

Quality Improvement Guidelines for Percutaneous Management of the Thrombosed or Dysfunctional Dialysis Access

John E. Aruny, MD, Curtis A. Lewis, MD, John F. Cardella, MD, Patricia E. Cole, PhD, MD, Andrew Davis, MD, Alain T. Drooz, MD, Clement J. Grassi, MD, Richard J. Gray, MD, James W. Husted, MD, Michael Todd Jones, MD, Timothy C. McCowan, MD, Steven G. Meranze, MD, A. Van Moore, MD, Calvin D. Neithamer, MD, Steven B. Oglevie, MD, Reed A. Omary, MD, Nilesh H. Patel, MD, Kenneth S. Rholl, MD, Anne C. Roberts, MD, David Sacks, MD, Orestes Sanchez, MD, Mark I. Silverstein, MD, Harjit Singh, MD, Timothy L. Swan, MD, Richard B. Towbin, MD, Scott O. Trerotola, MD, Curtis W. Bakal, MD, MPH, for the Society of Interventional Radiology Standards of Practice Committee

J Vasc Interv Radiol 2003; 14:S247-S253

PERCUTANEOUS management of hemodialysis access grafts and fistulas is a complementary treatment alternative to surgical thrombectomy and revision (1). Successful declotting procedures with thrombolysis (2-8), suction thrombectomy (9), mechanical thrombectomy (10,11), or balloon thrombectomy (12,13) are being performed. An integral part of this procedure includes the performance of angiography of the graft or fistula and its arterial inflow and venography of the draining veins to the level of the superior vena cava-right atrial junction. This is performed with either conventional film screen (14) or digital techniques (15). The results are used to locate the stenosis(es) that can be implicated as the anatomic etiology of access failure. Stenoses can be treated with balloon angioplasty (2-4,13, 16-23), endovascular stents (24-31), and, in selected instances atherectomy (19,32) to restore the luminal diameter to a functional state. These procedures frequently are the initial treatment for thrombosed dialysis access. It is now recognized that percutaneous intervention with transluminal angioplasty is

the preferred treatment of central vein stenosis (1).

The procedure is usually performed on an outpatient basis with the patient being able to return immediately home or to the dialysis unit for treatment. Percutaneous management results in reduced morbidity compared to standard surgical therapy with reduced postprocedure pain and wound edema.

Participation of the interventional radiologist with the dialysis team in patient follow-up is an integral part of percutaneous hemodialysis access management. This workgroup supports the statement of the National Kidney Foundation Dialysis Outcomes Quality Initiative (DOQI) that "Management of vascular access complications relies on a multidisciplinary approach involving nephrologists, nephrology nurses, vascular interventionists, and surgeons. The goal of these management efforts is the preservation of vascular access" (1). This close follow-up, with monitoring and management of the patient in the dialysis unit after the procedure can help prevent rethrombosis. Regularly scheduled multidisciplinary conferences are suggested as an excellent way to provide optimum care of patients with vascular access complications. If the clinical and hemodynamic parameters become abnormal, the patient should undergo repeated angiog-

raphy and venography to reevaluate the access for the presence of recurrent stenosis requiring subsequent reintervention (1).

These guidelines are written to be used in quality improvement programs to assess percutaneous management procedures for dialysis accesses. The most important processes of care are (a) patient selection, (b) performing the procedure, and (c) monitoring the patient. The outcome measures or indicators for these processes are indications, success rates, and complication rates. Outcome measures are assigned threshold levels.

DEFINITIONS

A *thrombosed dialysis access* is defined as either a native fistula or synthetic graft that contains occlusive thrombus and has no significant blood flow. Thrombus may extend into the runoff veins or inflow arteries. The diagnosis of a thrombosed access is most frequently made by physical examination.

A *dysfunctional dialysis access* is defined as (a) an access that has a hemodynamically significant stenosis, or (b) a native fistula that has failed to mature during an adequate time period, or (c) an access that cannot be successfully punctured to perform dialysis.

A *functionally significant stenosis* is defined as a >50% reduction of normal vessel diameter (graft or draining venous system) accompanied by a he-

This article first appeared in J Vasc Interv Radiol 1999; 10:491-498.

From the Society of Interventional Radiology, 10201 Lee Highway, Suite 500, Fairfax, VA 22030.

© SIR, 2003

DOI: 10.1097/01.RVI.0000094593.83406.45

modynamic or clinical abnormality, such as:

1. Abnormal recirculation values of 10% (two needle urea-based method) or 5% (nonurea-based dilutional method) (1). Recirculation should be performed as per DOQI protocol (see Appendix A).
2. Elevated venous pressures recorded during dialysis (static and dynamic pressures) or measured within the graft during a diagnostic study (static pressures). Dynamic pressures are measured as per DOQI protocol (see Appendix B).
3. Detection of decreased blood flow.
4. Swollen extremity.
5. Unexplained reduction in Kt/V.
6. Various clinical parameters such as: prolonged bleeding after needle withdrawal, altered characterization of pulses or thrill in the graft or thrombosis of the access.
7. Elevated negative arterial pre-pump pressures that prevent increasing to acceptable blood flow.

Percutaneous management of thrombosed or dysfunctional dialysis access grafts and fistulas is defined as the use of catheter-based endovascular techniques to restore or maintain adequate blood flow within the access to support effective hemodialysis. Percutaneous techniques have been shown to be effective in treating an access that has thrombosed or that is dysfunctional. Prospective intervention is currently unwarranted for anatomical stenoses found in arteriovenous grafts and draining veins without an associated hemodynamic or clinical abnormality.

Causes of dialysis access failure may be divided into anatomic and physiologic categories.

An anatomic cause of dialysis access dysfunction or thrombosis is defined as any arterial or venous abnormality responsible for unacceptable access function.

Examples of anatomic causes include:

1. Venous anastomotic stenosis of synthetic grafts.
2. Intragraft stenoses within synthetic grafts.
3. Stenosis at or around the anas-

tomotic site of a native arteriovenous fistula access.

4. Stenoses of the venous runoff from the venous anastomosis to the central veins.
5. Central vein stenosis that may occur after the placement of a central venous catheter ipsilateral to the site of the access.
6. Intragraft stenosis or stenoses of the hypertrophied venous segment of a native fistula.
7. In the case of the native fistula, multiple venous runoff channels may prevent the development of a hypertrophied vein suitable for puncture (failure to mature) (1).
8. Stenosis of the inflow artery proximal to the access.
9. Extrinsic compression. The great majority of anatomic causes are intrinsic to the graft or vessel. However, rarely, extrinsic compression can contribute to access dysfunction (eg, synthetic graft kinking, pseudoaneurysm compression of the access or compression from a periaxillary hematoma).
10. Arterial anastomotic stenosis of synthetic grafts.

A physiologic cause of dialysis access failure is defined as a process that can result in thrombosis of the dialysis access in the absence of an anatomic cause. A physiologic cause of dialysis access failure may have a synergistic effect with anatomic causes to accelerate failure of the dialysis access.

Examples of physiologic causes include:

1. Hypercoagulable states.
2. Low cardiac output states including postdialysis hypotension.

A diagnostic angiogram/venogram (fistulogram) is defined as one that thoroughly visualizes the dialysis access from the arterial anastomosis of a graft or fistula connection through the runoff veins to the superior vena cava-right atrial junction. This should include multiple oblique views of a suspected problematic segment and more extensive visualization of the proximal arteries if inadequate inflow is suspected.

Percutaneous thrombus removal is defined as the removal of occlusive thrombus from within the graft or native fistula, including the outflow

veins and inflow arteries to restore blood flow to the access. Removal of thrombus may be accomplished by any of several percutaneous catheter-directed methods, such as thrombolysis, suction thrombectomy, balloon thrombectomy, clot maceration, or mechanical thrombectomy.

Percutaneous treatment of a stenosis is defined as the restoration of an acceptable luminal diameter to the segment (anatomic success) and resolution of the functional abnormality (1). Stenoses may be treated with balloon angioplasty. In selective instances stents or directional atherectomy may be required to maintain patency.

Anatomic success of a treated stenosis is defined as less than a 30% residual diameter stenosis. For treatment of thrombosed accesses, restoration of flow combined with a less than 30% residual diameter stenosis for any significant underlying stenosis are both required to report anatomic success (33).

Clinical success after treatment of a thrombosed access is defined as the resumption of normal dialysis for at least one session. After treatment of a stenosis, clinical success is defined as the improvement of clinical and hemodynamic parameters. After treatment of either a thrombosed dialysis graft or a graft-related stenosis, a continuous palpable thrill (no pulse) extending from the arterial anastomosis can be considered one indicator of clinical success (33).

Hemodynamic success is defined as the restoration of hemodynamic parameters. Reduction of venous dialysis pressures to below predefined threshold values can be considered evidence of hemodynamic success. It is the true intraaccess static pressure that correlates with the degree of stenosis. Therefore, a reduction of static intragraft systolic pressure/cuffed brachial systolic pressure ratios to below predefined thresholds can be considered evidence of hemodynamic success. Measurement of intragraft pressures to determine the hemodynamic significance of stenoses has been described by Sullivan and Besarab (see Appendix C). This study used a ratio of 0.4 to give a 91% sensitivity of identifying synthetic access graft stenoses of at least 50% (34). However, it should be recognized that there are currently no uniformly accepted criteria of percent

reduction from pretreatment values to determine hemodynamic success (33).

Procedural success is defined as anatomic success and at least one indicator of hemodynamic or clinical success (33).

Primary patency is defined as the uninterrupted patency after intervention until the next access thrombosis or re-intervention. Primary patency ends with treatment of a lesion anywhere within the access circuit, from the arterial inflow to the superior vena cava-right atrial junction (33).

Assisted primary patency is defined as patency after intervention until the access thromboses or a surgical intervention that excludes the treated lesion from the access circuit. Percutaneous re-treatments of restenosis or a new arterial or venous outflow stenosis/occlusion (excluding access thrombosis) are compatible with assisted primary patency. Assisted primary patency ends with percutaneous thrombolysis/ thrombectomy or simple surgical thrombectomy (33).

Secondary patency after intervention is defined as patency until the access is surgically declotted, revised, or abandoned by surgeon, renal transplant, loss to follow-up, and so forth. Thrombolysis and percutaneous thrombectomy are compatible with secondary patency, as are multiple repetitive treatments (33).

Cumulative patency is defined as the total time that the access remains patent (regardless of number of primary interventions and /or thrombectomies) during the given time period. Cumulative patency begins at the time that the graft is first placed (1).

A *mature arteriovenous fistula* is defined as a fistula suitable for use when the diameter of the vein is sufficient to allow successful cannulation, but not sooner than 1 month (and preferably 3–4 months) after construction (1).

While practicing physicians should strive to achieve perfect outcomes (eg, 100% success, 0% complications), in practice all physicians will fall short of this ideal to a variable extent. Therefore, indicator thresholds may be used to assess the efficacy of ongoing quality improvement programs. For the purpose of these guidelines, a threshold is a specific level of an indicator that should prompt a review. "Procedure thresholds" or "overall thresholds" reference a group of indicators for a procedure (eg,

major complications of percutaneous management of thrombosed or dysfunctional dialysis access). Individual complications may also be associated with complication-specific thresholds. When measures such as indications or success rates fall below a (minimum) threshold, or when complication rates exceed a (maximum) threshold, a review should be performed to determine causes and to implement changes, if necessary. Thresholds may vary from those listed here. For example, patient referral patterns and selection factors may dictate a different threshold value for a particular indicator at a particular institution. Therefore, setting universal thresholds is very difficult and each department is urged to alter the thresholds as needed to higher or lower values to meet its own quality improvement program needs.

Complications can be stratified on the basis of outcome. Major complications result in admission to a hospital for therapy (for outpatient procedures), an unplanned increase in the level of care, prolonged hospitalization, permanent adverse sequelae, or death. Minor complications result in no sequelae; they may require nominal therapy or a short hospital stay for observation (generally overnight) (see Appendix D). The complication rates and thresholds below refer to major complications.

INDICATIONS

Treatment of stenoses without thrombosis that occur in a dialysis graft or native fistula should be treated with percutaneous techniques if the stenosis is >50% of the lumen diameter and is considered functionally significant (see Definitions).

Treatment of a stenosis in the setting of graft thrombosis may be corrected by angioplasty. Thrombosis is associated with underlying venous stenosis in >85% of cases.

Treatment of central vein stenosis is indicated when the stenosis is >50% lumen diameter and when the graft is hemodynamically compromised. The decision to treat central vein stenosis should be based primarily on clinical parameters, such as arm swelling or the frequently failing access. Percutaneous intervention with transluminal angioplasty is the preferred treatment of central vein stenosis (1).

Treatment of native arteriovenous fistulas that have failed to mature after an appropriate amount of time may be treated with endovascular techniques.

1. Balloon angioplasty of the anastomosis to increase inflow to the maturing venous limb.
2. Embolization of small venous tributaries that shunt flow away from the main maturing vein to increase flow through this segment.

ENDOLUMINAL STENT PLACEMENT

The role of endoluminal stents has not yet been fully defined. Several feasibility studies have demonstrated reasonable patencies for stent deployment after balloon angioplasty failure, especially for central vein lesions (24,26,35). At the present time, possible indications for endoluminal stent placement in dialysis accesses include, but are not necessarily limited to:

1. A peripheral lesion that has failed balloon angioplasty and surgical access is difficult, surgery is contraindicated, or there are limited remaining access sites.
2. Central vein lesion that has either failed balloon angioplasty or recurred within a 3-month period after an initially successful balloon angioplasty (1).
3. Rupture of an outflow vein after balloon angioplasty.

The threshold for these indications is 95%. When fewer than 95% of procedures are for these indications, the department will review the process of patient selection.

Absolute Contraindications

1. Infected access site.

Relative Contraindications

1. Severe contrast allergy.
2. Severe hyperkalemia, acidosis, or other life-threatening abnormality of blood chemistry that requires immediate dialysis.
3. Contraindications to thrombolytic therapy, such as recent stroke, major abdominal surgery, known central nervous system neoplasm, and so forth (for procedures to be performed

Table 1
Success and Patency in Graft Stenoses without Thrombosis Treated with Balloon Angioplasty

	Reported Rates (%)	Suggested Thresholds (%)
Clinical Success	85–98	85
Cumulative Patency		
6-month primary	38–63	40*
12-month primary	23–44	†
12-month secondary‡	81–82	†

* This working group believes that 40% is an achievable primary patency rate at 6 months when only grafts are considered. DOQI reported that, in grafts and native fistulas combined, 50% primary patency rate at 6 months was realistic (1). The group believes that a 50% 6-month primary patency would be ideal but that this may not be achievable until native fistulas (with inherently longer patency rates) make up a larger share of the functioning dialysis accesses in the United States.

† Inadequate data exist at the present time to propose threshold values.

‡ Included thrombolysis.

Table 2
Success and Patency in Graft Stenoses Associated with Thrombosis Treated with Thrombolysis or Mechanical Thrombectomy

	Reported Rates (%)	Suggested Threshold (%)
Clinical Success	75–94	85
Cumulative Patency		
3-month primary	37–58	40 (1)
6-month primary	18–39	20
6-month secondary	62–80*	65
12-month secondary	57–69*	

* These patency rates reflect the limited literature for thrombolysis only and do not include results for mechanical thrombectomy. Sufficient data have yet to be generated.

with fibrinolytic therapy). A variety of mechanical techniques may be utilized as an alternative in this situation.

4. Right to left shunt.
5. Severe pulmonary disease.

The decision to treat a dialysis access with percutaneous techniques is always made in light of the patient's clinical condition, the number of alternative access sites available, and the expertise of the treating physician.

SUCCESS RATES

An important indicator of success is the ability to rapidly treat access thrombosis. This minimizes the need for temporary access. This workgroup endorses the DOQI position that before patency is restored to the throm-

bosed access: "No more than one and preferably no femoral vein catheterizations should be required" (1).

The success rates and patency data presented below refer to synthetic grafts. Data referring to native fistulas are limited. It is recognized that extenuating circumstances may cause lower patency rates, not related to stenosis of the graft or fistula. These include but are not limited to:

1. Overcompression of the graft to achieve hemostasis.
2. Dehydration of the patient, decreasing the effective circulating volume.
3. Unusual extrinsic pressure on the graft or fistula, such as from tight fitting clothing or sleeping with the graft partially kinked.

Success and Patency in Graft Stenoses without Thrombosis

The figures in **Table 1** reflect the success in the treatment of graft stenoses with balloon angioplasty in a screened group of patients with hemodynamically significant stenoses without thrombosis. These patency rates are limited to those reported in the literature using modern techniques and reporting with life-table analysis (13,20,21,23). The stenoses are generally solitary and less than 6 cm in length. It is the consensus of this workgroup that longer stenoses and stenoses that have undergone multiple dilations will have poorer patency than more focal stenoses dilated for the first time.

If angioplasty is required more than two times within 3 months, the patient should be referred for surgical revision if such an option is available and if the patient is a good surgical candidate.

Success and Patency in Graft Stenoses Associated with Thrombosis

The figures in **Table 2** reflect success in the treatment of synthetic graft stenoses associated with thrombosis that is treated with thrombolysis or mechanical thrombectomy. These success rates are more difficult to achieve than those for stenoses detected by prospective monitoring; treatment of stenoses associated with thrombosis is, therefore, associated with poorer outcomes for both surgical and percutaneous techniques. If the access thromboses more than two times within a 1-month interval and a recurrent correctable lesion is identified, the patient should be referred for surgery if there are no contraindications. This work group believes that there are instances when factors other than correctable lesions cause thrombosis, such as hypotension or extrinsic compression. These patients need not be referred for surgery. Primary patency data for thrombolysis and mechanical thrombectomy are similar and the results are reported together in **Table 2** (2–4,6,10,12,13,36–42).

Cumulative Patency of All Grafts

The cumulative patency rate of all dialysis grafts beginning with the time

Table 3
Specific Major Complications for Percutaneous Management of Hemodialysis Access

Complication	Rate (%)	Suggested Threshold (%)
Symptomatic embolization, arterial	1-9	2
Hematoma/bleed, remote site	2-3	0.5*
Vascular perforation or rupture	2-4	0.5†
Death‡	<1	0.5§
Symptomatic pulmonary embolism	<1	0.5
Puncture site complications	<1	1

* Thrombolysis with prolonged infusion.

† Perforation requiring blood transfusion, emergent surgery or resulting in limb-threatening ischemia.

‡ Procedure-related, 30-day mortality data are not available but should be reported (33).

§ All deaths should prompt the appropriate case review.

Note.—See Appendix E. Published rates for individual types of complications are highly dependent on patient selection and are based on series comprising several hundred patients, which is a volume larger than most individual practitioners are likely to treat. It is also recognized that a single complication can cause a rate to cross above a complication-specific threshold when the complication occurs in a small volume of patients (eg, early in a quality improvement program). In this situation, the overall procedure threshold is more appropriate for use in a quality-improvement program.

of surgical creation should be at least 70% at 1 year, 60% at 2 years, and 50% at 3 years (1).

COMPLICATIONS

Published complication rates and suggested thresholds are given in **Table 3** (5,10,12,14).

Major and minor complications occur in up to 10% of patients. Complication rates can be expected to be lower when considering management of the nonthrombosed dialysis access.

APPENDIX A

PROTOCOL FOR UREA-BASED MEASUREMENT OF RECIRCULATION (43)

Perform test after approximately 30 minutes of treatment and after turning off ultrafiltration.

1. Draw arterial (A) and venous (V) line samples.
2. Immediately reduce blood flow rate (BFR) to 120 mL/min.
3. Turn blood pump off exactly 10 seconds after reducing BFR.
4. Clamp arterial line immediately above sampling port.
5. Draw systemic arterial sample (S) from arterial line port.

6. Unclamp line and resume dialysis.
7. Measure BUN in A, V, and S samples and calculate percent recirculation (R).
 Recirculation formula:

$$R = \frac{S - A \times 100}{S - V}$$

APPENDIX B

DYNAMIC VENOUS DIALYSIS PRESSURE MONITORING PROTOCOL (44)

1. Establish a baseline by initiating measurements when the access is first used.
2. Measure venous dialysis pressure from the hemodialysis machine at Qb 200 mL/min during the first 2-5 minutes of hemodialysis at every hemodialysis session.
3. Use 15-gauge needles (or establish own protocol for different needle size).
4. Ensure that the venous needle is in the lumen of the vessel and not partially occluded by the vessel wall.
5. Pressure must exceed the threshold three times in succession to be significant.

6. Assess at same level relative to hemodialysis machine for all measurements.

INTERPRETATION OF RESULT

Three measurements in succession above the threshold are required to eliminate the effect of variation caused by needle placement. Hemodialysis machines measure pressure with different monitors and tubing types and lengths. These variables, as well as needle size, influence venous dialysis pressure. The most important variable affecting the dynamic pressure at a blood flow of 200 mL/min is the needle gauge (45,46). It is essential to set thresholds for action based on machine manufacturer, tubing type, and needle gauge.

With use of 15-gauge needles, the threshold that indicates elevated pressure and, therefore, the likely presence of a hemodynamically significant venous outlet stenosis for Cobe Centry 3 machines is a pressure of 150 mm Hg. Data for Baxter, Fresenius, Althin, and other dialysis machines are not available, but are likely to be similar to those of Cobe Centry 3 if the same gauge venous needle is used. Trial and error at each institution will determine each unit's threshold pressure.

Trend analysis is more important than any single measurement. Upward trends in hemodialysis pressure over time are more predictive than absolute values. Each unit should establish its own venous pressure threshold values. Patients with progressively increasing pressures or those who exceed the threshold on three consecutive hemodialysis treatments should be referred for venography.

APPENDIX C

STATIC PRESSURE MEASUREMENTS IN SYNTHETIC DIALYSIS GRAFTS

Intra-access pressure measurements are made with a straight end-hole catheter. The catheter tip can be positioned in the native artery or vein as well as at any position within the graft. Because pressure in the graft reflects the patient's systemic blood pressure, the systolic graft pressure is divided by the systemic systolic pres-

sure measured from a blood pressure cuff on the contralateral arm, yielding a normalized ratio (47). A normalized systolic pressure ratio of 0.4 has both a high sensitivity (91%) and specificity (86%) in identifying at least 50% stenosis.

The positive predictive value is 92% and the negative predictive value is 84%.

The goal of intervention is to achieve a pressure ratio of less than 0.5 in the arterial limb and less than 0.33 in the venous limb of the graft.

APPENDIX D

SIR STANDARDS OF PRACTICE COMMITTEE CLASSIFICATION OF COMPLICATIONS BY OUTCOME

Minor Complications

1. No therapy, no consequence.
2. Nominal therapy, no consequence; includes overnight admission for observation only.

Major Complications

3. Require therapy, minor hospitalization (, 48 hours).
4. Require major therapy, unplanned increase in level of care, prolonged hospitalization (>48 hours).
5. Permanent adverse sequelae.
6. Death.

APPENDIX E

METHODOLOGY

Reported complication-specific rates in some cases reflect the aggregate of major and minor complications. Thresholds are derived from critical evaluation of the literature, evaluation of empirical data from Standards of Practice Committee Member Practices, and when available, the SIR HI-IQ[®] system national database. Consensus on statements in this document was obtained utilizing a modified Delphi technique (48,49).

Technical documents specifying the exact consensus and literature review methodologies are available upon request from the Society of Interventional Radiology, 10201 Lee Highway

Suite 500, Fairfax, VA 22030. The SIR HI-IQ[®] system is the computer system software program on health information for inventory and quality assurance developed by the Society of Interventional Radiology.

ADDENDUM

Dr. John Aruny authored the first draft of this document and served as topic leader during subsequent revisions. Dr. Curtis A. Lewis is Chairman and Curtis W. Bakal is Councilor of the Standards of Practice Committee. All other authors are listed alphabetically. Other members of the Standards of Practice Committee and SIR who participated in the development of this clinical practice guideline are: Kimberly Bloomfield, MD, Dana Burke, MD, Paramjit S. Chopra, MD, Steven J. Citron, MD, Martin Crain, MD, Elizabeth A. Drucker, MD, JD, Neil J. Freeman, MD, Jeffrey Georgia, MD, Ziv J. Haskal, MD, Patrick C. Malloy, MD, Louis G. Martin, MD, Theodore Mirra, MD, Sally Mitchell, MD, Albert Nemcek, Jr, MD, Patricia E. Thorpe, MD, Anthony C. Venbrux, MD, and Daniel J. Wunder, MD.

References

1. Owens JR, Roberts J, Alexander S, et al. NKF-DOQI clinical practice guidelines for hemodialysis adequacy. *Am J Kid Dis* 1997; 30(Suppl 2):S15-S64.
2. Berger MF, Aruny JEA, Skibo LK. Recurrent thrombosis of PTFE dialysis fistulas after recent surgical thrombectomy: salvage by means of thrombolysis and angioplasty. *J Vasc Interv Radiol* 1994; 5:725-730.
3. Cohen MAH, Kumpe DA, Durham JD, Zwerdinger SC. Improved treatment of thrombosed hemodialysis access sites with thrombolysis and angioplasty. *Kidney Int* 1994; 46:1375-1380.
4. 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* 1995; 164:1495-1500.
5. Roberts AC, Valji K, Bookstein JJ, Hye RJ. Pulse-spray pharmacomechanical thrombolysis for treatment of thrombosed dialysis access grafts. *Am J Surg* 1993; 66:221-226.
6. Davis GB, Dowd CF, Bookstein JJ, Maroney TP, Lang EV, Halasz N. Thrombosed dialysis grafts: efficacy of intrathrombotic deposition of concen-

trated urokinase, clot maceration, and angioplasty. *AJR* 1987; 149:177-181.

7. Summers S, Drazan K, Gomes A. Urokinase therapy for thrombosed hemodialysis access grafts. *Surg Gynecol Obstet* 1993; 176:534-538.
8. 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. *Radiology* 1998; 206:403-414.
9. Turmel-Rodrigues L, Sapoval M, Pengloan J, et al. Manual thromboaspiration and dilation of thrombosed dialysis access: mid-term results of a simple concept. *J Vasc Interv Radiol* 1998; 8:813-824.
10. Uflacker R, Rajagopalan PR, Vujic I, Stutley JE. Treatment of thrombosed dialysis access grafts with the Amplatz device. *J Vasc Interv Radiol* 1996; 7:185.
11. 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* 1997; 8:563-567.
12. Sharafuddin MJA, Kadir S, Joshi SJ, Parr D. Percutaneous balloon-assisted aspiration thrombectomy of clotted hemodialysis access grafts. *J Vasc Interv Radiol* 1996; 7:177-183.
13. Middlebrook MR, Amygdalos MA, Soulen MC, et al. Thrombosed hemodialysis grafts: percutaneous mechanical balloon declotting versus thrombolysis. *Radiology* 1995; 196: 73-77.
14. Gilula LA, Staple TW, Anderson CB, Anderson LS. Venous angiography of hemodialysis fistulas. *Radiology* 1975; 115:555-562.
15. Picus D, van Breda A, Katzen BT, Steinberg DL. Use of digital subtraction angiography for evaluation of vascular access for hemodialysis. *Cardiovasc Intervent Radiol* 1987; 10:210-214.
16. Saeed M, Newman GE, McCann RL, Sussman SK, Braun SD, Dunnick NR. Stenoses in dialysis fistulas: treatment with percutaneous angioplasty. *Radiology* 1987; 164:693-697.
17. Glanz S, Gordon DH, Butt KMH, Hong J, Lipkowitz GS. The role of percutaneous angioplasty in the management of chronic hemodialysis fistulas. *Ann Surg* 1987; 206: 777-781.
18. Gmelin E, Winterhoff R, Rinast E. Insufficient hemodialysis access fistulas: late results of treatment with percutaneous balloon angioplasty. *Radiology* 1989; 171:657-660.
19. Zemel G, Katzen BT, Benenati JF, Lempart TE, Moskowitz L. Directional atherectomy in the treatment of stenotic dialysis access fistulas. *J Vasc Interv Radiol* 1990; 1:35-38.

20. Beathard GA. Percutaneous transvenous angioplasty in the treatment of vascular accesses stenosis. *Kidney Int* 1992; 42:1390-13397.
21. Kanterman RY, Vesely TM, Pilgram TK, Guy BW, Windus DW, Picus D. Dialysis access grafts: anatomic location of venous stenosis and results of angioplasty. *Radiology* 1995; 195:135-139.
22. Schwartz CI, McBrayer CV, Sloan JA, Meneses P. Thrombosed dialysis grafts: comparison of treatment with transluminal angioplasty and surgical revision. *Radiology* 1995; 194:337-341.
23. Safa AA, Valji K, Roberts AC, Ziegler TW, Hye RJ, Oglevie SB. Detection and treatment of dysfunctional hemodialysis access grafts: effect of a surveillance program on graft patency and the incidence of thrombosis. *Radiology* 1996; 199:653-657.
24. Gray RJ, Horton KM, Dolmatch BL, et al. Use of Wallstents for hemodialysis access-related venous stenoses and occlusions untreatable with balloon angioplasty. *Radiology* 1995; 195:479-484.
25. Beathard GA. Gianturco self-expanding stent in the treatment of stenosis in dialysis access grafts. *Kidney Int* 1993; 43:872-877.
26. Vorwerk D, Guenther RW, Mann H, et al. Venous stenosis and occlusion in hemodialysis shunts: follow-up results of stent placement in 65 patients. *Radiology* 1995; 195: 140-146.
27. Schoenfield R, Hermans H, Novick A, et al. Stenting of proximal venous obstructions to maintain hemodialysis access. *J Vasc Surg* 1994; 19:532-539.
28. Quinn SF, Schuman ES, Hall L, et al. Venous stenoses in patients who undergo hemodialysis treatment with self-expandable endovascular stents. *Radiology* 1992; 183:499-504.
29. Hoffer EK, Sultan S, et al. Prospective randomized trial of a metallic intravascular stent in hemodialysis graft maintenance. *J Vasc Interv Radiol* 1997; 8:965-973.
30. Turmel-Rodrigues LA, Blanchard D, Pengloan J, et al. Wallstents and Cragstents in hemodialysis grafts and fistulas: results for selective indications. *J Vasc Interv Radiol* 1997; 8:975-982.
31. Turmel-Rodrigues L, Pengloan J, Blanchard D, et al. Insufficient dialysis shunts: improved long-term patency rates with close hemodynamic monitoring, repeated percutaneous balloon angioplasty and stent placement. *Radiology* 1993; 187:273-278.
32. Gray RJ, Dolmatch BL, Buick MK. Directional atherectomy treatment for hemodialysis access: early results. *J Vasc Interv Radiol* 1992; 3:497-503.
33. Gray RJ, Sack D, Martin LG, Trerotola SO, and the members of the Technology Assessment Committee. Reporting standards for percutaneous interventions in dialysis access. *J Vasc Interv Radiol* 1999; 10:1405-1415.
34. Sullivan KL, Besarab A. Hemodynamic screening and early percutaneous intervention reduce hemodialysis access thrombosis and increase graft longevity. *J Vasc Interv Radiol* 1997; 8:163-170.
35. Vesely TM, Hovsepian DM, Pilgram TK, Coyne DW, Shenoy S. Upper extremity central venous obstruction in hemodialysis patients: treatment with Wallstents. *Radiology* 1997; 204:343.
36. 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* 1991; 178:243-247.
37. Beathard GA. Mechanical versus pharmacomechanical thrombolysis for the treatment of thrombosed dialysis access grafts. *Kidney Int* 1994; 45:1401-1406.
38. Sands JJ, Patel S, Plaviak DJ, Miranda CL. Pharmacomechanical thrombolysis with urokinase for treatment of thrombosed hemodialysis access grafts. *ASAIO J* 1994; 40: M886-M888.
39. Swan TL, Smyth SH, Ruffenach SJ, Berman SS, Pond GD. Pulmonary embolism following hemodialysis access thrombolysis/thrombectomy. *J Vasc Interv Radiol* 1995;6:683-686.
40. Trerotola SO, Lund GB, Scheel PJ, Saver SJ, Venbrux AC, Osterman FA Jr. Thrombosed dialysis access grafts: percutaneous mechanical de-clotting without urokinase. *Radiology* 1994; 191:721-726.
41. Beathard GA, Welch BR, Maidment HJ. Mechanical thrombolysis for the treatment of thrombosed hemodialysis access grafts. *Radiology* 1996; 200:711-716.
42. Vorwerk D, Sohn M, Schurmann K, Hoogeveen Y, Gladziwa U, Guenther RW. Hydrodynamic thrombectomy of hemodialysis fistulas: first clinical results. *J Vasc Interv Radiol* 1994; 5:813-821.
43. Owen JRW, Robert J, Alexander S, et al. NKF-DOQI clinical practice guidelines for hemodialysis adequacy. *Am J Kid Dis* 1997; 30(Suppl 2):S15-S64, Guideline 12, Table 4.
44. Owen JRW, Robert J, Alexander S, et al. NKF-DOQI clinical practice guidelines for hemodialysis adequacy. *Am J Kid Dis* 1997; 30(Suppl 2):S15-S64, Guideline 10, Table 3.
45. Besarab A, Sullivan KL, Ross RP, Moritz MJ. Utility of intra-access pressure monitoring in detecting and correcting venous outlet stenoses prior to thrombosis. *Kidney Int* 1995; 47: 1364-1373.
46. Besarab A, Dorrell S, Moritz M, Michael H, Sullivan K. Determinants of measured dialysis venous pressure and its relationship to true intra-access venous pressure. *ASAIO Trans* 1991; 37:M270-M271.
47. Sullivan KL, Besarab A. Hemodynamic screening and early percutaneous intervention reduce hemodialysis access thrombosis and increase graft longevity. *J Vasc Interv Radiol* 1997; 8:163-170.
48. Fink A, Koseff J, Chassin M, Brook RH. Consensus methods: characteristics and guidelines for use. *Am J Public Health* 1984; 74: 979-983.
49. Leape LL, Hilborne LH, Park RE, et al. The appropriateness of use of coronary artery bypass graft surgery in New York State. *JAMA* 1993; 269:753-760.

The clinical practice guidelines of the Society of Interventional Radiology attempt to define practice principles that generally should assist in producing high-quality medical care. These guidelines are voluntary and are not rules. A physician may deviate from these guidelines, as necessitated by the individual patient and available resources. These practice guidelines should not be deemed inclusive of all proper methods of care or exclusive of other methods of care that are reasonably directed toward the same result. Other sources of information may be used in conjunction with these principles to produce a process leading to high-quality medical care. The ultimate judgment regarding the conduct of any specific procedure or course of management must be made by the physician, who should consider all circumstances relevant to the individual clinical situation. Adherence to the SIR Quality Improvement Program will not assure a successful outcome in every situation. It is prudent to document the rationale for any deviation from the suggested practice guidelines in the department policies and procedure manual or in the patient's medical record.