

manually compressed just beyond the arterial anastomosis to see whether this maneuver redirects flow toward the hand or alleviates symptoms.

Other nonstenotic abnormalities, such as a PSA, hematoma, and an abscess, can be diagnosed by a combination of grayscale and duplex Doppler ultrasound. Color Doppler imaging should be used to evaluate any collection adjacent to the fistula. Grayscale and color Doppler imaging can diagnose aneurysmal dilatation, which may not be detected angiographically if a mural thrombus fills at least 50% of the lumen.³¹ A small aneurysm in a draining vein may not require treatment if the overlying skin remains intact. However, a PSA secondary to repeated needle sticks in a graft or, rarely, an AVF may worsen and lead to hemorrhage; it can require surgical management if greater than 1 cm in diameter, especially if it contains a mural thrombus.⁴⁰

Evaluation of an AVF for Failure to Mature

A normal AVF may take up to 3 months to fully mature and be usable for dialysis. Additionally, a large proportion (28%–60%) of surgically created AVFs do not initially adequately mature such that they become usable for hemodialysis within a typical maturation period of 6 weeks to 6 months.^{41–44} A mature AVF must be easily palpable and support cannulation by two 17-gauge needles. Clinical determination of fistula maturity by skilled nursing was reportedly 80% accurate⁴⁵ in one study; however, palpation had 96% sensitivity in another study if a thrill was present.⁴⁶ If an adequate AVF is not clinically identified in the first 4 to 8 weeks after surgical access creation, an ultrasound examination can be performed to assess for a potentially correctable anatomic problem. In a series of 153 patients with surveillance Doppler evaluations 4 to 8 weeks after access creation (but before attempted hemodialysis), ultrasound detected 9 occluded fistulas. An additional 40% had significant lesions, even though only 17% had abnormal clinical examination findings. In this series, 70% of the AVFs that underwent secondary interventions matured, compared with 25% without interventions.⁴⁷ If the fistula is still not useable after 3 months despite interventions, it is considered failure to mature.⁴⁸ A prospective study of 602 fistulas suggested that low blood flow and a small venous diameter at 2 weeks are predictive of AVFs that may not develop optimally at 6 weeks.⁴⁵ A follow-up

evaluation of the 602 AVFs showed that measurement of the AVF blood flow rate, AVF diameter, and distance of the anterior AVF vein wall from the skin was moderately predictive of AVF maturation.⁴⁹ A separate study showed an increased risk of failure to mature if blood flow was less than 413 mL/min at 2 weeks after fistula creation.⁵⁰

The anastomosis is evaluated for stenosis using the same diagnostic criteria defined in the section above on an upper extremity AVF examination for fistula dysfunction. Again, a greater than 3:1 PSV ratio of anastomosis compared with the feeding artery 2 cm upstream should suggest anastomotic stenosis. Special attention is given to detect stenosis of the draining vein, using a 2:1 threshold ratio for stenosis at the point of narrowing relative to 2 cm upstream.

Blood flow is measured in the midportion of the AVF draining vein where the vein is straight and non-tapering, without turbulent flow typically around 10 cm cranial to the anastomosis.³³ The Doppler gate is adjusted to encompass the lumen of the vein with alignment of the sample volume markers perpendicular to the venous walls. The angle of Doppler insonation for blood flow calculation is standardized at 60° or less to minimize the degree of measurement error. A sequence of 3 to 5 cardiac cycles is obtained to allow calculation of time-averaged velocities, and the average of 3 separate measurements is reported.¹⁷ On follow-up examinations, blood flow should be measured in the same location.

If no stenosis is identified, thresholds for the AVF vein diameter and blood flow and AVF depth from the skin may suggest whether the AVF is adequately mature for hemodialysis.⁴⁹ An AVF with a venous diameter of at least 0.4 to 0.6 cm and blood flow of at least 500 to 600 mL/min predicts that an AVF has a high likelihood of supporting successful hemodialysis.^{19,33} The lower range of values may be chosen to reduce abandonment of a fistula that may subsequently mature and recognize the measurement error in determining flow volumes. In one study, fistulas measuring greater than 0.4 cm in diameter and with volume flow greater than 500 mL/min were usable for hemodialysis in 95% of patients, whereas, those measuring less than 0.4 cm in diameter and with volume flow less than 500 mL/min matured in only 33% of patients.¹⁹ Another study of