J, et al. Reteplase in the treatment of thrombosed hemodialysis grafts. *J Vasc Interv Radiol*. Nov 2001;12(11):1257-62. [Medline].

38. Farner MC. Regarding "Endovascular versus surgical treatment for thrombosed hemodialysis: a prospective, randomized study". *J Vasc Surg*. Nov 2000;32(5):1038-9. [Medline].

39. Marston WA, Criado E, Jaques PF, Mauro MA, Burnham SJ, Keagy BA. Prospective randomized comparison of surgical versus endovascular management of thrombosed dialysis access grafts. *J Vasc Surg*. Sep 1997;26(3):373-80; discussion 380-1. [Medline].

40. Beathard GA. Mechanical versus pharmacomechanical thrombolysis for the treatment of thrombosed dialysis access grafts. *Kidney Int*. May 1994;45(5):1401-6. [Medline].

41. Turmel-Rodrigues LA, Beyssen B, Raynaud A, Sapoval M. Thromboaspiration to treat inadvertent arterial emboli during dialysis graft declotting. *J Vasc Interv Radiol*. Sep-Oct 1998;9(5):849-50. [Medline].

42. Sofocleous CT, Hinrichs CR, Weiss SH, Contractor D, Barone A, Bahramipour P, et al. Alteplase for hemodialysis access graft thrombolysis. *J Vasc Interv Radiol*. Aug 2002;13(8):775-84. [Medline].

43. Dolmatch BL, Gray RJ, Horton KM. Will iatrogenic pulmonary embolization be our pulmonary embarrassment?. *Radiology*. Jun 1994;191(3):615-7; discussion 618. [Medline].

44. Valji K. Transcatheter treatment of thrombosed hemodialysis access grafts. *AJR Am J Roentgenol*. Apr 1995;164(4):823-9. [Medline].

45. Cynamon J, Lakritz PS, Wahl SI, Bakal CW, Sprayregen S. Hemodialysis graft declotting: description of the "lyse and wait" technique. *J Vasc Interv Radiol*. Sep-Oct 1997;8(5):825-9. [Medline].

46. Welber A, Schur I, Sofocleous CT, Cooper SG, Patel RI, Peck SH. Endovascular stent placement for angioplasty-induced venous rupture related to the treatment of hemodialysis grafts. *J Vasc Interv Radiol*. May 1999;10(5):547-51. [Medline].

47. Borzumati M, Funaro L, Mancini E, Resentini V, Baroni A. Survival and complications of arteriovenous fistula dialysis access in an elderly population. *J Vasc Access*. Apr 18 2013;0(0):0. [Medline].

48. Sofocleous CT, Schur I, Koh E, Hinrichs C, Cooper SG, Welber A, et al. Percutaneous treatment of complications occurring during hemodialysis graft recanalization. *Eur J Radiol*. Sep 2003;47(3):237-46. [Medline].