Steven Wu · Sanjeeva P. Kalva *Editors*

Dialysis Access Management

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Dedicated to my wonderful patients, fellows and teachers who have taught me in many different ways

Steven Wu

To my trainees, colleagues and mentors who inspire me everyday

Sanjeeva P. Kalva

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Part I

Principles and Basics of Endovascular Interventions

Angiographic Imaging Equipment

1

Chieh Suai Tan, Robert M. Sheridan, and Steven Wu

Introduction

Since the accidental discovery of x-rays in 1895, technology has evolved so rapidly that minimally invasive endovascular interventions are routinely performed under radiological guidance.

Having good fluoroscopic is pivotal for endovascular intervention. Hence, it is important to know your machine well and understand some of the common terminology.

Angiographic Imaging System

Interventional suites may be equipped with either a stationary (Fig. 1.1) or mobile fluoroscopic imaging system (Fig. 1.2). The common features of these systems are the presence of a C-arm, an angiographic procedure table and a console or computer

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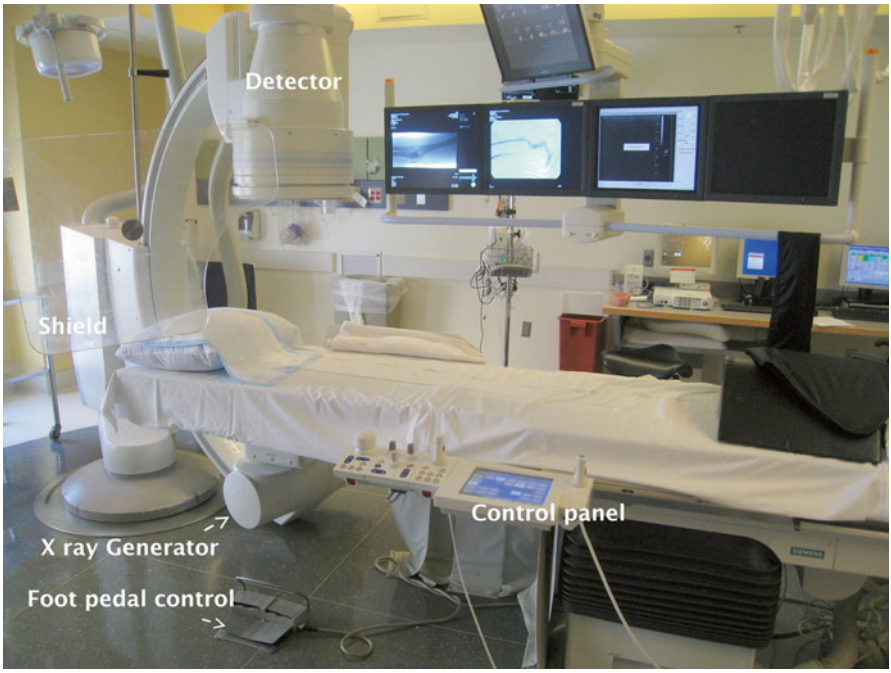

Fig. 1.1 Layout of an angiography suite with a stationary fluoroscopic imaging system

system to process and project the images for viewing on a screen. C-arms, as the name suggests, consists of a C shaped metal mount equipped with an X-ray generator at one end and an X-ray receptor at the opposite end of the C-arm. The patient is placed on a radiolucent procedure table, between the X-ray tube and the receptor for image-guided procedures.

A stationary fluoroscopy system consists of a ceiling or floor mounted C-arm, ceiling mounted monitors and floor mounted procedure table. The entire set up is fully mechanized and the patient is positioned within the fluoroscopy field by either moving the motorized procedure table or the C-arm. Stationary system usually has a larger generator that can provide higher image resolution and has the advantage of maximal C-arm mobility for multiple views.

A mobile fluoroscopy system consists of a portable C-arm and monitor that can be moved from room to room. The angiographic procedure table is usually stationary and the radiographer manually positions the C-arm over the area of intervention. They are generally less expensive and have smaller X- ray generators and lower heat capacity compared to the stationary systems. Some of the newer generation portable C-arm systems are able to produce high quality images and have image processing capability similar to that of the stationary systems.

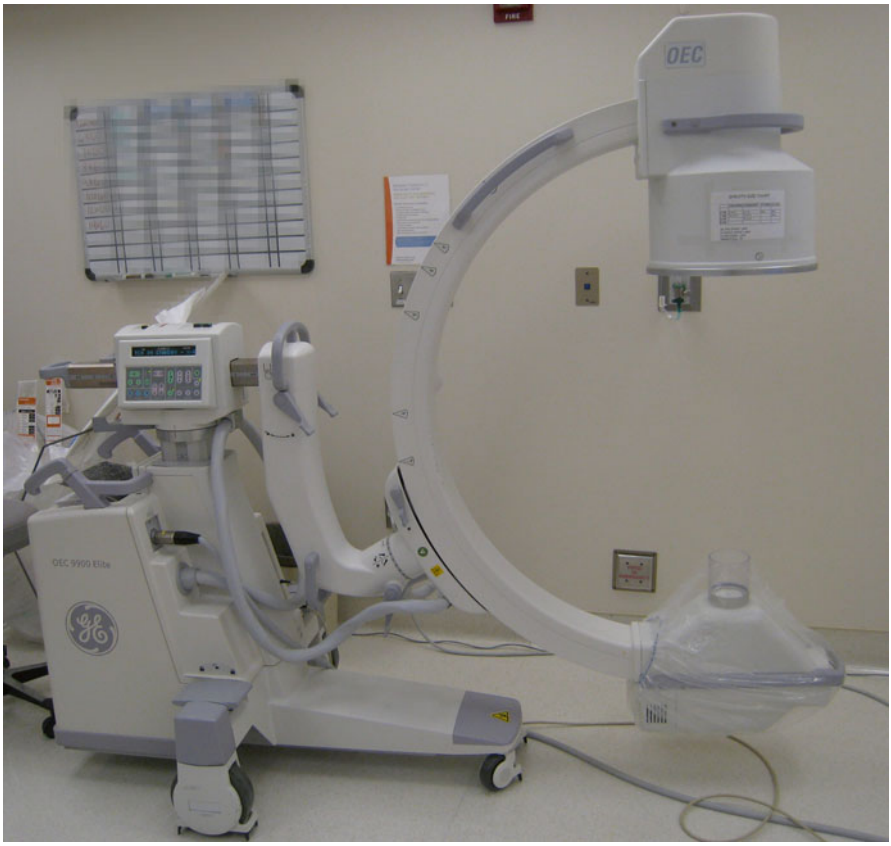

Fig. 1.2 The portable C-arm of a mobile fluoroscopic imaging system. The radiographer manually positions the C-arm over the area of intervention

C-arm

The C-arm consists of an x-ray generator and an X-ray receptor (Fig. 1.3a, b). The x ray beam that is generated travels through the patient and is captured by the receptor which can be either an image intensifier or a digital flat-panel detector. The current that is required to generate x-rays is measured in milliampere/second (mAS). It ranges from 0.5–5 mA for fluoroscopy and is triggered when the fluoroscopy pedal is pressed. The current determines the density of the image. Peak kilo-voltage (kVp), which is a measure of the potential difference across the anode and cathode, determines the maximum kinetic energy of the X-ray beam. The kinetic energy of the X-ray beam impacts the penetrability of the X-ray beam and the contrast of the image. In an automated system, the interaction between the mAs and kVp is determined by the computer to provide the best image quality at the lowest radiation dose to the patient.

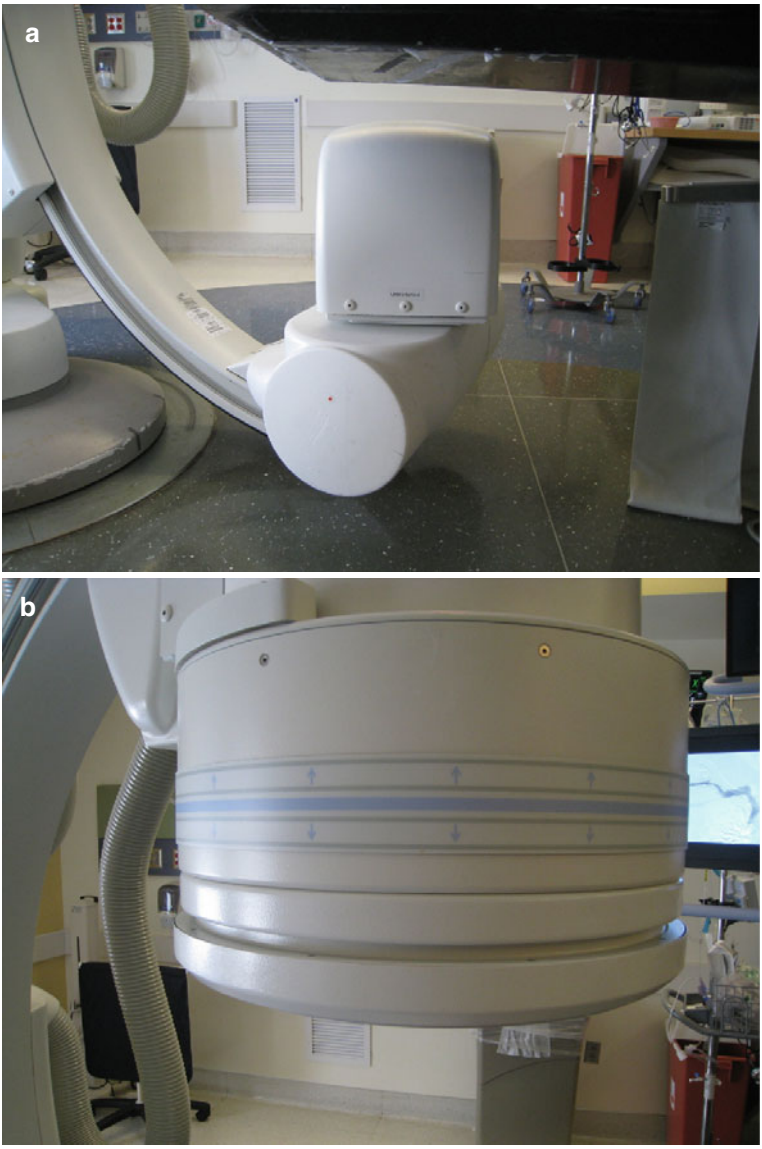

Fig. 1.3 (**a**) The generator is mounted on the lower end of the C-arm and is located under the table. (**b**) The x ray detector is mounted on the top end of the C-arm

Foot Switch

A foot switch control is used to start the generation of X-rays by the C-arm (Fig. 1.4). The pedals are programmed to begin imaging using fluoroscopy or digitally subtracted angiography when depressed respectively. X rays are generated once the pedal is depressed and continued until the pedal is released.

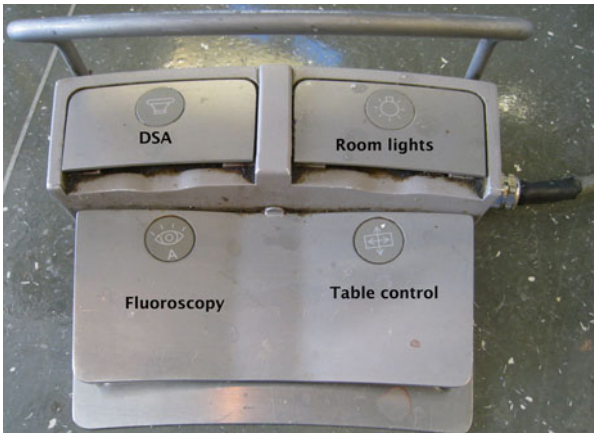

Fig. 1.4 Layout of a foot switch

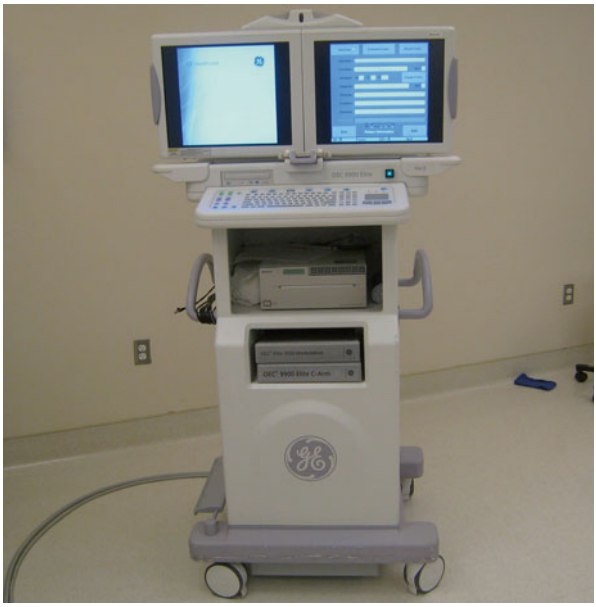

Fig. 1.5 The monitor console in a mobile fluoroscopic imaging system is mounted on wheels and can be moved together with the mobile C-arm from room to room

Monitor Console

The monitor console usually has two or more computer screens to display the images (Fig. 1.5). The screen on the left shows the "active" or "live" images while the one on the right can be used to display the last recorded image frame or replay the image sequences.

Table and Control Panel

The procedure table is made of carbon fiber to allow for easy penetration of the X ray beam. In the stationary system, along with the control panel located within the control room, another set of control panel can be found on the side of the procedure table (Fig. 1.6a–c).

Imaging Options

Pulsed Fluoroscopy

Variable rated pulsed fluoroscopy is an important feature on digital angiographic imaging system (Fig. 1.7a, b). In pulsed mode, the X ray beam is not generated continuously but delivered intermittently in synchrony with image display to produce the appearance of a smooth continuous image. The use of pulsed fluoroscopy can significantly reduce X-ray dose but "flickering" of images can occur when it is set too low. The default setting in our center is 15 pulses per second although in general, 8 pulses per second is sufficient for dialysis access intervention. The X ray dose at 30 pulses per second is equivalent to that of continuous fluoroscopy.

Fluoroscopy Versus Digital Subtraction Angiography (DSA)

In standard fluoroscopy, electron dense objects such as bones and iodinated contrast materials absorb more energy and appear white on a black background. This is usually reversed digitally such that bone and contrast will appear black on a white background.

In digital subtraction angiography (DSA), a "mask" of the area of interest is first taken and used as a reference to digitally remove or subtract the "background" tissues or structures from the images that are subsequently acquired during contrast material administration. Vessels that are filled with the contrast material appear black on a "white out" background. Subtraction angiography improves contrast resolution of the image (Fig. 1.7c–e).

Acquisition of DSA images is described in "frames per second". The image acquisition frame rate can be adjusted in accordance to the target vasculature. While a slow acquisition frame rate may not be able to capture the flow of contrast material adequately, a high frame rate may be unnecessary and may result in high radiation dose. In general, 3 frames per second is sufficient when imaging the central veins (to compensate for chest movement artifact) while 1–2 frames per second is adequate for peripheral dialysis access intervention.

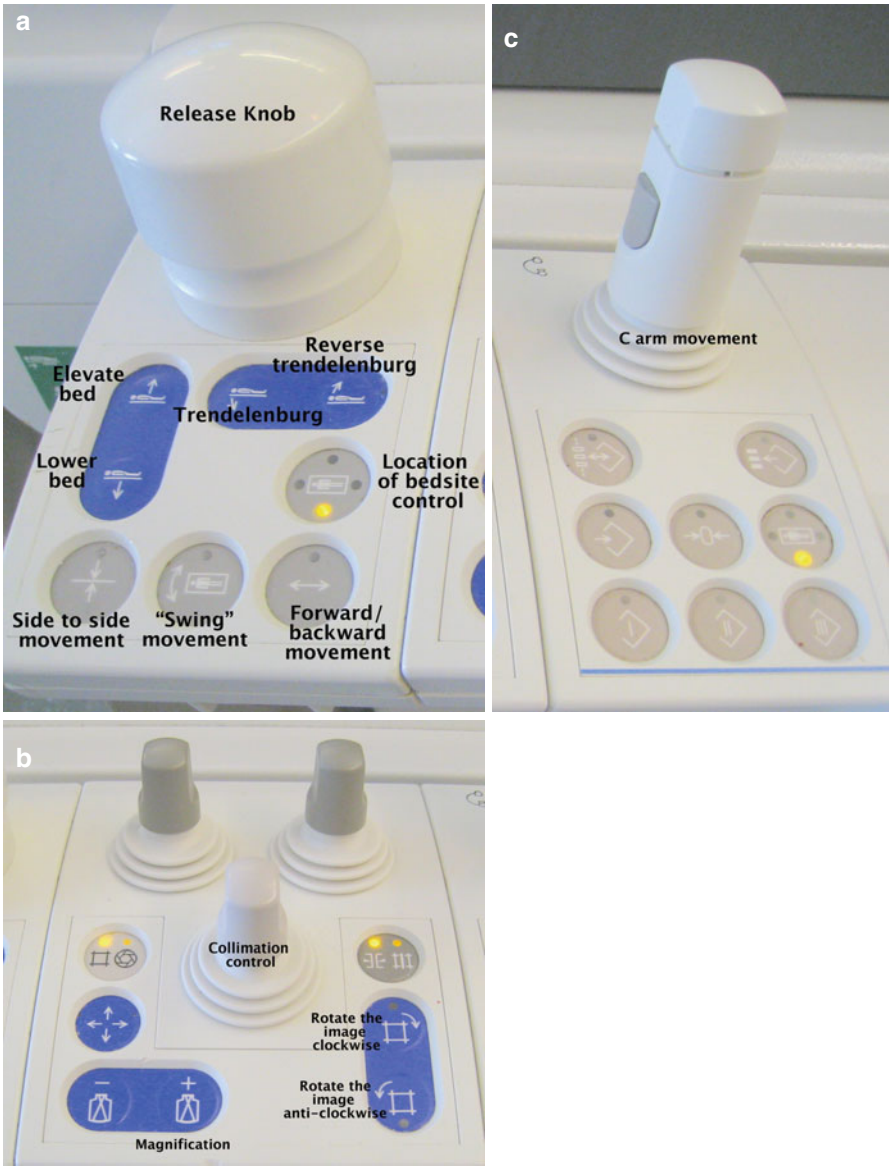

Fig. 1.6 (**a**) Horizontal movement of the table in all direction is possible once the release knob is depressed. The 3 grey colored buttons are used when restriction in a particular direction of the table movement is required. (**b**) This panel here control the generation of images by the C-arm. Collimation is used to restrict the field of view to the area of interest while magnification is used to magnify the area of interest for detailed examination. The images can also be rotated clockwise or anti-clockwise. (**c**) This control stick controls the movement of the C-arm. It is used to rotate the C-arm around the patient

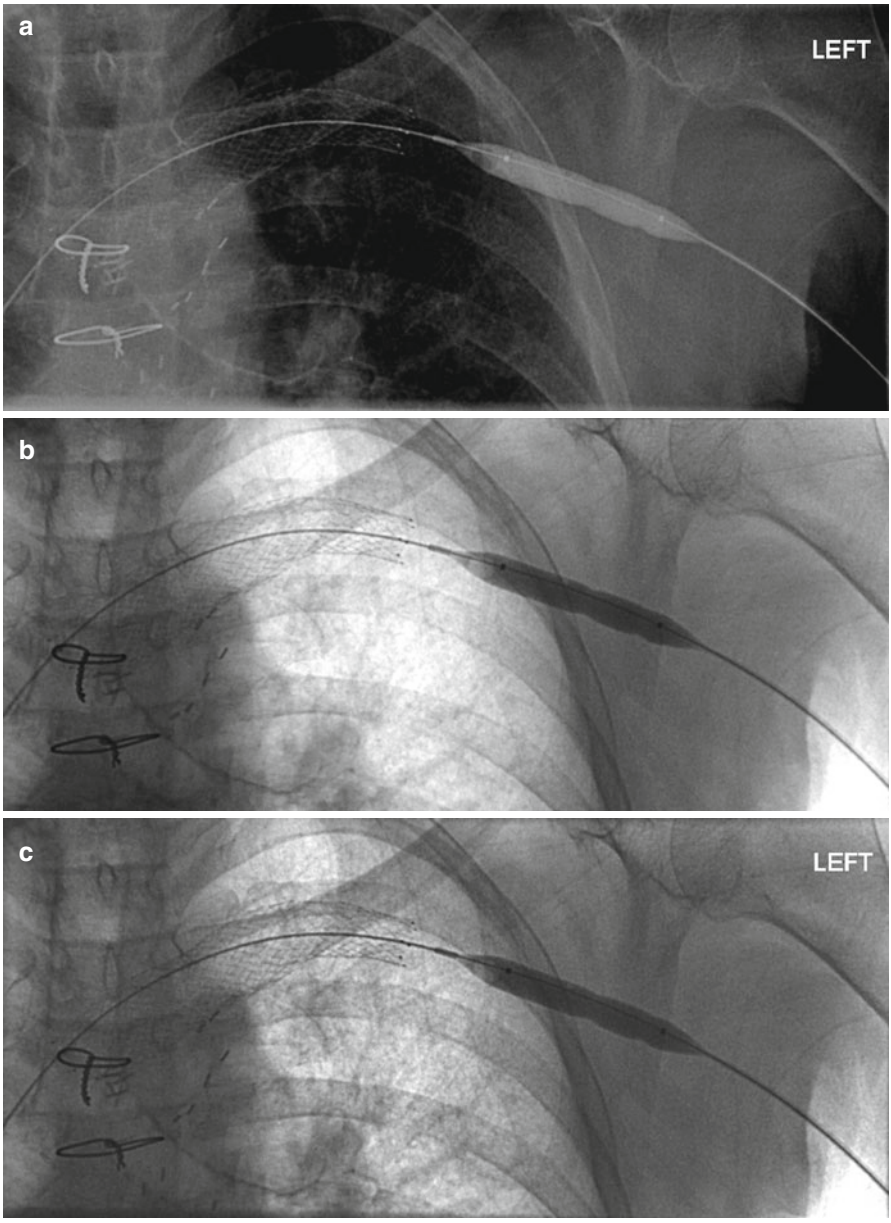

Fig. 1.7 (**a**) Fluoroscopy with "white on black" setting. The angioplasty balloon which is filled with radio-opaque contrast will appear white. (**b**) Fluoroscopy with "black on white" setting. The angioplasty balloon which is filled with radio-opaque contrast will appear black. (**c**) In digital subtraction angiography, a "mask" of the area is first created. (**d**) Using the "mask" that was initially acquired, background tissues or structure are then digitally removed from the subsequently acquired images. (**e**) The injected contrast will appear black on a "white out" background that has been digitally subtracted or modified using the "mask" image as the reference image

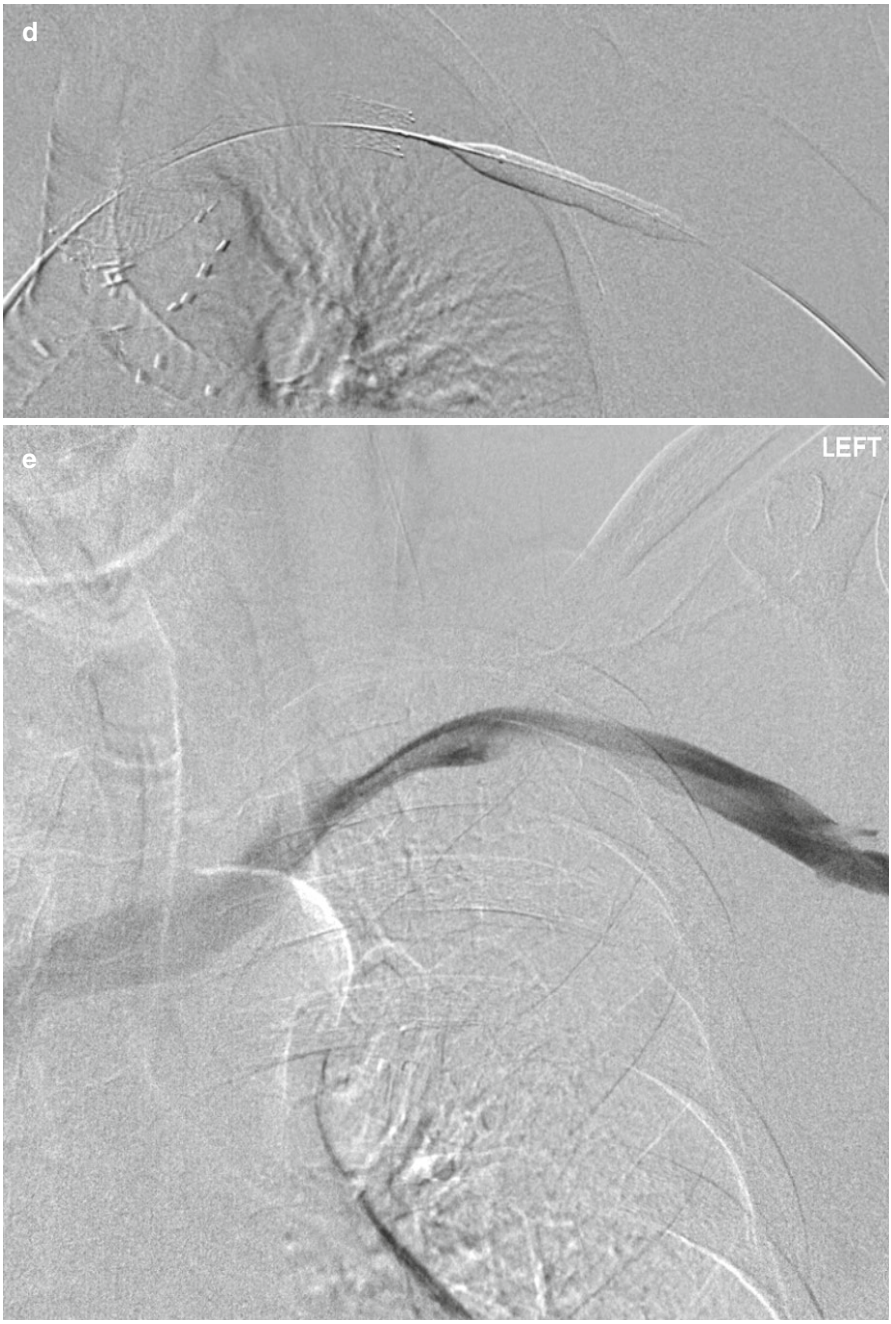

Fig. 1.7 (continued)

Collimation Versus Magnification

Collimation is used to limit the size of the field of view to the area of interest. It helps to decrease the radiation dose to the patient and improve image quality by reducing scattered radiation.

Magnification is used to magnify or enlarge the area of interest. Magnification results in an increase in the radiation dose to the patient and should be used only when fine detail is needed.

Optimizing Image Quality

The quality of the images will have an impact on the ability to make appropriate interpretation. While obtaining the best image possible is important, one must be mindful of the potential adverse effects of radiation. Some of the techniques to improve image quality are as follows:

1. Minimize the distance between the X ray detector and the patient. This improves image quality and decreases scatter radiation.
2. Remove radio-opaque objects such as oxygen tubing and ECG leads from the field of view (Fig. 1.8).
3. Minimize patient movements to decrease movement artifacts, e.g., breath holding during imaging of the central veins will help improve image quality.
4. Position the patient and x ray detector before starting imaging.
5. Keep the area of interest in the center of the image.

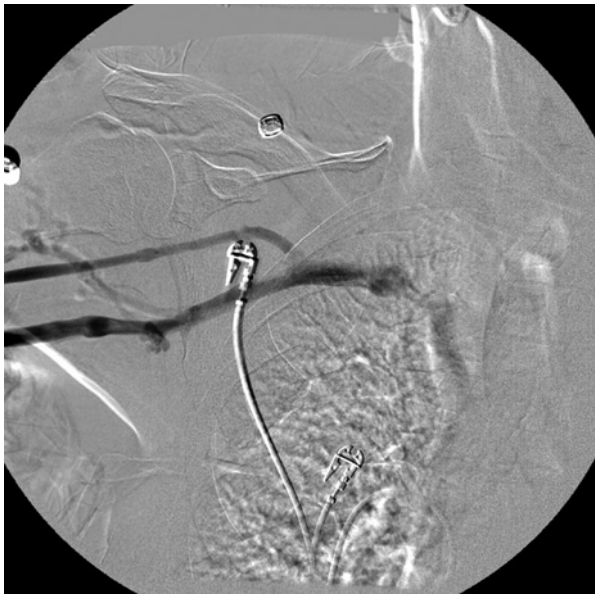

Fig. 1.8 ECG leads should not be placed within the fluoroscopic field

6. Use collimation to “remove” unnecessary area.
7. Use magnification to see details in a specific area when necessary.
8. Increase the number of pulses per second or frames per second where necessary.
9. Use full strength iodinated contrast material rather than diluted contrast material, especially when imaging the proximal or central vessels.
10. Oblique views may be necessary to delineate overlapping vessels and detecting eccentric vascular disease.

Endovascular Tools

2

Chieh Suai Tan, Zubin D. Irani, and Steven Wu

Introduction

The Seldinger technique, first described in 1953, revolutionized the way angiography is performed. It overcomes the traditional need for surgical exposure of a blood vessel before catheterization by using a guide wire to introduce devices into a blood vessel via a percutaneous puncture. The technique involves percutaneous puncture of a blood vessel with a hollow needle, introduction of a guidewire through the needle into the blood vessel lumen, removal of the needle while maintaining the guidewire in position, followed by advancement of a catheter over the guidewire.

Refinement of this technique by placement of a sheath over the puncture site allows devices to be introduced via the same puncture site without the need for multiple punctures. The tools for endovascular interventions are outlined in this chapter.

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Access Needle

All endovascular intervention begins with the insertion of a vascular access needle. There is a great variety of access needles that can be used. Examples include the micropuncture needle, introducer needle, sheath needle and angiocath (Fig. 2.1a–c). Their common feature is the presence of a central channel for introduction of a guidewire. The diameter of a needle is described using the stubs iron wire gauge system in "gauge" or "G". The maximum guidewire diameter that an 18 and 21-G needle can accommodate is 0.035 and 0.018 in. respectively. An 18G angiocath is routinely used to obtain access to an arteriovenous fistula or a graft in our institution.

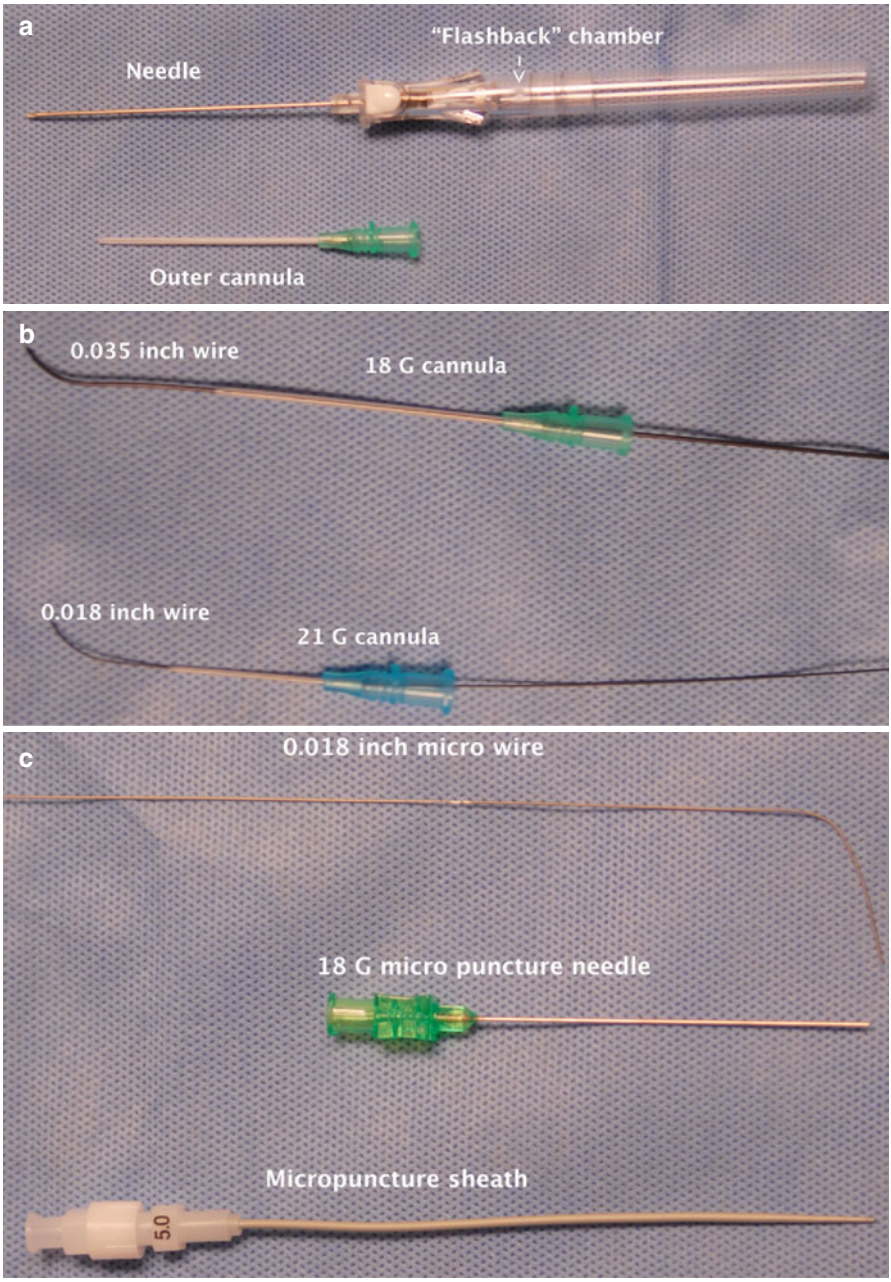
Sheath

Sheaths are used to secure the puncture site for vascular intervention. They are plastic tubes that are open on one end and capped with a hemostatic valve at the other (Fig. 2.2a). The hemostatic valve prevents bleeding and air embolism during the procedure and allows wires, catheters and other devices to be introduced into the vessel. The valve end usually has a short sidearm that can be used for flushing, contrast material administration and medications

Sheaths are sized by their inner diameter described using the "French" (Fr) system, which is based on "π". The diameter of the sheath is obtained by dividing the "Fr" by "π" or approximately 3. For example, a 6-Fr sheath is approximately 2 mm by the inner diameter. The outer diameter for a sheath is 1.5–2 Fr larger; hence a 6 Fr (2 mm) sheath will create an 8 Fr (2.5 mm) hole.

The size of the sheath to be inserted is determined by the diameter of the catheter or angioplasty balloon or device to be used (Fig. 2.2b). The product insert of the catheter or angioplasty balloon or device will specify the size of the sheath that is required.

Fig. 2.1 (**a**) An angiocath consists of a hollow core needle with an outer sheath. The "flashback" chamber allows visualization of blood once the needle punctures the vessel. (**b**) An 18G cannula can accommodate a 0.035 in. wire while a 21G cannula can accommodate a 0.018 in. wire. (**c**) A micro puncture set consists of a micropuncture needle, wire and transitional sheath. The transitional sheath consists of an inner 3 Fr sheath and an outer 5 French sheath. The needle is used to puncture the vessel. The wire is threaded through the needle after a successful puncture. The needle is then removed and the sheath inserted over the guidewire. The inner 3 Fr sheath can accommodate the 0.018 system while the outer 5 Fr sheath is able to accommodate the 0.035 system. The design of the transitional sheath permits upsizing from the 0.018 to 0.035 system when required


a
Needle
"Flashback" chamber
Outer cannula
b
0.035 inch wire
18 G cannula
0.018 inch wire
21 G cannula
c
0.018 inch micro wire
18 G micro puncture needle
Micropuncture sheath
5.0

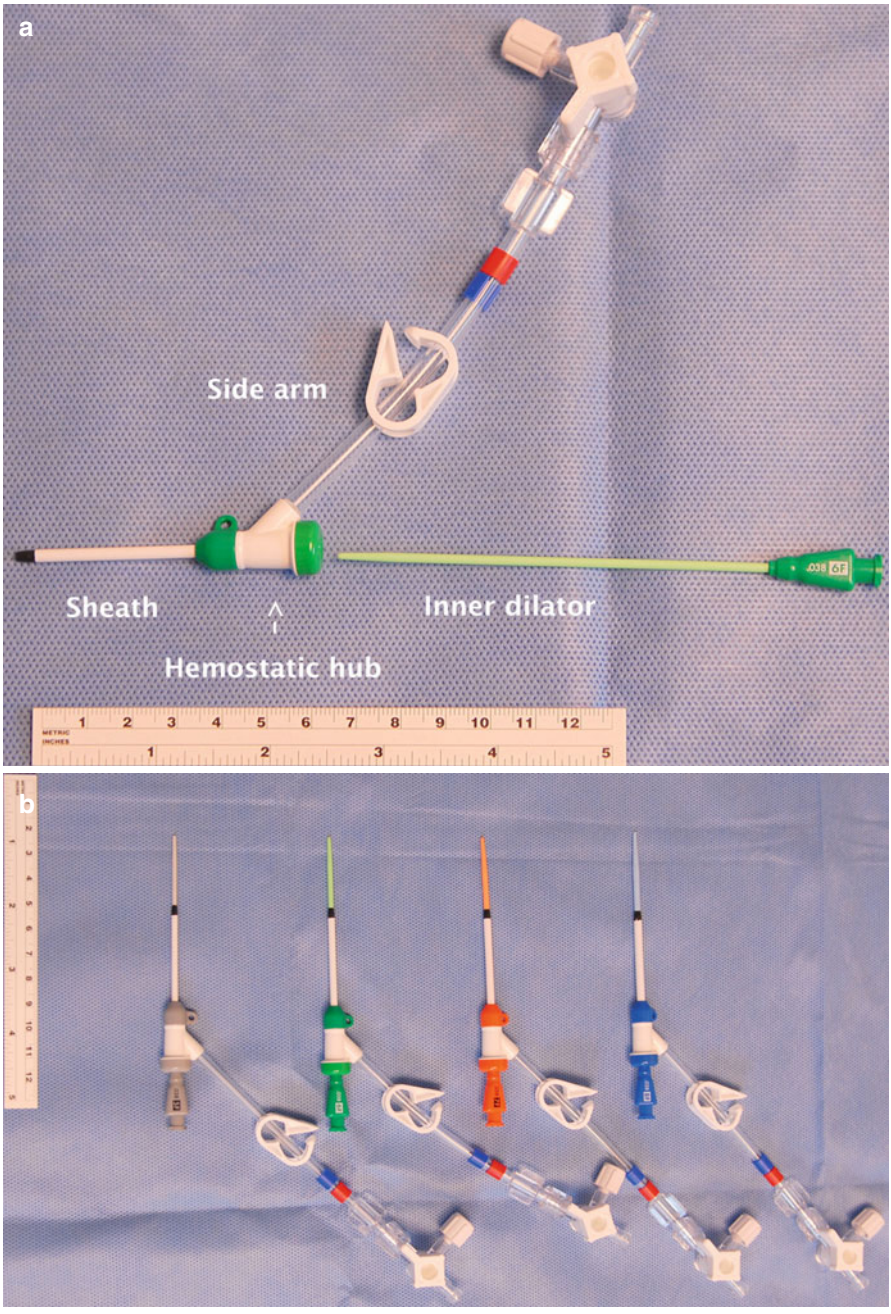


Fig. 2.2 (**a**) Components of a vascular sheath. (**b**) In general, short sheaths (4 cm) are used for dialysis access interventions. Sheaths are described by their inner diameters. The different sheath sizes are shown here. The 6 F sheath is frequently used as the routine sheath

Sheaths also come in different lengths. For AV access interventions, a short sheath (4 cm) is routinely used. In general, a 4 cm 6 Fr short sheath is often used as the routine sheath for intervention. The sheath can be "up-sized" if larger angioplasty balloon or stent deployment is required.

Dilator

Dilators are used to enlarge the puncture tract to facilitate the placement of sheaths, catheters or devices. Dilatation is done by sequentially passing larger dilators over a guide wire till the tract is adequately sized to accept the intended sheath, catheter or device (Fig. 2.3). Unlike sheaths that are sized by their inner diameter, dilators are sized by their outer diameter. Hence, a 7–8 Fr dilator is needed to enlarge the tract for a 6 Fr sheath. In general, sheaths come together with their appropriately sized dilator in a pack and extra dilators are not required unless you are planning to upsize the sheath by 2 Fr or more.

Catheter

Similar to dilators, catheters are sized by their outer diameter using the Fr system. Again, there is a huge variety of catheters available for diagnosis and intervention. Broadly, catheters can be classified based on their intended use. The material, shape

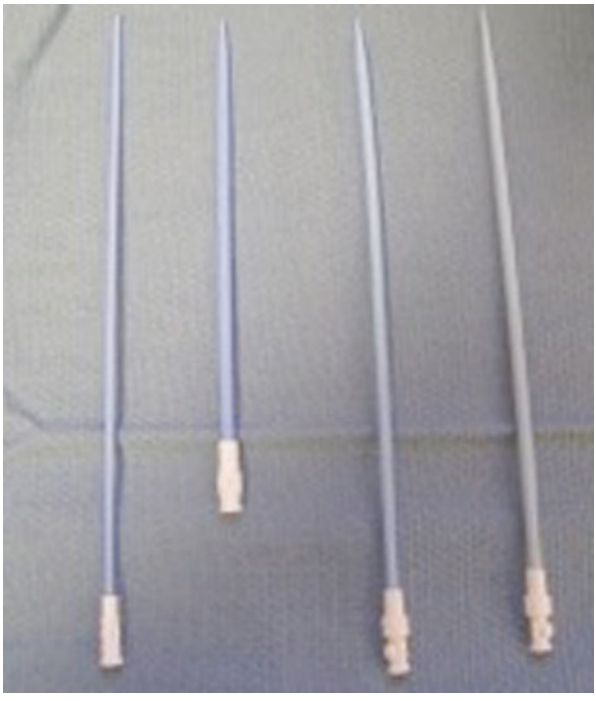


Fig. 2.3 Dilators come in different diameters and lengths. The common feature is the presence of a tapered end

of the catheter tip, end hole diameter, configuration of side holes (location, size and number) of each catheter are designed to fulfill its specific purpose.

Non Selective or Flush Catheter

A flush catheter is used for diagnostic angiography. It has an end hole and multiple smaller side-holes to allow for a uniform dispersion of contrast material during administration. The "pigtail" catheter is a typical flush catheter with a curled tip that is used for aortography.

Selective Catheter

Selective catheters are used to seek the orifice of vessels and direct guidewire into a specific location. For this reason, they come in many different shapes They have less or no side holes and generally have end hole design for angiography to perform angiography. The tip of the catheter may be angled like a hockey stick, such as a Kumpe catheter (Cook Medical, Bloomington, Ind) or have complex curvatures such as the "Cobra" catheters (Cook Medical, Bloomington, Ind).

Guiding Catheters

These are hybrid between diagnostic catheter and sheath. They are typically used in place of sheaths to access vessel of interest and to deliver tools for intervention. They are non-tapered with a lumen that is large enough to accommodate a standard catheter. Their French size refers to their outer diameter.

In summary, every catheter has its own unique characteristics and purpose. The best catheter is one that you are familiar with and is versatile enough to meet your expectations and requirements most of the time. A Kumpe catheter is routinely used for AV access intervention in our institution (Fig. 2.4a–d).

Guidewire

Guide wires come in different thicknesses, lengths, stiffness, coating and tip configurations (Fig. 2.5). The diameters of a guidewire are measured in inches and are available in sizes ranging from 0.008 to 0.038 in.. The common sizes in everyday use are the 0.018 and 0.035 in. wires. Guidewires may have a hydrophilic coating to enhance their maneuverability. The hydrophilic or "water seeking" coating enables the wire to be advanced easily within the vessels. Hydrophilic wires with

steerable or angled tip designs are especially useful in crossing critically stenotic lesion. However, the hydrophilic coating makes the wire feel slippery and can give an impression of movement when it is stationary. A 180 cm 0.035 in. regular angled tip hydrophilic wire is routinely used for dialysis access intervention in our institution.

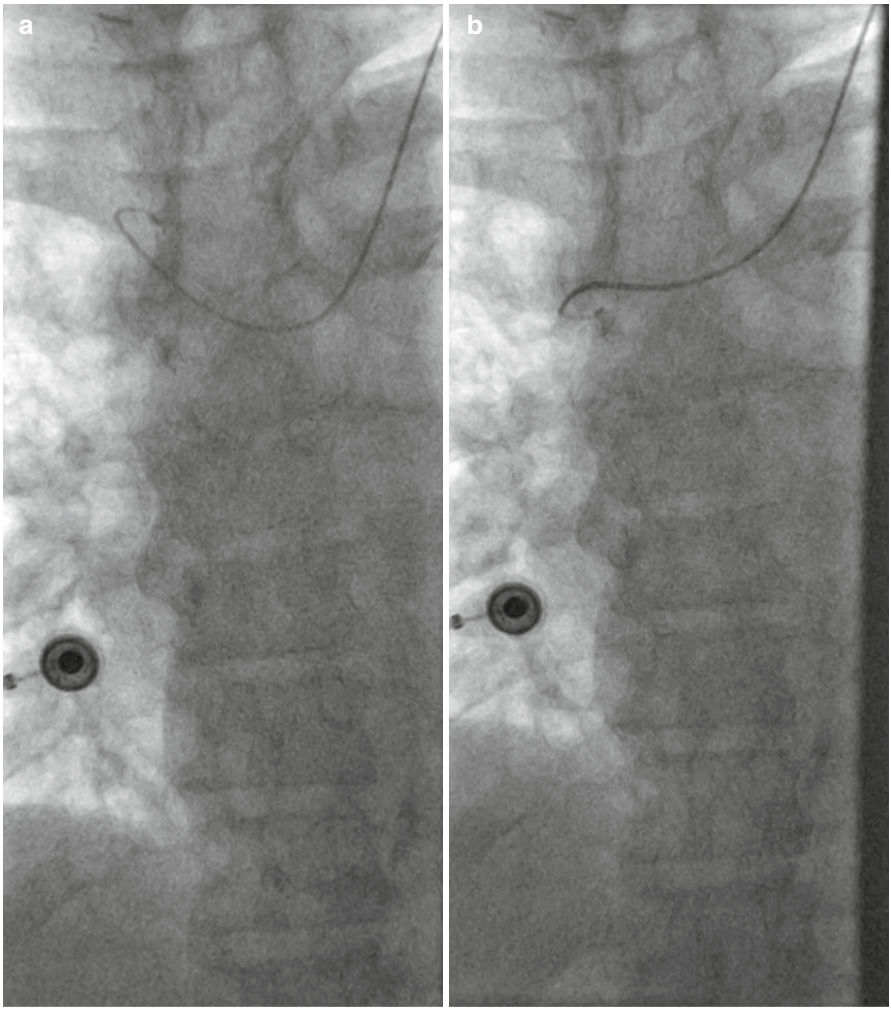


Fig. 2.4 (**a**) The guidewire repeatedly curled upward while attempting to maneuver it into the inferior vena cava. (**b**) A Kumpe catheter was introduced to "stiffen" the wire and exert more control on its movement. (**c**) The guidewire was navigated towards the IVC with the aid of the Kumpe catheter. (**d**) The guidewire finally passed into the inferior vena cava

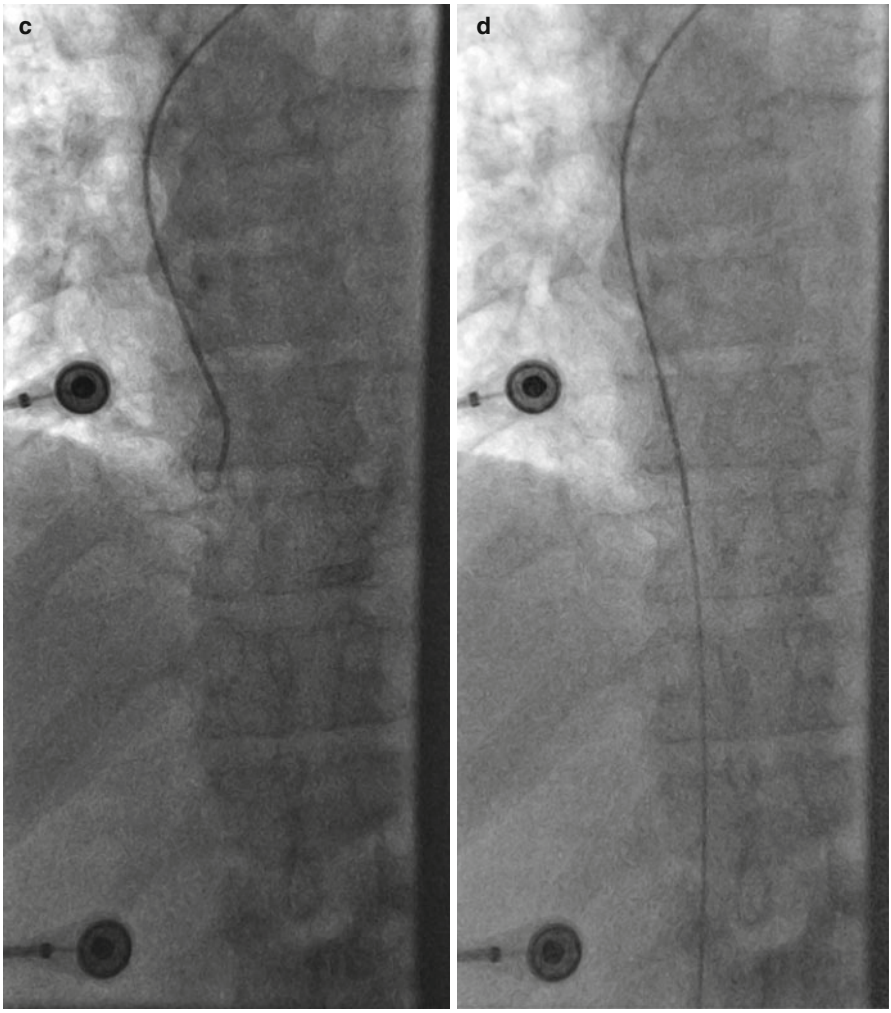


Fig. 2.4 (continued)

Balloon Catheter

There are two basic types of balloons: high pressure, noncompliant balloon that is used for angioplasty or low pressure, compliant balloon (e.g. Forgarty balloon) that is used for embolectomy or temporary vascular occlusion. These balloons are mounted on catheters and the shaft of the balloon catheter is described using the Fr system (Fig. 2.6a–g) and the length of the shaft in centimeters.

The size of the balloon, on the other hand, is described by its diameter when inflated in millimeter; followed by its length in centimeters. For example an "8 by

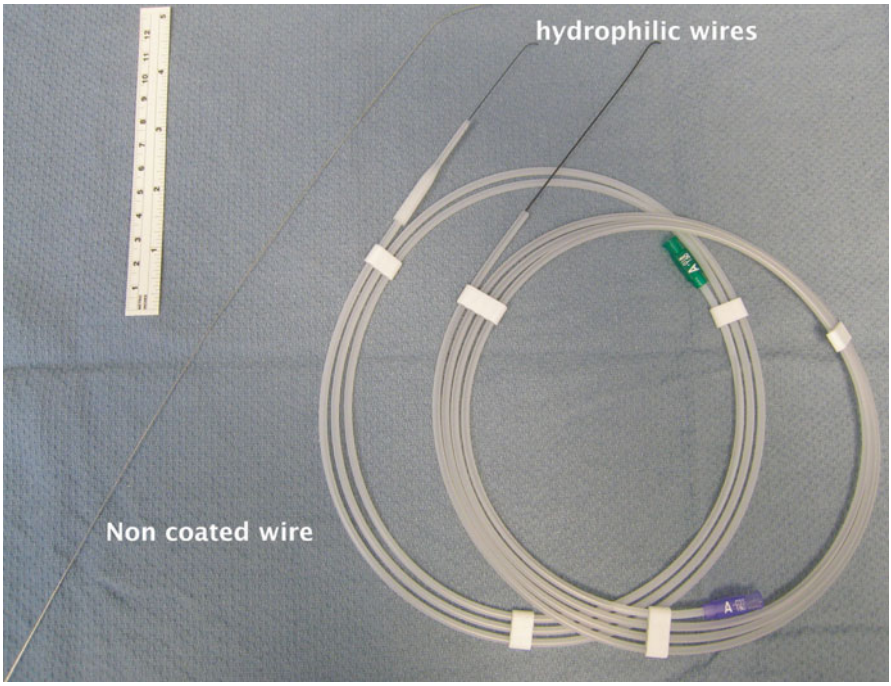


Fig. 2.5 Guidewires can come in different lengths, tip designs and coating

4" balloon has an 8 mm diameter and a 4 cm length when inflated and may be mounted on a 5 Fr shaft. The balloon is tightly wrapped around the balloon catheter before inflation. After use, the deflated balloon will not return to its original size and can be larger in diameter than the shaft that it is mounted on. As such, a 8 mm balloon that is mounted on a 5 Fr balloon catheter will require a 6 Fr sheath to permit smooth removal of the balloon catheter. The size of the sheath required to permit the passage of the balloon catheter is usually described in the product insert. .

A "cutting" or "scoring" balloon is a noncompliant balloon with atherotomes or blades mounted on its surface to "cut" or "score" the stenotic lesion during inflation. It is useful in the treatment of stenotic lesions that are resistant to balloon angioplasty.

It is important to know the nominal pressure and the rated burst pressure of the balloon when performing an angioplasty procedure. These pressures are usually indicated in the product insert of the angioplasty balloon. The nominal pressure is the inflation pressure at which the stated diameter of an angioplasty balloon is achieved. The rated burst pressure (RBP) is the pressure at which 99.9 % of balloons can maximally withstand before rupture with 95 % confidence. It is advisable not to inflate beyond the rated burst pressure as rupture of the angioplasty balloon can result in embolism of the balloon fragments and retrieval of a ruptured balloon may be difficult.

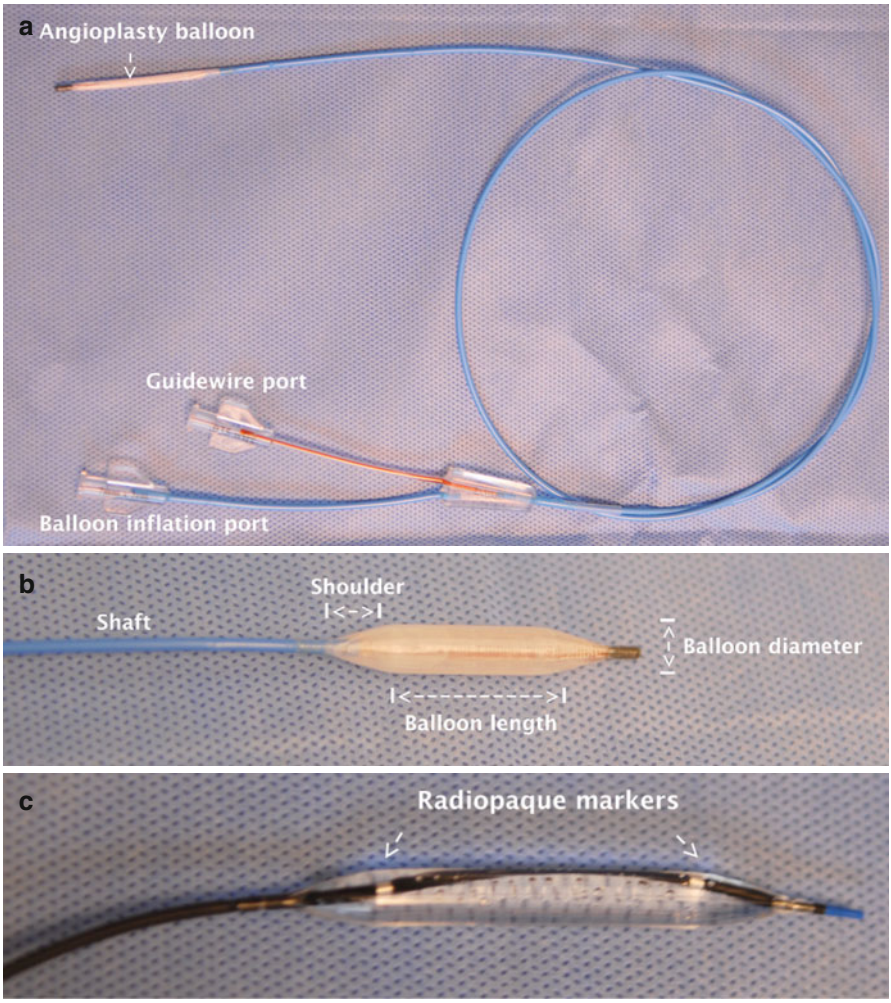


Fig. 2.6 (**a**) Components of an angioplasty balloon catheter. This is an example of a high pressure, non compliant balloon. (**b**) The size of an angioplasty balloon is described by its diameter when inflated in millimeter; follow by its length in centimeters. The balloon is mounted on the tip of a catheter. (**c**) Radiopaque markers are present to mark the position of the balloon during fluoroscopy. (**d**) The characteristics of the angioplasty balloon catheters are described in the product insert. Information on the recommended sheath size, guide wire and rated burst pressure of the balloon are indicated. (**e**) The nominal pressure and rated burst pressure are usually indicated in the product insert. The nominal pressure is the inflation pressure at which the stated diameter of an angioplasty balloon is achieved. The rated burst pressure (RBP) is the pressure at which 99.9 % of balloons can maximally withstand before rupture with 95 % confidence. (**f**) The deflated angioplasty balloon will not return to its pre-inflated size after being used and is bigger than the diameter of the balloon catheter that it is mounted on. Therefore, even though it is mounted on a 5 Fr balloon catheter, a 6 F sheath is required to permit smooth removal of the entire balloon catheter after use. (**g**) The Forgarty balloon (Edwards Lifesciences, Irvine, CA) is an example of a low pressure, compliant balloon

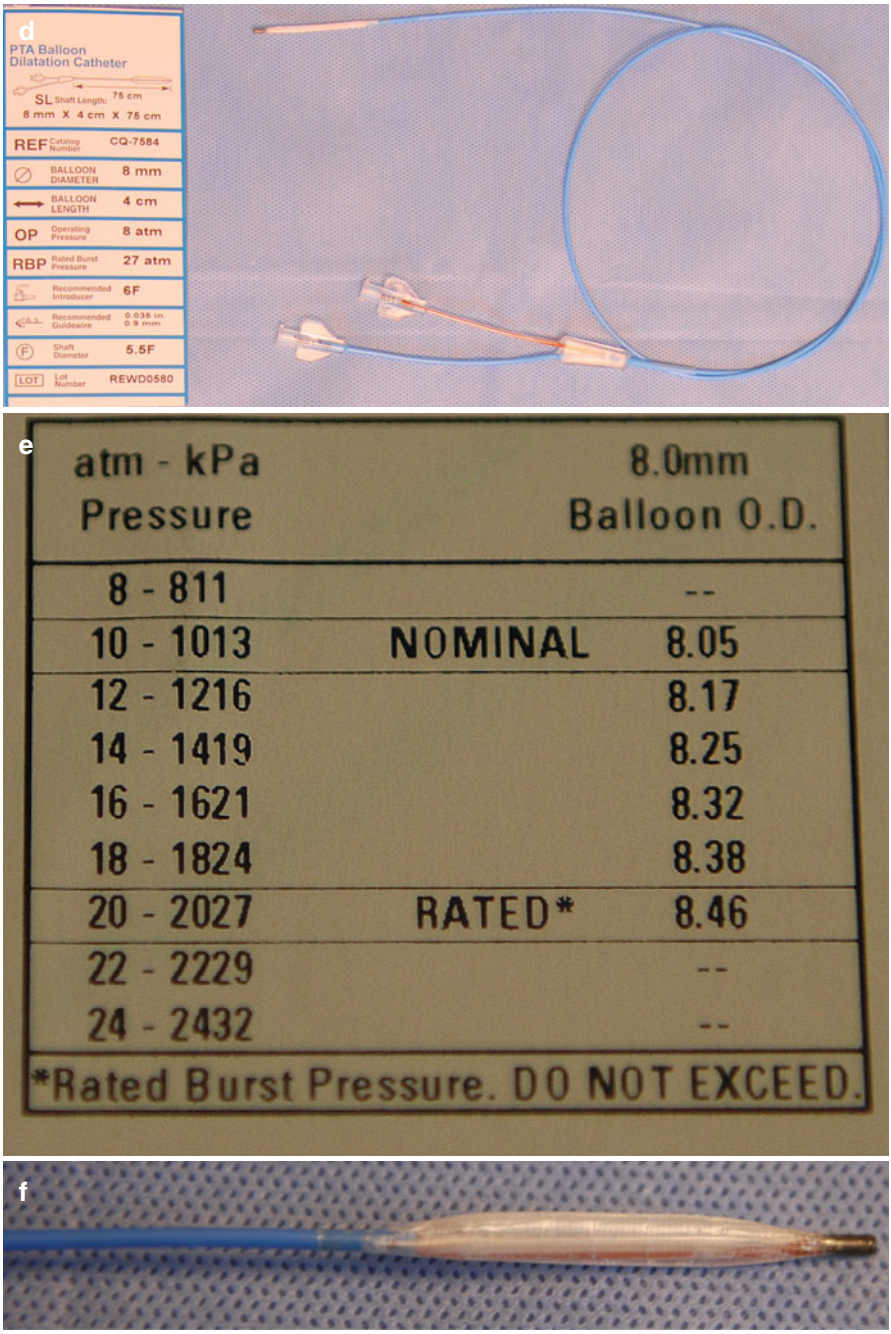


Fig. 2.6 (continued)

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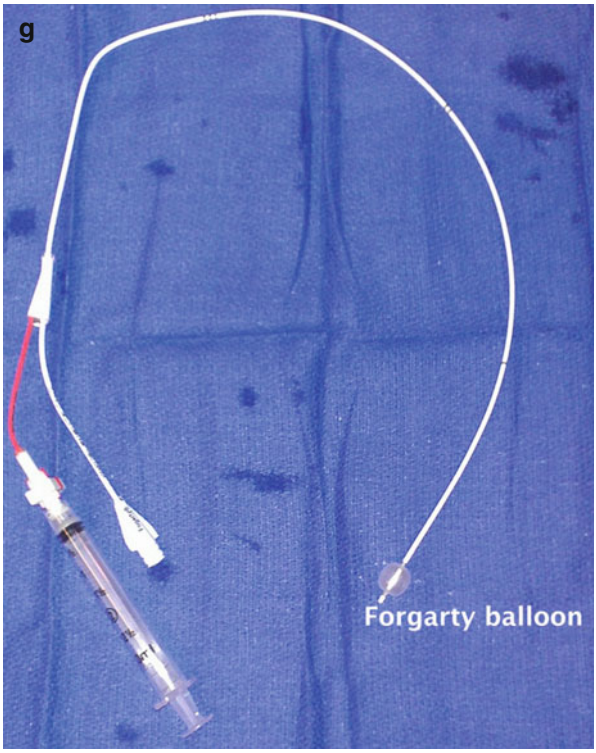

The angioplasty balloon can be inflated either using an inflation device or a syringe assembly. The inflation device looks like a huge syringe with an attached manometer. It has a locking mechanism to maintain pressure and allow inflation of an angioplasty balloon to a precise pressure. These devices are designed for one time use and may be costly. An alternative is to manually inflate the balloon using a syringe assembly consisting of a 3 and 10 mL syringe connected via a 3-way stopcock. The balloon is first inflated using the 10 mL syringe. The 3-way stopcock is then turned and pressure is maintained using the 3 mL syringe. The pressure should be maintained for approximately 3 min to ensure adequate dilatation and effacement of the stenosis.

Stents

Stents are broadly classified into balloon expandable or self-expanding balloon stents. Balloon expandable stents requires balloon dilatation to increase their diameter from the compressed state. They have greater radial strength and can be over dilated but they will not return to their deployed shape when crushed or compressed; hence they are less suitable to be used in peripheral vessels in the limbs. However, they are preferred when accurate positioning of the stent is of paramount

importance. One such example is during the treatment of subclavian artery ostial stenosis, wherein the stent has to be positioned accurately across the stenosis with minimal protrusion of the stent into the aortic lumen. Self-expanding stents will conform to the vessel wall and expand to its designed diameter. They have greater flexibility and will return to original shape after bending or compression.

The flexibility and strength of a stent is dependent on the construction material, design and configuration of its "cells". A stent is made up by multiple cells that are connected by struts. A closed cell design is one where struts support every cell. In comparison, in a stent with open cell design, some cells are not in contact with any struts at all. By varying the cell designs and number of struts, the flexibility and radial strength of a stent can be altered.

Stents can be constructed with stainless steel or alloys such as Nitinol and Elgiloy (Fig. 2.7a). Nitinol exhibits shape memory, allowing it to regain its shape after compression. Stents that are constructed using Nitinol provide better long-term patency compared with stainless steel stents in the treatment of hemodialysis graft related stenosis [1].

Stents may also be "bare" or "covered" with relatively inert polymeric covering such as expanded polytetrafluroethylene (PTFE) (Fig. 2.7b). The intention of the covering is to decrease the high restenosis rates associated with bare metal stents that is caused by neointimal hyperplasia. The covering is postulated to work by providing a barrier to prevent migration of smooth muscle cells and separate the thrombogenic wall surfaces from the luminal blood flow. The characteristics of the four types of self expanding covered stents that are available in the United States are summarized in Table 2.1 [2]. Except for the Flair stents, which are approved by

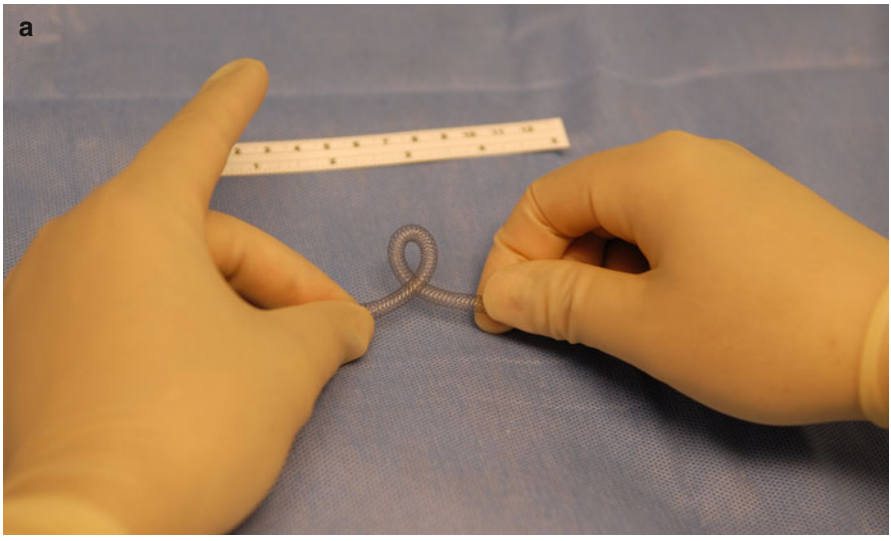

Fig. 2.7 (**a**) Bare nitinol stents exhibit great flexibility and return to their original shape after compression. (**b**) Different types of stents

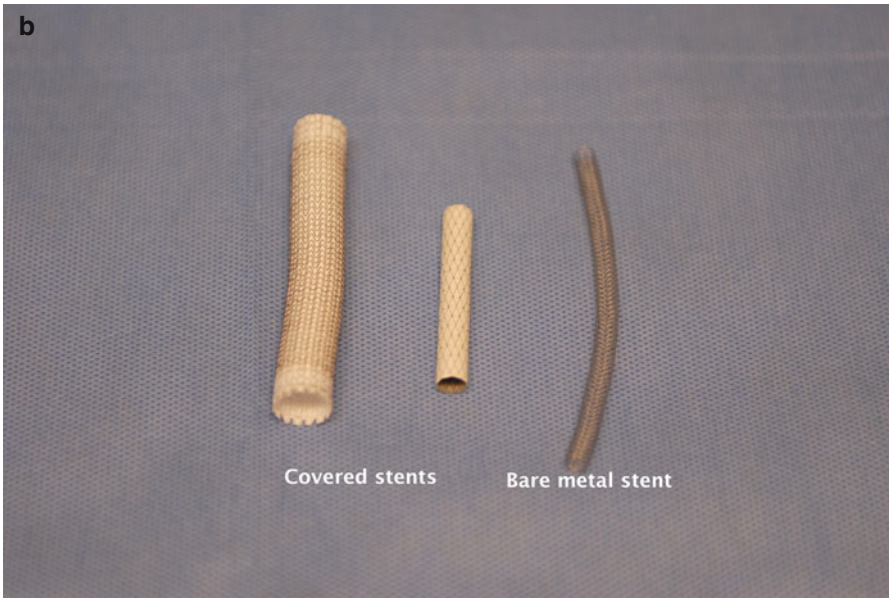

Fig. 2.7 (continued)

Table 2.1 Types of stents used in dialysis vascular access intervention

Name of stents	Wallgraft	Viabahn	Fluency	Flair
Stent material	Elgiloy	Nitinol	Nitinol	Nitinol
Covering	Polyethylene terephthalate	Expanded PTFE	Expanded PTFE	Expanded PTFE
FDA approval	Trachiobronchial indications	Treatment of arterial occlusive lesions	Tracheobronchial indications	Venous anastomotic stenoses in AVGs
Characteristics	Relatively rigid with poor contourability	Very flexible	Stiffer than Viabahn	Very flexible, available in straight or flared configuration

FDA for the treatment of venous anastomotic stenosis in arteriovenous grafts, the use of the covered stents for all other purposes in dialysis access management remains off label.

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Basic Endovascular Skills and Techniques

3

Chieh Suai Tan, Suvranu Ganguli, Sanjeeva P. Kalva, and Steven Wu

Introduction

Performing interventional procedures requires a different skill set not traditionally associated with nephrology training. It involves mastering fluoroscopic eye-hand coordination, manipulating guidewires, appreciating the behaviors of various guidewires, utilizing catheter combinations and more. Nevertheless, with the right attitude and training, it is something that can be readily learned and mastered.

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Preparation for Intervention

1. Always review the indications and examine the patient. Review images from any previous interventions and operations. Plan the approach in advance and identify the initial puncture site. Anticipate any problems that you might come across during the procedure (Fig. 3.1a).
2. The equipment needed for the intervention should be prepared and laid out on the procedure table in a sterile fashion. Flush the lumens of all the sheaths and catheters with normal saline solution (Fig. 3.1b).
3. The patient should be positioned such that you are working forehand with your master hand most of the time.
4. Clean and drape the patient in a sterile fashion. Only the area of intervention should be exposed. The rest of the body and surfaces of equipment should be covered by sterile drapes (Fig. 3.1c). Proper drapes are required as the length of wires and catheters can be long, and the wires or catheters can easily get contaminated when they fall on an uncovered area.

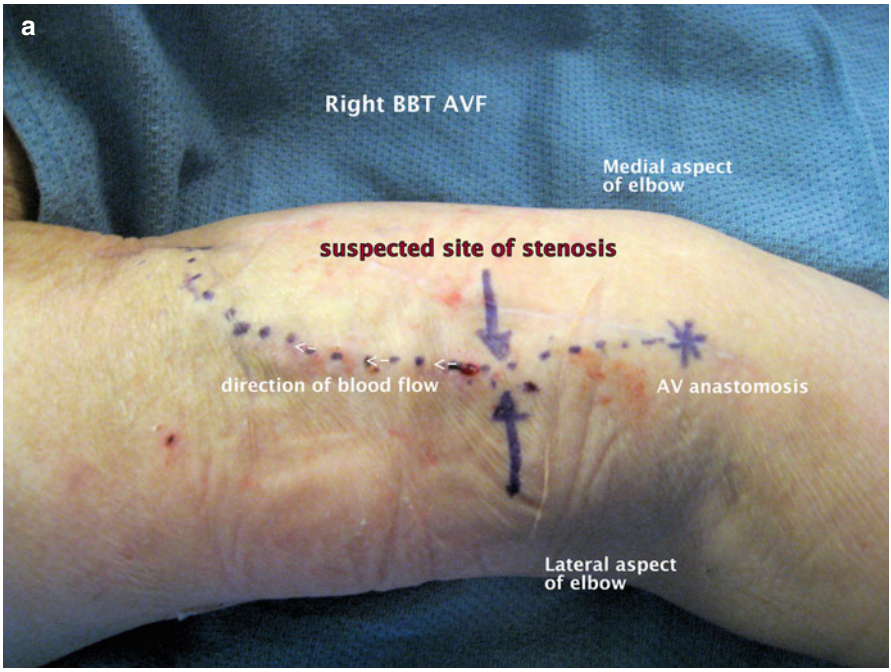

Fig. 3.1 (**a**) Right arm of the patient. Note the needling sites which are on the medial side of the arm and the presence of a scar that runs along the AVF. This patient has a right brachiobasilic arteriovenous fistula. Assess the direction of blood flow and the possible site of stenosis. (**b**) Prepare your equipment on a table in a sterile fashion. (**c**) Clean and drape the patient, leaving only the area of interest exposed. Cover the sides of the table and image detector with clear sterile sheets

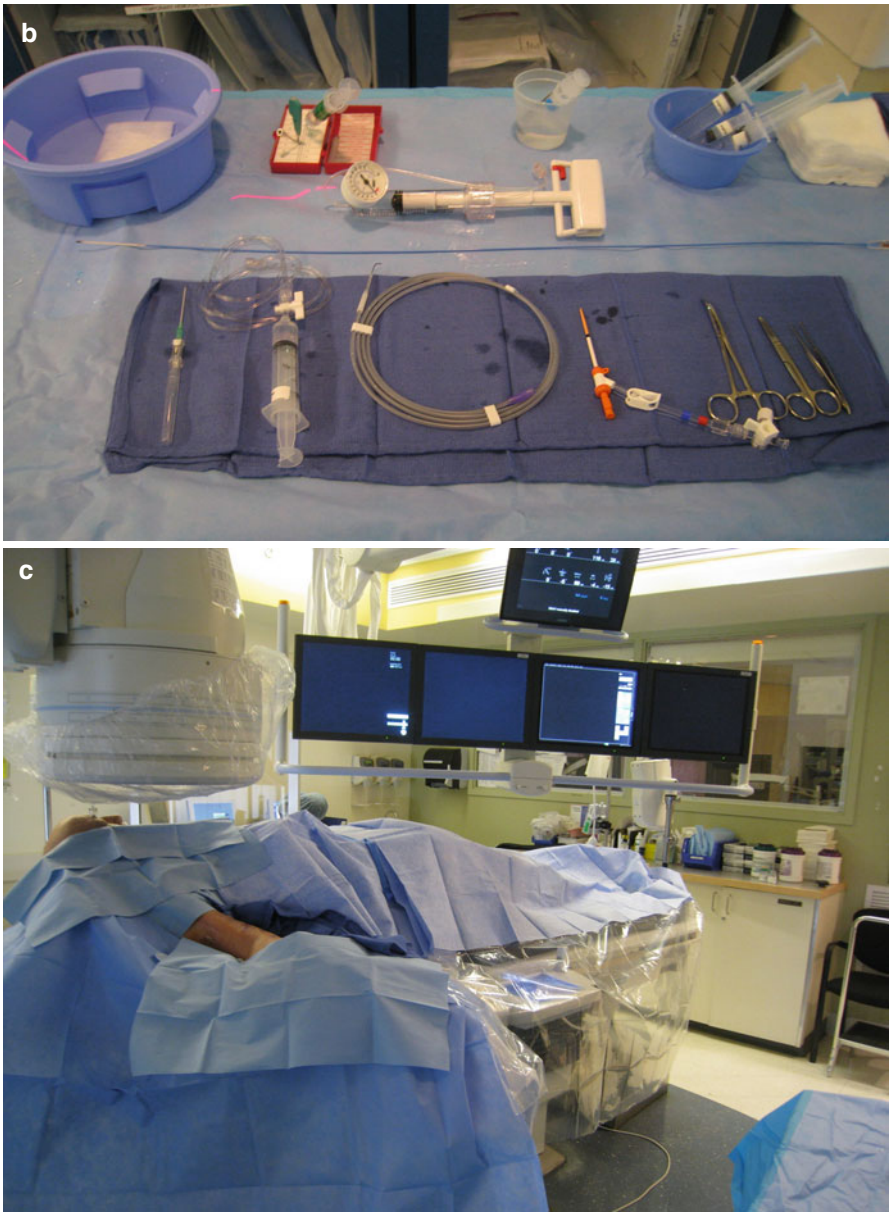

Fig. 3.1 (continued)

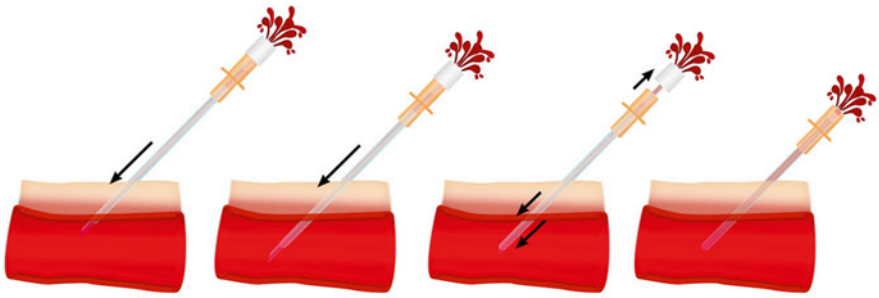

Fig. 3.2 The plastic cannula of the angiocath does not cover the needle completely. Therefore, even if there is "backflash" of blood when the needle tip enters the vessels, the cannula may not yet be within the vessel. There will be difficulties threading the cannula into the vessels. Hence, advance the angiocath a few millimeters more after the initial "flashback" before pushing the cannula into the vessel

The Initial Puncture

We routinely use an angiocath (intravenous catheter) for the initial puncture of the vascular access. The angiocath consists of a needle and a plastic cannula (Fig. 3.2). The plastic cannula does not cover the needle completely. The cannula ends just before the tip of the needle becomes bevelled. Hence, the angiocath needs to be advanced an extra few millimeter after seeing the initial back flash of blood. This is required as the needle tip has entered the lumen of the vessel but the cannula may still be within the vessel wall. Premature withdrawal of the needle from the cannula will lead to an inability to thread the cannula into the AV access.

1. Locally anesthetize the area with lidocaine before placing angiocath (Fig. 3.3a). Hold the vessel or graft between the left thumb and index finger.
2. Hold the angiocath in your right hand like a pen (Fig. 3.3b).
3. The angle of the puncture should usually be about 40–45 degrees. It should not be too steep in order to allow for smooth passage of the guide wire.
4. Advance the angiocath gently. Once a back flash of blood is seen, advance the angiocath by a few millimeters more. Hold the needle in position while advancing in the cannula (Fig. 3.3c). Remove the needle from the cannula and attach a syringe to the cannula (Fig. 3.3d). Initial diagnostic fistulogram or graftogram can be performed by injecting contrast material through the cannula. Adding an extension tubing between the cannula and the syringe can allow the operator to inject the contrast material from a distance, thus decreasing the radiation dose to the operator.
5. A "flashback" will not be seen when puncturing a thrombosed graft or fistula. Instead, you will feel a "give" when the needle enters the graft or fistula. Advance the cannula and remove the needle. Jiggle the cannula in and out of the graft. If you are within the graft, some blood (dark colored) may appear within the cannula. Confirm the position by passing a 0.035 in. guide wire into the cannula gently and checking under fluoroscopy.

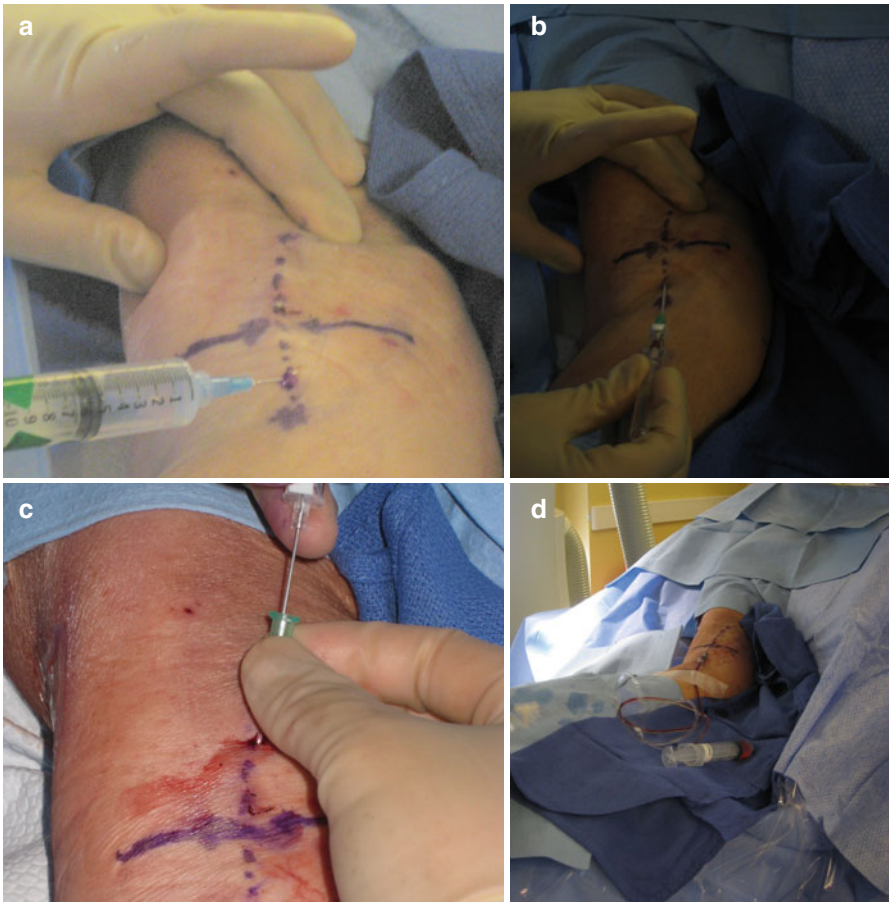

Fig. 3.3 (**a**) Anesthetize the puncture site with lidocaine. (**b**) Hold the angiocath like a pen. (**c**) Hold the needle and push the cannula into the vessel. (**d**) Connect the syringe to the cannula to do a diagnostic fistulogram

Sheath Placement

The puncture site is secured by exchanging the cannula for a vascular sheath over the guidewire.

1. Insert a guidewire into the cannula. The floppy tip of the guidewire can sometimes be difficult to pass through the hub of cannula or needle. Grasp the wire near its leading edge between the thumb and the index finger while pinning the wire against the palm with the rest of the fingers. Straighten the wire tip by applying an upward traction force using the thumb and index finger. Occasionally, the wire may not pass as the cannula/ access needle is abutting against the vessel wall. Pull back the cannula/access needle to advance the wire (Fig. 3.4).

2. The guidewire should be advanced a few centimeters at a time (Fig. 3.5a). If the distance between the catheter hub and location where the guidewire is grasped is too far apart, the guidewire will buckle during advancement (Fig. 3.5b).
3. The insertion of the guidewire should be under fluoroscopic guidance (Fig. 3.5c, d). The tip of the guide wire should be advanced up the vessel as far as possible. Once in position, pin down the wire while removing the cannula (Fig. 3.5e).
4. The vascular sheath comes coupled to an inner dilator. Thread the vascular sheath with the inner dilator over the guidewire and advance it into position (Fig. 3.5f). The tapered leading edge of the inner dilator will help to dilate the path for the

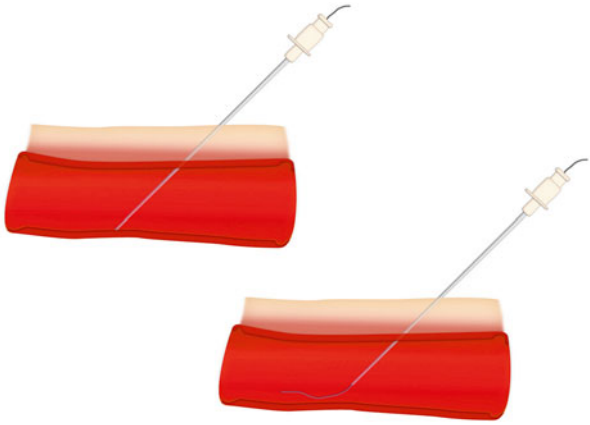

Fig. 3.4 The wire may appear to "jam" while passing through a cannula or access needle. This is seen when the angle of the needle entering the vessel is too steep or if the tip of cannula is abutting the vessel wall. Pull back the cannula slightly to advance the wire

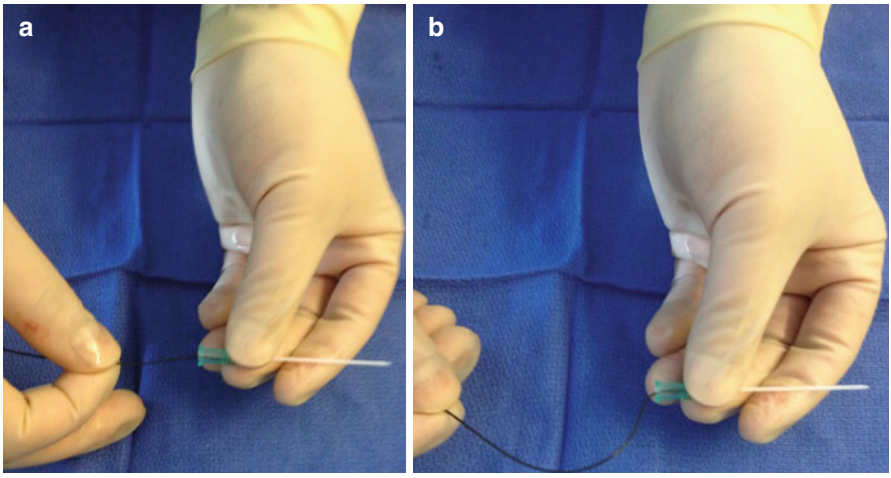

Fig. 3.5 (**a**) Hold the wire near the hub to advance it. (**b**) If the wire is grasped too far from the hub, it will buckle when you try to push. (**c**) Insert the wire into the cannula. (**d**) Push in the wire under fluoroscopic guidance. (**e**) To minimize bleeding, compress the venotomy site when removing the cannula. (**f**) Thread the sheath into the vessel over the guidewire, while holding and using the guidewire as a rail

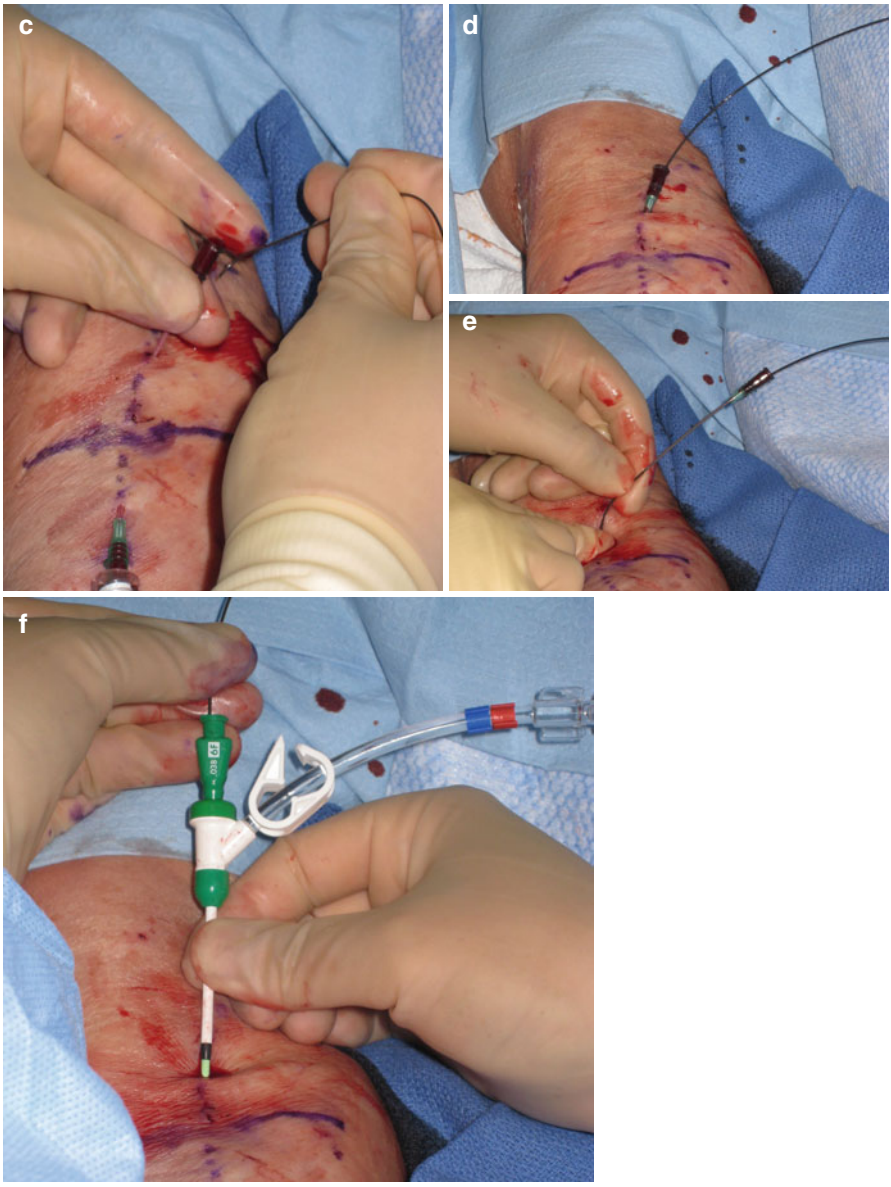

Fig. 3.5 (continued)

sheath. Once the sheath sits snugly over the initial puncture site, remove the inner dilator from the sheath.

5. With the sheath in place, catheters, angioplasty balloons and stents can be threaded over the guide wire into the vascular lumen for endovascular interventions.

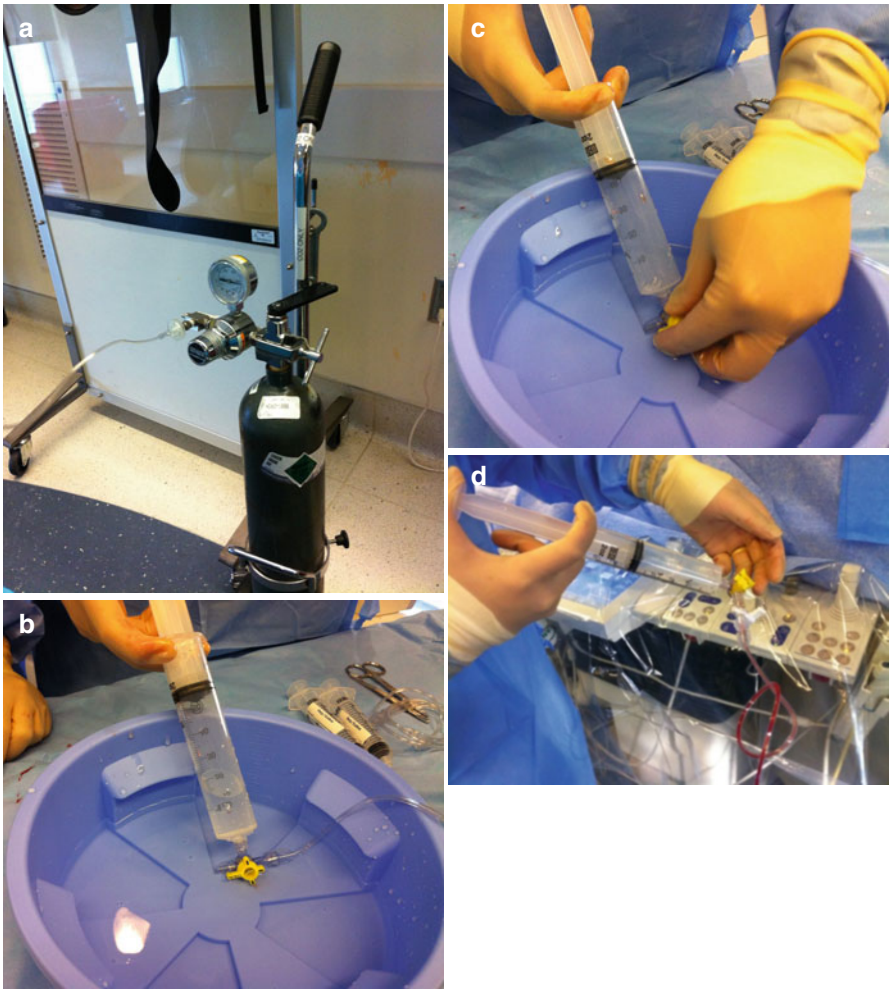

Fig. 3.6 (**a**) CO_2 is stored in pressurized tanks. A 60 cc syringe coupled with a 3 way stopcock and extension tubing is used to draw CO_2 from the tank. (**b**) As CO_2 is a colorless and odorless gas, there is a risk of inadvertent contamination by air while preparing the syringe. To minimize the risk of air contamination, always submerge the 3 way stopcock in saline while manipulating it. First, fill up the syringe with saline. Purge the syringe of saline and allow the syringe to be filled with CO_2. The syringe should fill up automatically when the connection to the pressurized CO_2 is opened. Maintain pressure on the plunger of the syringe while it is being filled up by CO_2. (**c**) Once the syringe is filled up with CO_2, turn the stopcock to expel it completely before allowing it to fill up from the CO_2 tank again. Repeat this process at least three times. On the final fill, turn the stopcock to "lock" the CO_2 within the syringe and disconnect the stopcock from the tubing. (**d**) As an added precaution to prevent air contamination, use a 2 way stopcock to connect the CO_2 syringe with its 3 way stopcock to the angiographic tubing. The CO_2 is now ready to be used as a contrast agent. Turn the stopcocks in the appropriate direction to delivery the CO_2 into the vessel

Contrast and Fluoroscopy Tips

1. "Half strength" contrast material is used when imaging the peripheral vessels. Dilute the contrast material with normal saline in a 50/50 mixture. "Half strength" contrast material is also used to fill up the insufflator to inflate angioplasty balloons.
2. "Full" strength (undiluted) contrast material is used when imaging the central veins. To decrease movement artifacts and improve image quality, the patient should be instructed to hold his or her breath while imaging the central veins. The digital subtraction angiography (DSA) pedal should only be depressed after the chest has stopped moving.
3. For DSA, inject the contrast only after the "mask" has been created, i.e., after the screen has changed to a "white-out" appearance.
4. Carbon Dioxide (CO_2) may be used as a contrast material in patients who are allergic to iodinated contrast material, or in pre-dialysis patients whose renal function need to be preserved. CO_2 may be delivered by a hand-held syringe method or by a plastic bag delivery system (AngioDynamics, Queensbury, NY). Preparation of the equipment for CO_2 angiography are as shown in Fig. 3.6a–d. A digital subtraction angiography system is a pre-requisite for use of CO_2 as a contrast material because it is often impossible to assess intravascular CO_2 on non-subtracted radiography.

Sheath Removal

1. To secure hemostasis after sheath removal, a strand of non-absorbable suture is used to apply a purse string suture around the sheath (Fig. 3.7a, b).
2. Tighten the two ends of the purse string suture while removing the sheath (Fig. 3.7c).
3. Compress the venotomy site while tying down the suture (Fig. 3.7d, e).
4. Examine the thrill of the AV access after hemostasis is secured.
5. Stitches can be removed in 1–2 days.

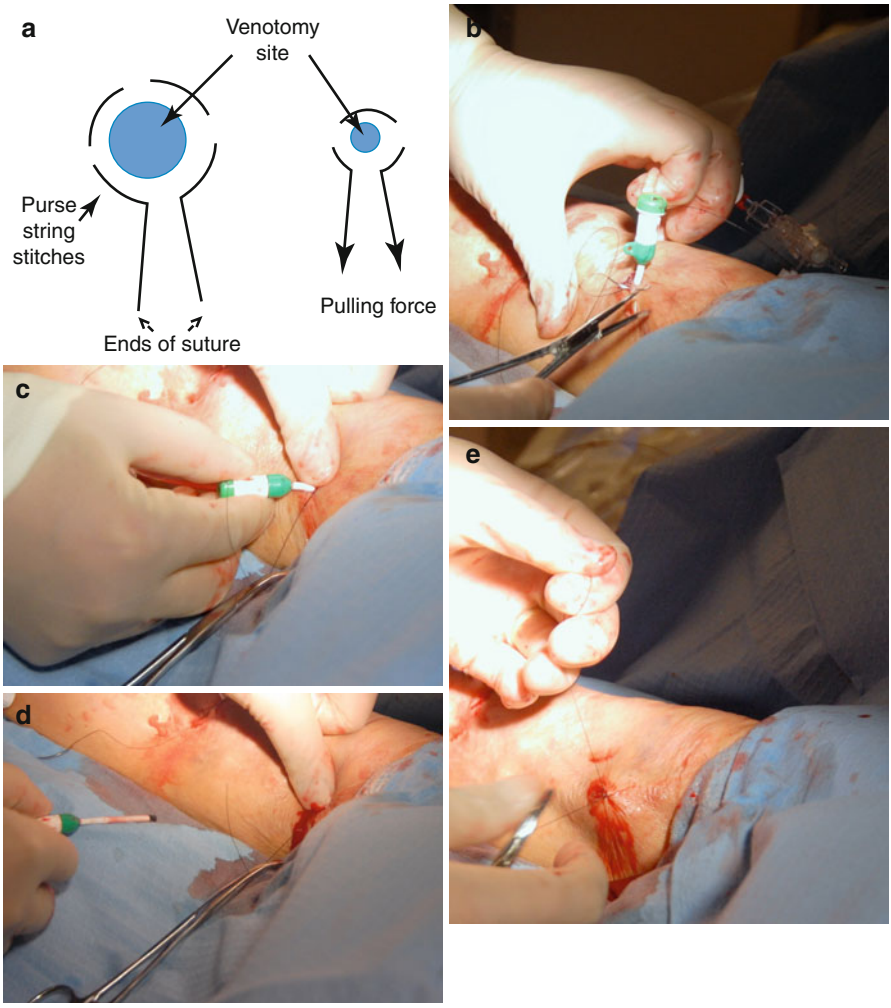

Fig. 3.7 (**a**) The purse string suture is performed by running the stitches in and out along the edge of a wound in circular fashion such that when the ends are drawn tight, the wound is closed like a purse. (**b**) Apply a purse string suture around the sheath, beginning at the 6 o'clock position. Keep a close distance to the sheath as you apply the stitches. Encircle the sheath with the purse string suture. (**c**) Pull the purse string suture as you remove the sheath. (**d**) Compress the venotomy site once the sheath has been removed. (**e**) Tie down the suture to secure hemostasis

Radiation Safety

4

Steven L. Hsu, Patrick D. Sutphin, and Sanjeeva P. Kalva

Introduction

At the end of 2009, 370,077 persons with end stage renal disease (ESRD) were treated with hemodialysis, and the number of ESRD individuals requiring hemodialysis will continue to increase in the foreseeable future [1]. The mortality rate for ESRD patients receiving dialysis has been declining since 2002 [1]. The combination of increasing prevalence of ESRD patients requiring hemodialysis and their improved survival will correspond to a growth in the number of fluoroscopically-guided hemodialysis access interventions.

Recognizing the serious injuries arising from prolonged radiation exposure during fluoroscopically-guided procedures, the United States Food and Drug Administration issued a Public Health Advisory in 1994, which not only raised the level of awareness and concern of physicians utilizing fluoroscopy, but also prompted investigations for improvements in reduction and documentation of radiation exposure.

In addition to acute radiation exposure injuries, hemodialysis patients are at a greater risk of all-cause mortality as well as an increased risk for cancer and cardiovascular disease. These patients tend to have multiple comorbidities and risk factors that contribute to the risk of cancer and cardiovascular disease, but the traditional risk factors may not account for all of the increased risk [2, 3]. A recently proposed risk factor in hemodialysis patients for both cancer and cardiovascular disease is the cumulative exposure to ionizing radiation. Kinsella et al. performed a

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retrospective study of 100 maintenance hemodialysis patients with a median follow up of 3.4 years. Review of patient records found a median annual dose of 6.9 mSv per patient year and a median cumulative effective dose (CED) of 21.7 mSv over the study period. Thirteen of the 100 patients studied had a CED greater than 75 mSv [4]. Additional studies confirmed the elevated CED in dialysis patients [5, 6]. As survival of patients on hemodialysis improves, the elevated CED for some patients may have significant clinical impact. This chapter will focus on methods to minimize radiation exposure during fluoroscopy guided dialysis access interventions.

Definitions and Units

Radiation Exposure

Radiation exposure is the amount of electrical charge produced by ionizing electromagnetic radiation in a unit mass of air. Exposure is expressed in coulombs per kilogram or roentgens [7, 8]. The quantity of ionization of air can be correlated to absorbed dose.

Air Kerma

Kerma is an acronym for *k*inetic *e*nergy *r*eleased in *ma*tter. Kerma is measured in the clinical setting as air kerma, which is the kinetic energy released into air and expressed in units of gray (Gy) [7, 8].

Absorbed Dose

Absorbed dose (D) is amount of radiation energy absorbed per unit mass of matter. The absorbed dose can also be expressed in units of Gray, which facilitates comparison of air kerma and absorbed dose. An air kerma of 1 mGy is deemed to be approximately equivalent to an absorbed dose of 1 mGy [7, 8].

Peak Skin Dose

The peak skin dose is the highest radiation dose at a point on the patient's skin and expressed in units of Gray [9, 10].

Kerma-Area Product (KAP)

Kerma-area product is also known as roentgen-area product or dose-area product. KAP is computed by multiplying the entrance skin dose to the area of the radiation beam. KAP is expressed in $Gy.cm^2$. Temporal summation of KAP provides an estimate of the skin dose [7–9].

Effective Dose

Performance of a radiologic examination emphasizes targeted radiation exposure for the patient. For example, when a hemodialysis intervention is performed for a patient with elevated venous pressures recorded during hemodialysis and prolonged bleeding at the cannulation sites following hemodialysis, a fistulogram and central venogram of the hemodialysis access will uncover stenotic or occluded central venous segment(s), which will require venous angioplasty and/or stenting. Radiation exposure in this procedure should be limited to the patient's extremity and chest. Not all of the tissues in the extremity and chest will have the same sensitivity to the stochastic effects of radiation. Therefore a radiation-weighting factor for each organ has been computed to take into account the risk to each exposed organ. The effective dose is the weighted sum of the doses to all exposed organs. The effective dose provides a total estimated risk to the patient from radiation exposure [7–9, 11].

Effects of Radiation

Deterministic Effects

The deterministic effects of radiation exposure occur when a threshold radiation dose is exceeded. The severity of deterministic effects increases with the dose. An example of a deterministic effect is radiation-induced skin erythema, which occurs when a skin dose of 2 Gy has been surpassed [7–9, 12]. When the skin dose exceeds 5 Gy, then permanent partial epilation can occur, and when the skin dose exceeds 10 Gy, then permanent epilation occurs along with dermal atrophy or induration [12].

Stochastic Effects

Stochastic effects are not related to threshold doses. The probability of occurrence of a stochastic effect increases with increasing radiation dose. Radiation-induced cancer is the most concerning stochastic effect. Although radiation exposure may not engender cancer for all individuals, increasing the radiation exposure will increase the probability of inducing cancer.

Dose Limits

The International Commission on Radiological Protection (ICRP) was founded in 1928 and has published recommendations to limit the detrimental effects of radiation for all individuals [13]. ICRP has published the recommended dose limits for radiation workers and members of the public. The following are occupational dose limits and do not pertain to planned exposure of patients.

Whole Body Dose

The ICRP recommends a whole body dose limit equal to an effective dose of 20 mSv per year averaged over a 5-year period. Thus, the total effective dose should not exceed 100 mSv during the 5-year time interval. Furthermore, within any single year, the effective dose should not exceed 50 mSv [13].

Extremity Dose

The recommended dose limit for extremities is 500 mSv per year [13]. The majority of radiation exposure in hemodialysis interventions is directed at the extremity. Skin and bone are relatively insensitive to the stochastic effects of radiation, thus the ICRP dose limit for extremities is correspondingly higher compared to the average whole body effective dose. Although hemodialysis fistulas and grafts are more durable than tunneled hemodialysis catheters, fistulas and grafts typically require repeat interventions to optimize their function and prevent access loss, thus the interventional radiologist should be mindful of one's occupational exposure and also the patient radiation exposure and deterministic effects which can occur.

Methods to Reduce Radiation Exposure During Dialysis Access Interventions

Pre-procedural Planning

Reduction of patient radiation exposure begins during the pre-procedural planning phase. The details of a patient's prior interventions and associated images should be reviewed to familiarize the interventional radiologist with the patient's vascular anatomy, identify appropriate sites of vascular access, and anticipate problematic locations. Meticulous review can reduce the procedural time, utilization of the angiography suite, and dramatically lower radiation exposure.

Prior to performance of a procedure, the cumulative radiation dose should be aggregated and the dates of prior procedures should be noted. The effects of radiation exposure as it relates to skin injury are considered additive when acquired within a 60-day period [9, 14]. Any poorly functioning or completely nonfunctional hemodialysis access should be managed expeditiously. Although the cumulative radiation dose acquired within the 60-day timeframe is taken into consideration, this should not thwart prompt performance of hemodialysis access interventions. Prior recent radiation exposure should guide interventional radiologists to inform patients of the potential for skin injury.

Once the patient arrives to the angiography suite, a confirmatory ultrasound of the arteriovenous graft or fistula should be performed to verify the planned sites of access and to further elucidate the locations of the graft or fistula requiring intervention.

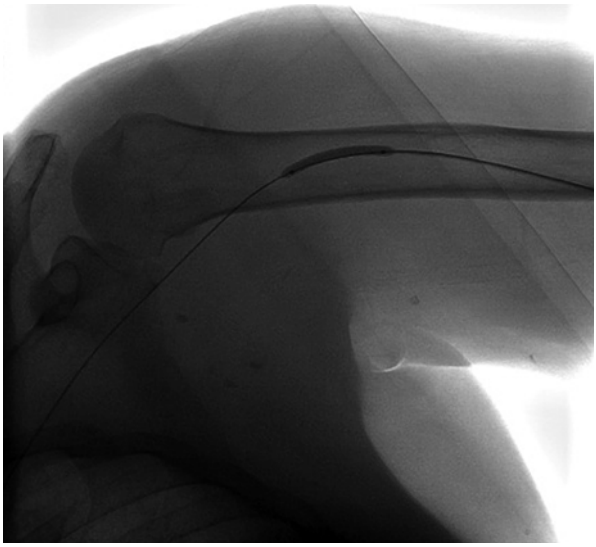

Fig. 4.1 Lack of collimation: Angioplasty performed within the cephalic vein at the site of outflow vein stenosis without consideration of collimation

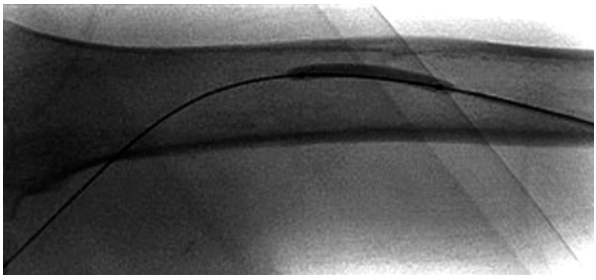

Fig. 4.2 Collimated image: Angioplasty performed within the cephalic vein at a second site of stenosis with collimation demonstrates a corresponding improvement in image contrast and quality while reducing radiation dose

Procedural Techniques for Patient Radiation Dose Reduction

The principle of ALARA (as low as reasonably achievable) must be a priority when imaging patients for diagnostic or therapeutic purposes. The following are techniques which minimize patient radiation exposure and permit adherence to the ALARA principle.

Collimation

Collimation involves defining the boundaries of radiation exposure. Only the immediate location where clinical information is required should be imaged. Not only does collimation reduce radiation dose to the patient, but collimation also improves image contrast and quality by reducing the scatter radiation incident on the detector (Figs. 4.1 and 4.2).

Exposure Time

Being cognizant of the radiation exposure time and making active attempts to reduce the exposure times help adhere to the ALARA principle. For a given pulse dose,

reducing the exposure time, will reduce the overall patient radiation exposure. At our institution, interventional radiologists are routinely notified when the exposure time exceeds 60 min. Following 60 min of exposure time, our technologists have been instructed to inform us when an additional 5 min of exposure time has transpired. Our institutional policies adhere to the guidelines for patient radiation dose management established by the Society of Interventional Radiology (SIR) [9]. The SIR guidelines recommend informing the operator when any one of several conditions occur. These conditions include exceeding a fluoroscopy time of 60 min, surpassing an air kerma of 5,000 mGy, exceeding a final peak skin dose of 3,000 mGy, and accumulating a kerma-area product of greater than 500 $Gycm^2$ [9]. Knowledge of the exposure time should not prompt an interventional radiologist to cancel or inadequately complete a procedure, however, knowledge of increasing exposure times should guide the physician toward alternative procedural approaches or seek consultation from more experienced colleagues.

Object-Detector and Source-Detector Distances

The distance from the patient to the image detector should be minimized. Minimizing the distance of the patient to the detector reduces scatter and beam intensity. Conversely, the source-detector distance should be maximized. The inverse-square law states that the radiation dose to an object is inversely proportional to the square of the distance from the radiation source to the object. Thus, the procedural table on which the patient is positioned should be elevated as much as possible from the radiation source, however, patient positioning should not limit the ability of the interventional radiologist access to the patient [15] (Figs. 4.3 and 4.4).

Last Image Hold

The last image hold option should be utilized routinely to document and assist with procedural planning rather than acquisition of additional spot fluoroscopic images or performance of digital subtraction angiograms [16]. As an example, prior to stent deployment, a hand contrast injection through the access sheath can be performed to confirm appropriate positioning of the stent. The last image hold option permits the operator the ability to select the appropriate fluoroscopic image, transfer this image to a second monitor, and utilize the image to assist with accurate stent deployment.

Reduction of Pulse Rate

The number of pulses of radiation delivered per second should be reduced to the lowest rate possible and balanced with acquisition of images of adequate quality. The default pulse rate on fluoroscopy units had been 30 pulses per second for many years [14]. At our institution, the default pulse rate has been established at 7.5 pulses per second, which has been deemed adequate for acquisition of quality images.

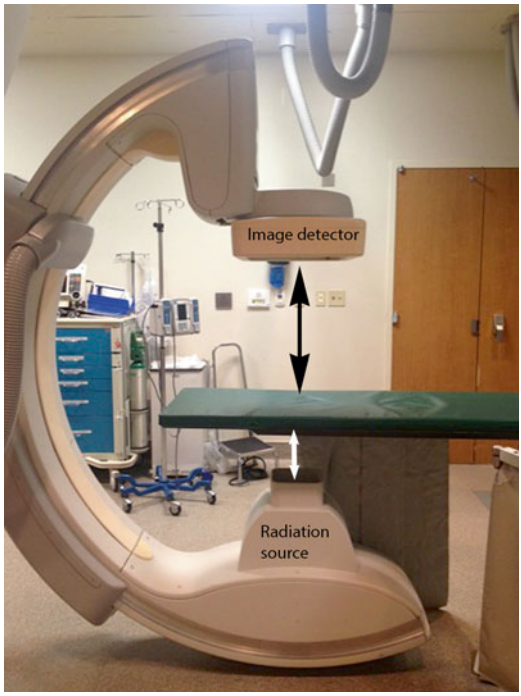

Fig. 4.3 Flat panel fluoroscopic unit. Image detector, radiation source, distance of the radiation source to the patient (*white arrow*), and distance of the patient to the image detector (*black arrow*) are identified

However, procedures such as catheter placements and tube exchanges, which do not require complex catheter and wire manipulations can be performed with pulse rates of 3 per second. Reduction of the fluoroscopic pulse rate has been shown to reduce radiation dose [17].

Road Mapping

A road map can be created through contrast injection into the hemodialysis graft or fistula or through performance of a digital subtraction angiogram. The image following contrast injection that delineates the outflow vessels can be displayed overlying real-time fluoroscopy images. This permits the interventional radiologist with a vascular map – "road map", to navigate through vessels without additional contrast enhanced images or digital subtraction angiograms, thus minimizing the patient's radiation dose [8].

Documentation of Radiation Exposure

An essential component of an effective radiation safety program within healthcare facilities where fluoroscopy-guided procedures are performed is documentation of patient radiation exposure. An initial document should be created listing the responsibilities of each angiography personnel. At our institution, two technologists are

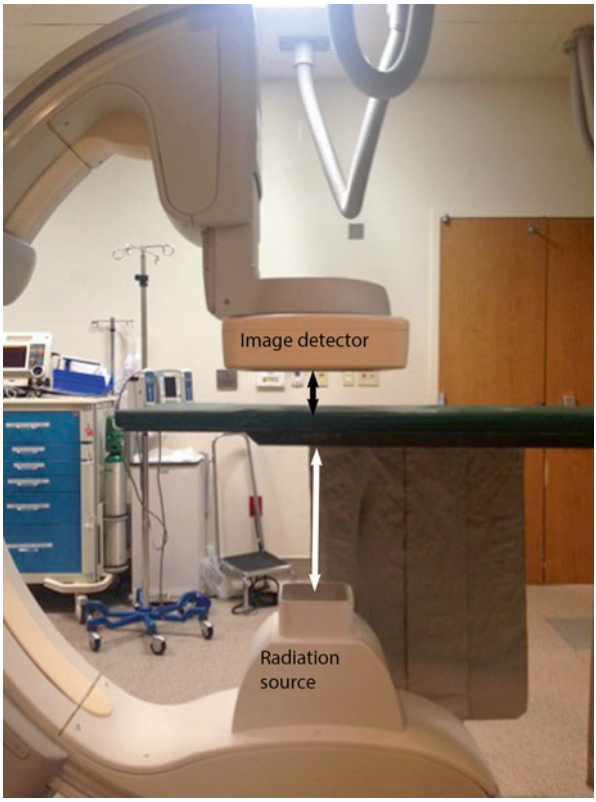

Fig. 4.4 Flat panel fluoroscopic unit illustrating minimization of distance from the image detector to position of the patient on the procedural table (*black arrow*) and maximizing the distance from the radiation source to the patient on the procedural table (*white arrow*)

assigned to each angiography suite. One technologist is gowned to assist with the procedure, while the second technologist circulates, supplies procedural personnel with appropriate equipment, and documents all supplies used and ultimately the radiation dose at the conclusion of the procedure. As stated before, the radiation dose from prior interventions will need to be rapidly retrieved, reviewed, and aggregated as part of the pre-procedural planning phase.

Patient Follow-Up

The SIR guidelines recommend follow-up clinic visits for patients who have received a significant radiation dose. A significant radiation dose can be implied when conditions arise whereby the operator is alerted per SIR guidelines. This includes attaining a peak skin dose of greater than 3,000 mGy, a reference point air kerma of greater than 5,000 mGy, a kerma-area-product greater than 500 Gy.cm^2 or when the exposure time has exceeded 60 min [9]. A follow-up visit can be set approximately 2 weeks from the date of the procedure to correspond to the time when transient erythema and epilation will manifest [14].

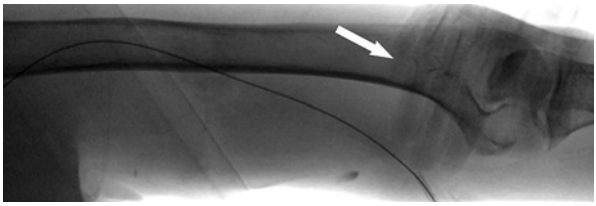

Fig. 4.5 Fluoroscopic image taken from a fistulogram with interventionist's hand (*arrow*) in the field of view

Radiation Exposure to the Interventionist

In addition to the cumulative radiation exposure to the hemodialysis patient, interventionists are also at risk from the cumulative exposure from a career of performing fluoroscopy-guided procedures (Fig. 4.5). A retrospective study by Stavas et al. found that radiation exposure to the hands was relatively high during restoration of flow in clotted dialysis access grafts [18]. Radiation exposure to both the right and left hands was tracked through the use of thermoluminescent ring dosimeters on each hand of five interventional radiologists over a total of 62 synthetic graft declot procedures. The mean right hand exposure was found to be 0.78 mSv, and the mean left hand exposure was 0.55 mSv. No patient-related factors such as position of the graft, age, sex, previous thrombosis or number of previous interventions were found to be significant factors in hand dose. On the other hand, technical factors such as fluoroscopic time and the number of angiographic runs were significant factors in total hand dose. In comparison, a multicenter study of radiation exposure found the median exposure of one hand per procedure to be 0.075 mSv over a wide variety of procedure types [19]. Similarly, a prospective single institution study found the average hand dose to be 0.0996 mSv over a variety of endovascular procedures including coronary angiography, pelvic angiography, and lower and upper extremity angiography [20].

The recommended annual occupational limits to the hand are 500 mSv by both (IRCP) and the National Council on Radiation Protection and Measurements (NCRP) [20]. Although it would take greater than 600 declot procedures to exceed the recommend exposure limits of 500 mSv, it is important to recognize the increased exposure during declot procedures and develop strategies to minimize exposure. Several strategies have been explored in addition to reducing fluoroscopic time and the number of angiographic runs. These strategies include: the use of leaded shields, leaded gloves, and radioprotective drapes. The use of a disposable radioprotective bismouth drape demonstrated a marked reduction of hand exposure by 29-fold [21]. A relatively new development is the introduction of an x-ray attenuating lotion which contains bismouth oxide (Bi_2O_3) ceramic powder (UltraBlox by Bloxr, Salt Lake City, UT) and can be applied to the hands [22].

Dialysis access thrombectomy tends to be the procedure associated with the greatest radiation dose both to the patient as well as the interventionist. One additional technique to reduce both the procedure time and radiation exposure in thrombectomy is the use of tissue plasminogen activator (tPA). One study compared the use of mechanical thrombectomy versus mechanical plus "no-wait

lysis" on the procedure time and radiation exposure. The no tPA group had an average procedure time of 55.5 minutes and the "no-wait lysis" group had a procedure time of 27.2 minutes and fluoroscopy times were reduced to 159 seconds in the "no-wait lysis" group from 243 seconds in the no tPA group [23].

Conclusion

Given the potential for serious patient injuries and long-term ill effects resulting from radiation exposure, meticulous pre-procedural planning should be undertaken and techniques for radiation reduction must be optimized. The ALARA principle is the guiding principle for all proceduralists utilizing fluoroscopy. Although much attention was been made toward patient radiation dose reduction, it should be mentioned that optimizing patient dose management translates into optimal operator dose management and provision of high quality patient care.

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Conscious Sedation and Anesthesia Care

5

Jason Qu and Chieh Suai Tan

Endovascular interventions for arteriovenous fistula (AVF) and graft (AVG) can cause significant pain and discomfort to the patients and adequate sedation and analgesia are often required; hence it is important for the interventionist to understand and appreciate some of the basic principles of sedation and anesthesia. In particular, many patients with ESRD have co-morbidities that may put them at risk of cardiac events during sedation and anesthesia. As such, proper assessment of patient and putting in place a robust crisis management plan is critical in the smooth operation of the intervention suite.

Pre-procedural Evaluation

The objectives of pre-procedural evaluation include establishing a doctor-patient relationship, reviewing the patient's overall health condition, especially the cardiopulmonary function and identifying risk factors for sedation. The following classification proposed by The American Society of Anesthesiologists (ASA) is a widely used guide for describing patient's baseline functional capacity [1]:

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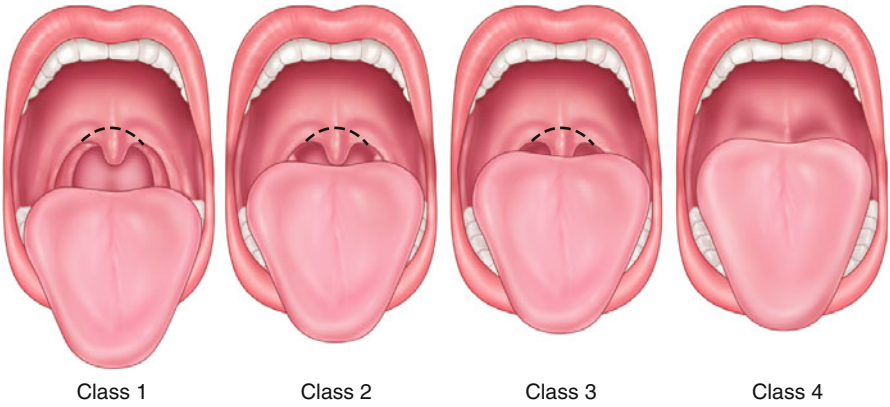

Fig. 5.1 Modified Mallampati airway classification

ASA Physical Status 1 – A normal healthy patient,
ASA Physical Status 2 – A patient with mild systemic disease,
ASA Physical Status 3 – A patient with severe systemic disease,
ASA Physical Status 4 – A patient with severe systemic disease that is a constant threat to life,
ASA Physical Status 5 – A moribund patient who is not expected to survive without the operation.

Patients with ASA physical status 3 and 4, especially with history of sleep apnea, poor heart function, COPD, difficult airway and complications from previous sedation and anesthesia should have anesthesia consult and be considered for monitored anesthesia care or general anesthesia. The modified Mallampati classification is widely used by the anesthesiologist to predict the difficulty of airway (Fig. 5.1). The assessment is made with the patient sitting upright, with the head in the neutral position, the mouth open as wide as possible, and the tongue protruded maximally without phonation.

Class I. Faucial pillars, soft palate, and uvular are visible,
Class II. Faucial pillars and soft palate may be seen, but the uvular is masked by the base of the tongue,
Class III. Only soft palate is visible. Intubation is predicted to be difficult,
Class IV. Soft palate is not visible. Intubation is predicted to be very difficult.

Patients should be instructed to abstain from solids food and clear fluids for 6 h and 2 h prior to procedure respectively. All routine drugs should be taken on the day of the procedure with a minimal amount of water, with the exception of diabetic medications. A procedure and sedation consent form should be obtained. Patients should be advised not to drive for at least 24 h after receiving sedation.

Safety in Sedation

The procedure room should be large enough to accommodate a portable resuscitation cart and personnel in the even of resuscitation. The physician and the nurse involved in the procedure should be trained in monitoring of patients under sedation and be certified in advance cardiac life support (ACLS). Qualified RN in sedation or anesthetist should be present the entire time and should have training in basic environmental safety, prevention of cross-infection and crisis management skills such as basic and advanced cardiac life support [2].

Monitoring, Airway Devices and Anesthesia Machine

The monitoring should be consistent with ASA standards, irrespective of the depth of the sedation or anesthesia [3] (Fig. 5.2). The monitoring devices must give an audible signal when their alarm thresholds are exceeded. Hemodynamic monitoring includes ECG and noninvasive blood pressure (NIBP) measurements at a minimum of 5 min interval. Respiration is monitored with pulse oximetry. Continuous monitoring of End-tidal carbon dioxide ($EtCO_2$) should be used for patients with preexisting pulmonary or cardiac diseases. Standard monitoring for general anesthesia involves oxygenation (oxygen analyzer and pulse oximetry), ventilation (capnography and minute ventilation), circulation (ECG, blood pressure, and perfusion assessment), and temperature.

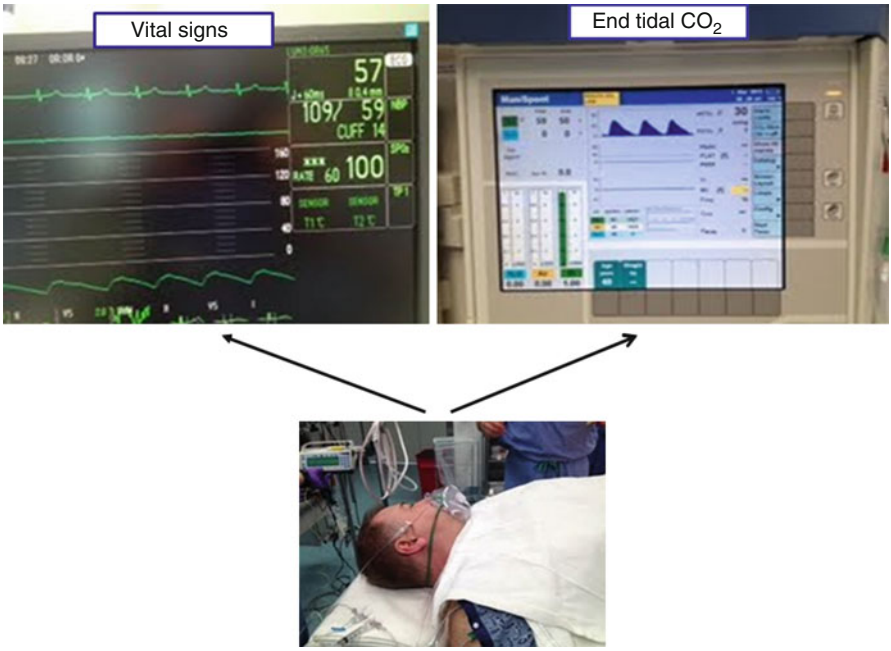

Fig. 5.2 ASA standard monitoring

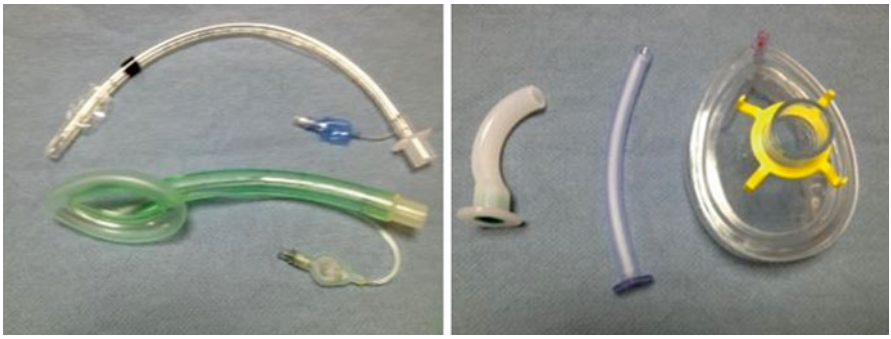

Fig. 5.3 Airway devices: endotracheal tube, laryngeal mask airway; oral airway, nasal airway and mask

When nasal cannula or facial mask cannot maintain adequate oxygen saturation, advanced airway management is warranted (Fig. 5.3). For mask ventilation, the mask can be connected to an Ambu bag or anesthesia circuit to provide positive pressure ventilation. Oral airway is inserted from the mouth to eliminate obstruction from the tongue while nasopharyngeal airway is inserted from nostril to bypass the airway obstruction. Laryngeal mask airway is inserted orally to align its opening to the vocal cords. Endotrachial intubation is the ultimate way of control ventilation. The endotracheal tube is inserted into trachea through the vocal cord under direct vision or using a video-imaging device.

Sedation Levels and General Anesthesia [4]

Moderate Sedation

"Moderate Sedation/Analgesia" ("Conscious Sedation") is a drug-induced depression of consciousness during which patients respond purposefully to verbal commands, either alone or accompanied by light tactile stimulation. No interventions are required to maintain a patent airway, and spontaneous ventilation is adequate. Cardiovascular function is usually maintained.

Deep Sedation

"Deep Sedation/Analgesia is a drug-induced depression of consciousness during which patients cannot be easily aroused but respond purposefully following repeated or painful stimulation. The ability to independently maintain ventilatory function may be impaired. Patients may require assistance in maintaining a patent airway, and spontaneous ventilation may be inadequate. Cardiovascular function is usually maintained."

General Anesthesia

General Anesthesia is a drug-induced loss of consciousness during which patients are not arousable, even by painful stimulation. The ability to independently maintain ventilatory function is often impaired. Patients often require assistance in maintaining a patent airway and positive pressure ventilation may be required because of depressed spontaneous ventilation or drug-induced depression of neuromuscular function. Cardiovascular function may be impaired.

Monitored Anesthesia Care

Monitored Anesthesia Care (MAC) is a specific anesthesia service for a diagnostic or therapeutic procedure. MAC may include varying levels of sedation, analgesia and anxiolysis as necessary. The provider of monitored anesthesia care must be prepared and qualified to convert to general anesthesia when necessary [5].

Local Anesthetics and Intravenous Sedation

Local anesthetics block nerve conduction by impairing propagation of the action potential in axons. There are two categories of local anesthetics by their chemical structures. The commonly used Amides include lidocaine, bupivacaine, mepivacaine, and ropivacaine; and Esters include procaine, chloroprocaine, and tetracaine. The choice of local anesthetics must take into account the rate of onset, duration, and the potential for local or systemic toxicity [6].

Adding epinephrine to local anesthetics can prolong the duration, decrease systemic toxicity, assist the detection of intravascular injection, provide local vasoconstriction and decrease surgical bleeding. The typical concentration of epinephrine in the local anesthetics is 1:200,000 solutions, or 5 ug/ml. Raising pH of the local anesthetics by adding Sodium bicarbonate will speed up the onset of action and increase the rate of diffusion. The commonly used local anesthetics are 0.5–5 % lidocaine with 1 % solution being most frequently used, and 0.25–0.75 % bupivacaine with 0.25 % being most frequently used (Fig. 5.4).

Intravenous Agents (Table 5.1)

A large number of sedatives, opioids, and adjunctive agents can be used for AVF procedural sedation. The general pharmacology and characteristics for each drug class should be thoroughly understood. The ideal sedation regimen in AVF procedure should provide adequate coverage for anxiety, sedation and pain.

Benzodiazepines are the conventional drugs of choice for any kind of sedation. The sedative, anxiolytic and amnestic effects of benzodiazepines are attributed to

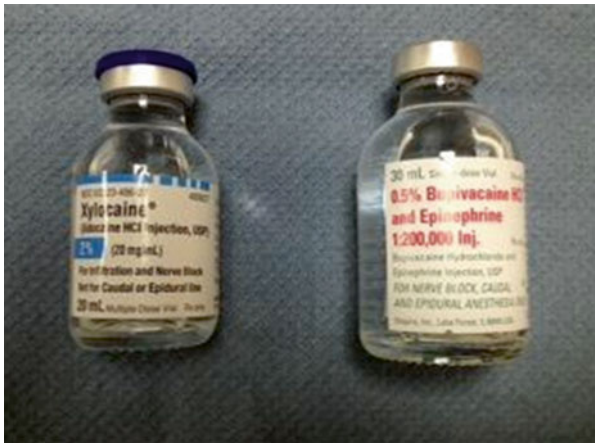

Fig. 5.4 Local anesthetics

Table 5.1 Local anesthetics

Anesthetics	Onset	Concentration (%)	Duration (hours)	Toxicity	Usual dose (ml) (70 kg patient)	Maximal dose (mg)
Amides						
Lidocaine (Xylocaine)	Rapid	0.5–1.0	0.5–2.0	Moderate	1–50	300 (500)
Bupivacaine (Marcaine, Sensorcaine)	Slow	0.25–0.5	2–4	High	1–45	175 (225)
Mepivacaine (Carbocaine)	Moderate	0.5–1.0	0.25–2.0	Moderate	1–50	300 (500)
Esters						
Procaine (Novocaine)	Rapid	0.5–1.0	0.25–0.5	Low	1–60	400 (600)
Chloroprocaine (Nesacaine)	Very rapid	2–3	0.25–0.5	Very low	1–100	800 (1,000)

Dose in epinephrine-containing solution in parenthesis. Adding epinephrine prolongs the analgesia duration of lidocaine, mepivacaine, procaine and chloroprocaine but not bupivacaine or ropivocaine

their ability to potentiate the inhibitory influences of GABA-the principal inhibitory neurotransmitter in the brain [7]. Midazolam has largely replaced the commonly used benzodiazepams such as diazepam and lorazepam because of its shorter distribution and elimination half-lives. The advantages of Midazolam are rapid onset with short duration of action and a greater degree of amnesia. It is water soluble and therefore essentially painless during injection. The onset of intravenous midazolam is 1–3 min with duration of action of 1 h. It is administered in 0.5–2 mg increments. Intravenous diazepam has an onset time of 2–3 min with duration of action of 6 h. Lorazepam has an even slower onset time but longer duration of action.

Opioids act by binding to endogenous opioid receptors in the central and peripheral nervous system. In addition to producing sedation, the primary effects of opioids are analgesia and inhibition of autonomic reflexes. As they depress catecholamine release and obtund sympathetic reflexes to noxious stimuli, opioids are also "cardioprotective". The sedative effect of opioids is synergistic with that of most sedatives. Fentanyl and meperidine are the most frequently used opioids. Despite its historical popularity in sedation regimens, meperidine has several properties that render it less attractive than fentanyl. Its anticholinergic properties can increase heart rate and depress myocardial contractility. Its active metabolite, normeperidine, is a CNS stimulant with a half-life of 18 h. Unlike meperidine, fentanyl does not promote histamine release. It acts rapidly with an onset time of 2–3 min and has a redistribution time of 30 min. It is administered in 25–50 ug increments. Fentanyl has a greater potential to produce skeletal muscle rigidity and apnea. Following repeated doses, it can accumulate and the respiratory depressant effect can last much longer than that of other analgesia. Morphine is rarely used in AVF procedure because of its long-acting properties and its active metabolite, morphine-6-glucuronide.

Antihistamines include diphenhydramine and promethazine, are less effective sedatives and anxiolytics than benzodiazepines. They are useful adjunct in potentiating the sedative effects of benzodiazepines but cannot be used as primary agents for procedural sedation.

Propofol is typically administered by anesthesiologists or CRNAs (Certified Registered Nurse Anesthetist) for general anesthesia and MAC. It is a hypnotic agent that facilitates inhibitory neurotransmission by enhancing the function of Υ-aminobutyric acid type A ($GABA_A$) receptors in the CNS. It has a rapid onset time of 30–45 s and rapid termination due to redistribution.

Sedation and Analgesia Related Complications and Treatment

Sedation for AVF patients can be challenging because most of the patients have preexisting pulmonary and or cardiac illness. Early recognizing cardiopulmonary compromise is the key to avoid devastating complications

Local Anesthetics

True allergic reactions to local anesthetics are uncommon. It is important to differentiate them from common nonallergic responses such as vasovagal episodes and responses to intravascular injection of local anesthetics and/or epinephrine. Systemic toxicity usually results from intravascular injection or overdose. Aspiration before injection, use of epinephrine-containing solution and small incremental volumes are techniques that will minimize intravascular injection. Clinical features of central nervous system toxicity include complaints of a metallic taste, numbness of the tongue and lips, light-headedness, tinnitus and visual disturbances. These may

progress to muscle twitching, loss of consciousness, tonic-colonic seizures and even coma.

Cardiovascular toxicity is rare but can be severe and difficult to treat. It can present as decreased ventricular contractility, refractory cardiac arrhythmias, and loss of peripheral vasomotor tone. Intravascular injection of bupivacaine may cause cardiovascular collapse, which is often refractory to therapy because of the high affinity of the drug for sodium channels. Ropivacaine is similar to bupivacaine in potency and duration of action but has less cardiac toxicity. At the first sign of toxicity, injection of local anesthetic should be discontinued and oxygen administered. If seizure activity is prolonged or interferes with ventilation, anticonvulsant treatment is indicated and midazolam (1–2 mg) or thiopental (50–200 mg) may be given. Endotracheal intubation should be performed to provide adequate oxygenation. Local anesthetic-induced cardiac arrhythmias and collapse are difficult to treat. The treatment includes intravenous amiodarone, electric cardioversion, 20 % intralipid infusion and cardiopulmonary bypass.

Intravenous Agents

Hypoxia or desaturation is the primary complication of sedation and analgesia. Continuous oxygen supply via cannula or mask should be used. The oxygen supply should be checked immediately when the pulse oximetry starts to drop. If the patient does not response to verbal command or rubbing to the chest, jaw thrust should be applied to stimulate the patient and open the airway which may be obstructed. Assisted positive mask ventilation with an Ambu bag should be initiated. The Anesthesia team should be called for advanced airway support if all the above effort failed.

Hypotension and hypertension are also common concerns during sedation and procedure. While hypertension may be related to agitation and pain, it may also be caused by hypoxia or hypercarbia. Hypotension is most likely related to cardiovascular depression. Common intravenous agents to treat hypotension during the procedure include phynelephrine, ephedrine or inotropes such as dopamine.

Inadequate sedation may be secondary to anxiety or pain. If necessary, additional benzodiazepine may be given to relieve anxiety. Additional local anesthetic or opioids can be given for pain relief if required.

Reversal Agents or Antagonists

When patient does not respond to repeated verbal or painful stimulation after procedure is completed or if the patient is hypotensive or in respiratory depression, overdose of benzodiazepines and/or opioids should be in the differential diagnosis. Pharmacologic antagonists such as naloxone for opioids and flumazenil for benzodiazepines can reverse the above effects. These antagonists must be used with caution, with careful titration to effect. The recommended dose for flumazenil is 0.2 mg/min. Naloxone can be titrated with 0.04 mg every 2–3 min as needed.

Postprocedure Recovery

Patient should be continually monitored in the recovery room the same as in the procedure room. Discharge criteria should follow the recommendation by ASA [8]. Patient should have returned to their baseline level of consciousness with stable vital signs that are in the acceptable limits. Sufficient time should be allowed for patient who received reversal agents to ensure that patients do not become re-sedated after the reversal agents have worn off. The patients should receive specific written instructions, including management of pain, relevant postprocedural complications, and routine and emergency follow-up. Patients should not drive for at least 24 h.

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Part II

Hemodialysis Vascular Access Management: Basics

Vascular Anatomy for Hemodialysis Access

6

Chieh Suai Tan, Steven Wu, and Gerald A. Beathard

Introduction

The dialysis circuit can be considered as a closed loop system that begins and ends at the heart. Any obstruction or stenosis within this circuit can lead to access failure. A good knowledge of normal vascular anatomy and its variant in the upper limb, thorax and thigh is crucial in the management of dialysis vascular access.

Arterial Supply of the Upper Limb (Fig. 6.1a)

The aortic arch has three main branches: brachiocephalic artery, left common carotid artery and the left subclavian artery. The brachiocephalic artery in turn gives off two main branches, namely the right subclavian artery and the right common carotid artery (Fig. 6.1b).

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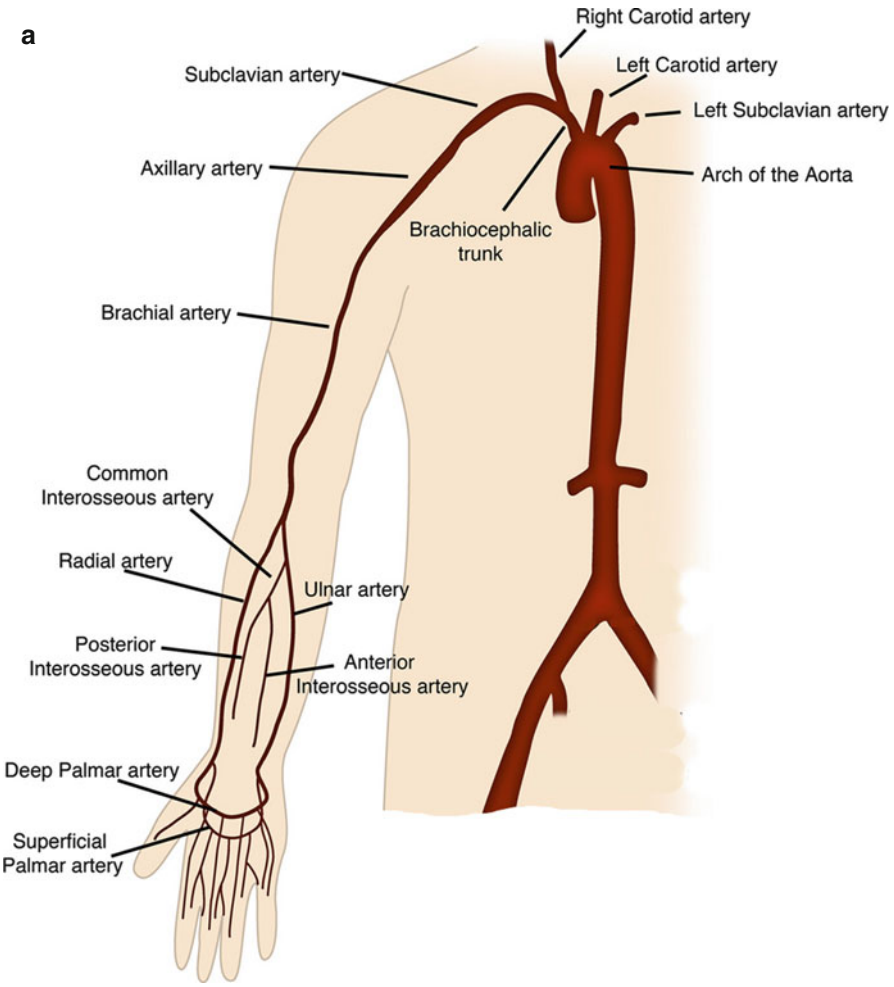

Fig. 6.1 (**a**) The main vessels of the arterial system of the upper limb and trunk are illustrated here. All interventionists should be familiar with the nomenclatures of the vessels. (**b**) The three main branches from the aortic arch are the brachiocephalic, left carotid and left subclavian artery. (**c**) The left subclavian artery becomes the axillary artery after crossing the first rib. The axillary artery continues as the brachial artery after crossing the lower border of the teres major. (**d**) The brachial artery runs medial to the humerus initially but it gradually turns to the front of the bone as it runs down the arm. Note the presence of a stenosis in the axillary artery. (**e**) The brachial artery ends approximately 1 cm below the bend of the elbow, where it divides into the radial and ulnar arteries. (**f**) Arterial anatomy of the forearm and hand. Note the presence of a radiocephalic fistula and the presence of a juxa-anastomotic stenosis

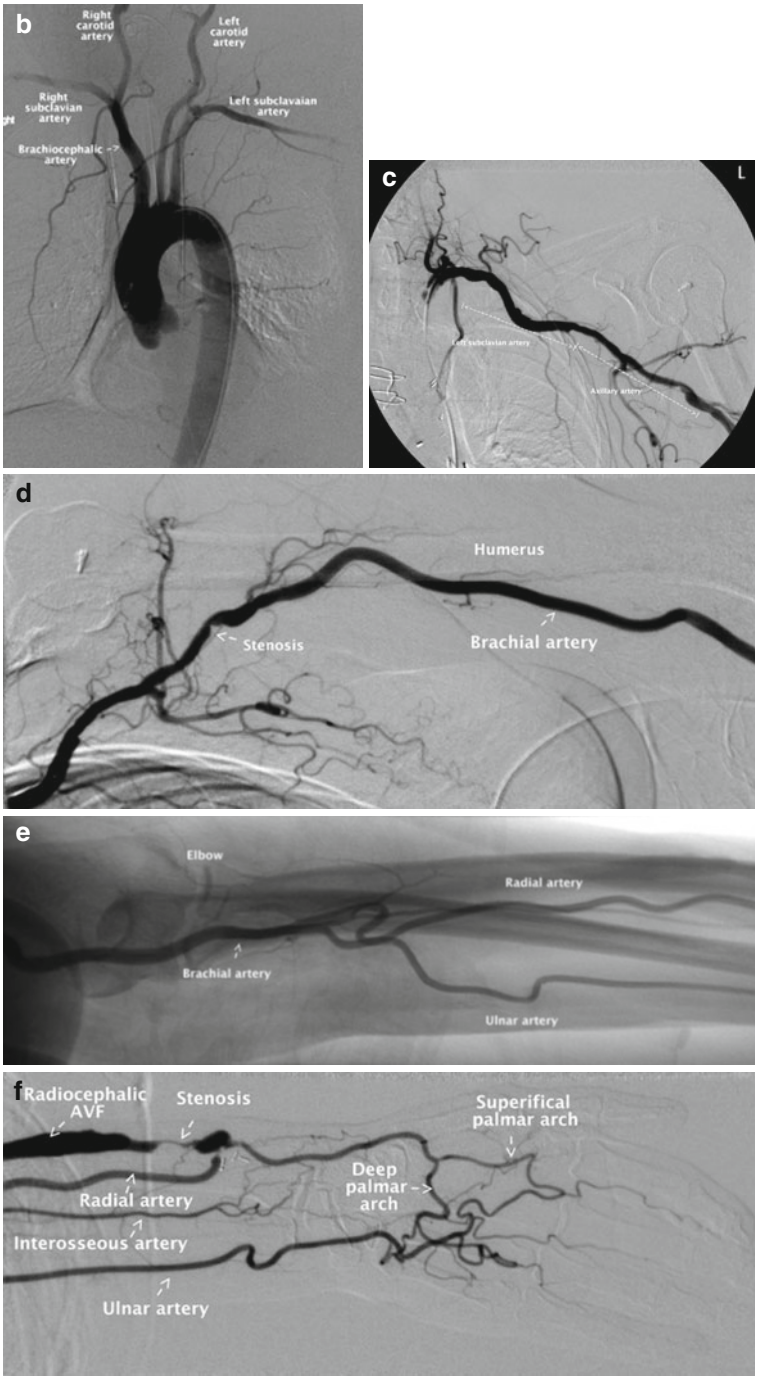

Fig. 6.1 (continued)

The subclavian artery continues to become the axillary artery after crossing the border of the first rib (Fig. 6.1c). The axillary artery passes through the axillary fossa and becomes the brachial artery after crossing the lower border of the teres major muscle, which cannot be seen radiologically (Fig. 6.1d).

The brachial artery continues down the arm and bifurcates into the ulnar and radial artery at the level of the elbow (Fig. 6.1e). The bifurcation may occur proximal to the elbow in some patients. Moreover, an accessory brachial artery may be present in 0.52 % of the patients [1]. This accessory branch, when present, is given off at the proximal 1/3 of the brachial artery and rejoins the main brachial artery proximal to the elbow.

The ulnar artery runs on the medial aspect of the forearm and terminates within the palm to form the superficial palmar arch with the superficial palmar branch of the radial artery. The common interosseous artery branches off from the ulnar artery below the radial tuberosity and further divides into the anterior and posterior interosseous artery in the forearm.

The radial artery runs on the lateral aspect of the forearm, passes through the anatomical snuffbox to terminate within the palm by forming the deep palmar arch with the deep branch of the ulnar artery.

Within the hand, digital arteries arise from both deep and superficial arches to supply the fingers (Fig. 6.1f). The superficial palmar arch is more distal than the deep palmar arch and may be "incomplete" (absence of anastomosis between the ulnar and radial branches) in approximately 15 % of the population. This may cause problem during instrumentation of the radial artery. The Allen test is used to test the patency of the palmar arches clinically.

Venous Drainage of the Upper Limb and Thorax

The venous drainage of the upper limb consists of both superficial and deep veins (Fig. 6.2a). The deep veins accompany the arteries and are connected to the superficial system by perforating veins. Dialysis vascular access is created by anastomosing one of the superficial veins to an artery.

Considerable variation in the anatomy of the superficial veins exists but three prominent veins: the basilic, cephalic and median antebrachial veins can be identified in most patients (Fig. 6.2b). The smaller and unnamed veins are usually referred to as accessory veins.

The basilic vein begins medially at the dorsal aspect of the hand and lies on the medial or posterior-medial aspect of the forearm. It crosses the elbow anteriorly and ascends obliquely in the grove between the bicep brachii and pronator teres where it runs across the brachial artery. It then runs along the medial border of the biceps brachii, pierces the brachial fascia to join up with the brachial vein to form the axillary vein. As it is fairly deep in the upper limb, transposition of the vein is often necessary after brachiobasilic arteriovenous fistula creation.

The median antebrachial vein ascends on the ulnar aspect of the forearm and drains into the basilc vein or the median basilic vein.

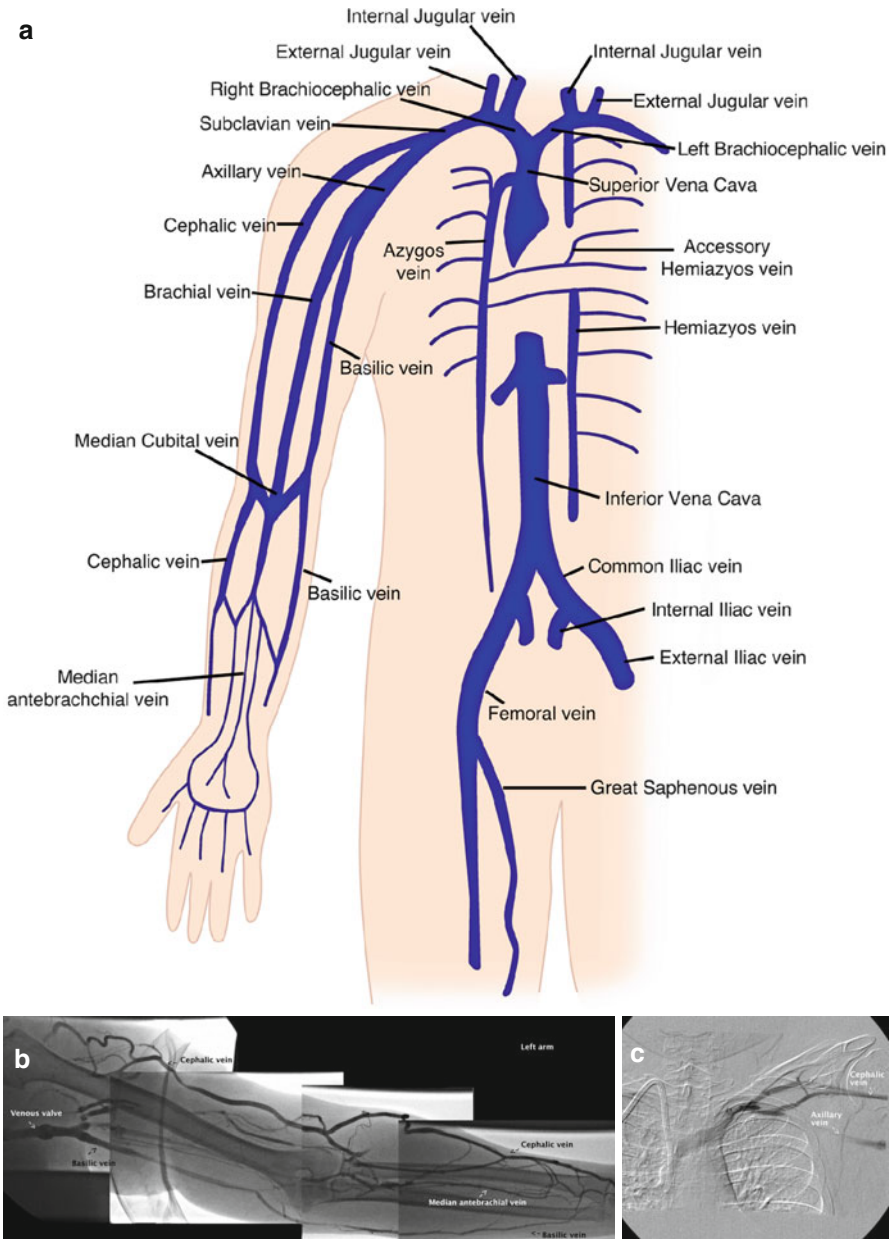

Fig. 6.2 (**a**) Venous drainage of the upper limb and body. (**b**) Considerable variations of the superficial veins exist but in general, these are the main vessels that can be used for AV access creation. (**c**) A double cephalic arch is seen here. It is a normal variant. (**d**) Anatomy of the cephalic arch. (**e**) The basilic and brachial veins join at the inferior border of the teres major, which is not visible radiologically, to form the axillary vein. The axillary vein becomes the subclavian vein after the cephalic arch. The subclavian vein becomes the brachiocephalic vein (on the right) or the innominate vein (on the left) after joining with the internal jugular vein. The brachiocephalic vein and innomiate vein join to form the superior vena cava. (**f**) The catheter is lying within a left sided superior vena cava. (**g**) The azygos veins are usually not visible unless there is an obstruction of the vena cave

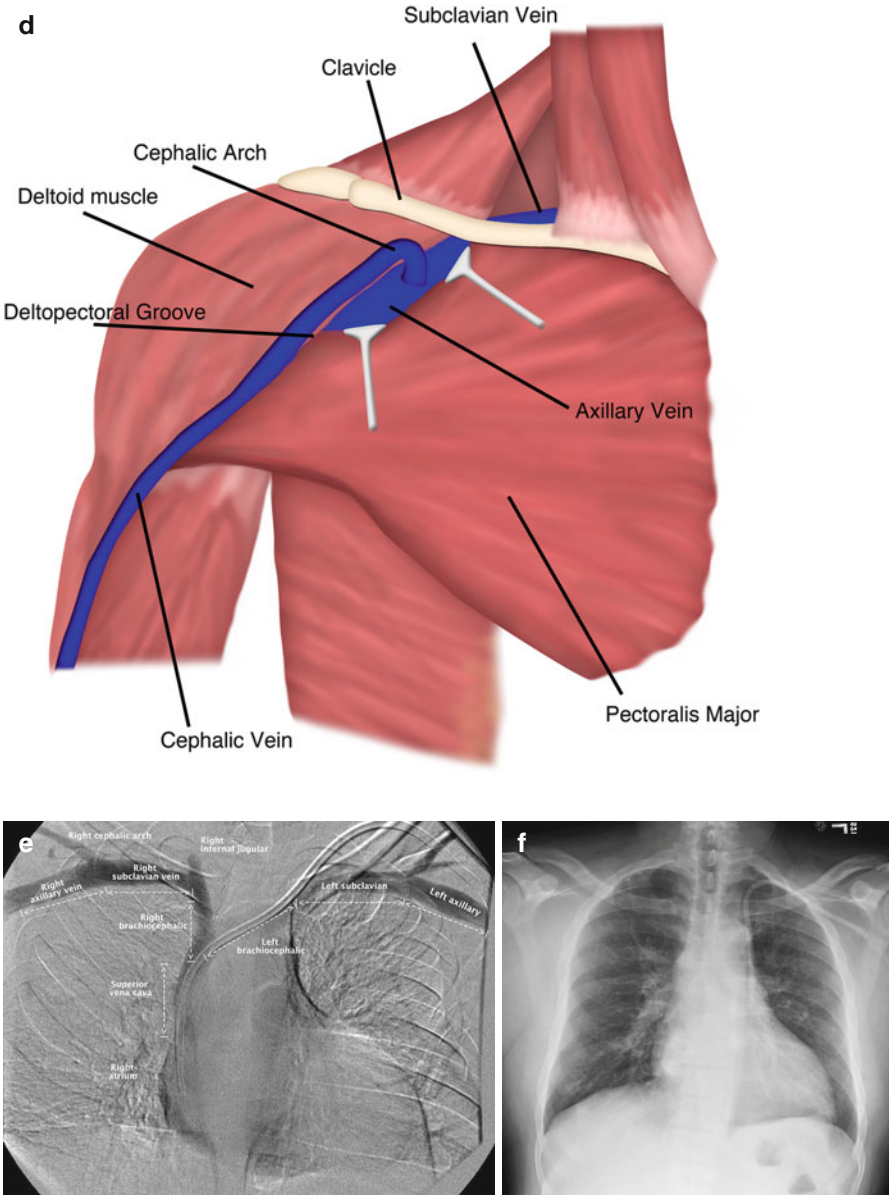

Fig. 6.2 (continued)

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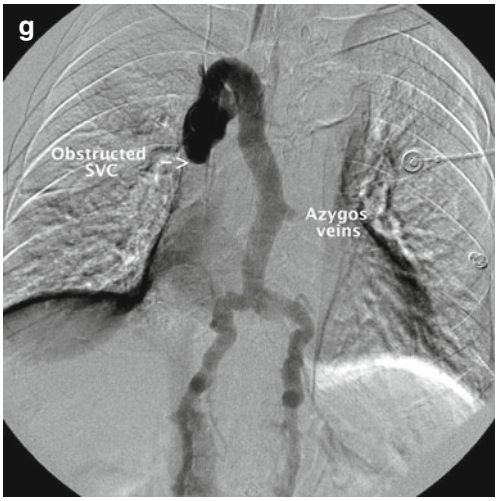

The cephalic vein begins in the radial part of the dorsal venous network of the hand and runs along the radial border of the forearm. A radiocephalic arteriovenous fistula is created by anastomosing the cephalic vein to the radial artery in the forearm.

Just below the anterior aspect of the elbow, the cephalic vein gives off the median antecubital vein to join the basilic vein. Within the elbow, anastomosing the cephalic vein to the brachial artery will create a brachiocephalic arteriovenous fistula.

The cephalic vein then crosses the elbow to ascend along the lateral border of the Biceps Brachii. It then passes between the pectoralis major and deltoid muscle to go below the clavicle where it turns sharply to pierce the clavipectoral fascia to drain into the axillary vein. Various anatomic variants have been described. These include direct drainage of the cephalic vein into the external and internal jugular veins, subclavian veins or the presence of a double arch (Fig. 6.2c).

The region where the cephalic vein drains into the axillary vein is called the cephalic arch (Fig. 6.2d). It is vulnerable to development of stenosis, especially in patients with brachiocephalic fistulas. The pathogenesis has been postulated to be secondary to the higher blood flow associated with brachiocephalic fistulas, presence of valves that restrict flow or a restrictive clavipectoral fascia to impede the dilatation the cephalic arch [2].

The axillary vein continues as the subclavian vein, which is then joined by the internal jugular vein to form the brachiocephalic vein on the right and innominate vein on the left. Radiologically, the cephalic arch on one end and the internal jugular vein at the other demarcates the subclavian vein.

The brachiocephalic vein together with the innominate vein forms the superior vena cava and drains into the right atrium (Fig. 6.2e). Occasionally, a left sided superior vena cava may be present and it may drain directly into the right atrium or via the coronary sinus (Fig. 6.2f).

The azygos system, consists of the azygos vein on the right and the hemiazygos and accessory hemiazygos veins on the left (Fig. 6.2g). They arise from the posterior aspect of the vena cava to provide an alternate route for blood to drain into the right atrium. They are interconnected to drain the intercostal, subcostal, mediastinal, esophageal and lumbar veins. The arch of the azygos drains the azygos vein into the superior vena cava. The azygos system is usually not visualized unless in the presence of superior or inferior vena cava obstruction.

Arterial Supply and Venous Drainage of the Lower Limbs

The arterial supply of the lower limb is derived from the femoral artery, which is a continuation of the external iliac artery. It is most superficial and palpable at the inguinal region where it lies just behind the midpoint of the inguinal ligament (Fig. 6.3a). The femoral vein is the main draining vein of the lower limb. It is a continuation of the popliteal vein and is most superficial at the inguinal region. It lies medial to the femoral artery and continues as the external iliac vein after passing under the inguinal ligament (Fig. 6.3b).

Placing a loop graft between the femoral artery and femoral vein creates a thigh arteriovenous graft (Fig. 6.3c). The femoral vein can also be used for placement of a dialysis catheter.

Venous Anatomy of the Neck

The internal and external jugular veins provide venous drainage of the head and neck.

The external jugular vein begins within the substance of the parotid gland and runs down the neck towards the midpoint of the clavicle. It courses across the sternocleidomastoid muscle and turn to perforate the deep fascia approximately 4 cm above the clavicle. The external jugular vein then drains into the subclavian vein.

The internal jugular vein begins at the jugular foramen and runs lateral and parallel to the common carotid artery in a straight-line direction from the mastoid process to the medial side of the clavicular head of the sternocleidomastoid muscle. For this reason, the anatomic triangle formed by the two head of the sternocleidomastoid muscle and the medial 1/3 of the clavicle is often used as a landmark for blind catheter insertion. However, in a study by Lin et al., the internal jugular vein was found to be anterior to the carotid artery in approximately 20 % of the ESRD patients [3]. This highlighted the importance of using ultrasound to facilitate catheter insertion.

The internal jugular vein joins the subclavian vein to form the brachiocephalic vein on the right and the innominate vein on the left.

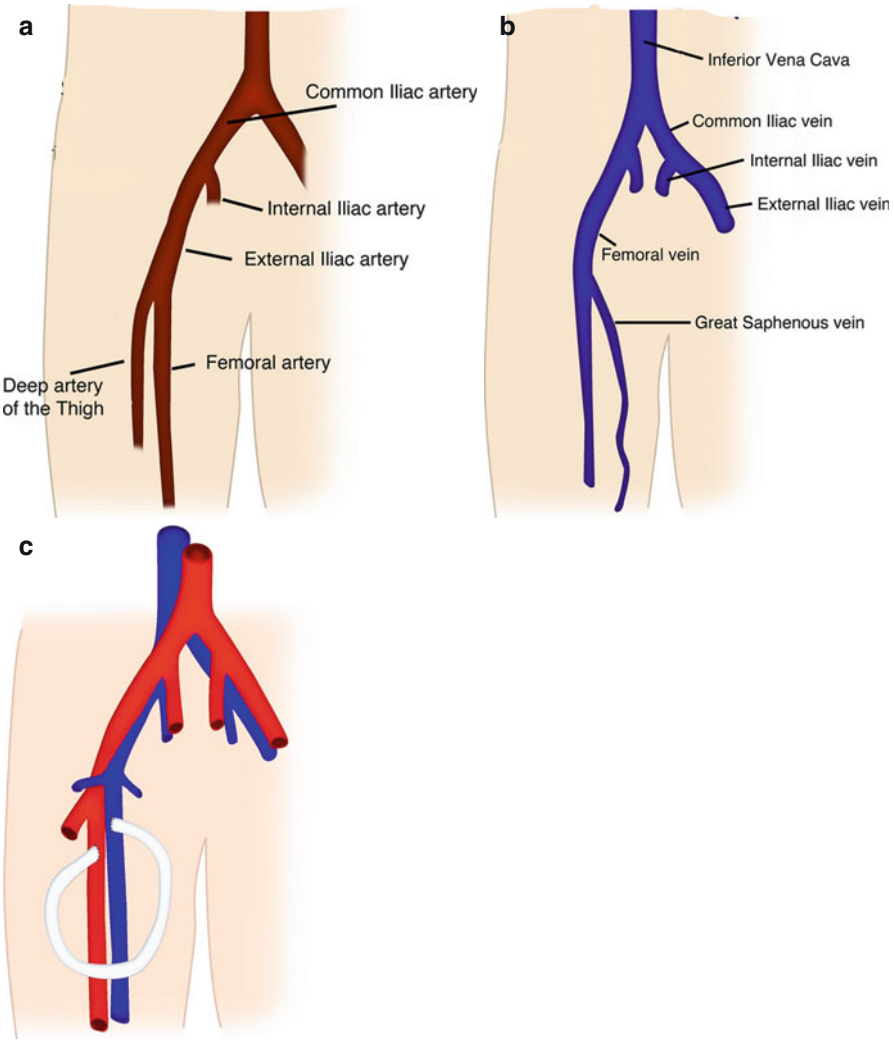

Fig. 6.3 (**a**) The main arterial supply of the lower trunk and thigh region is shown. (**b**) The main venous drainage of the thigh and lower trunk are shown here. (**c**) A thigh arteriovenous graft can be created by placing a loop graft between the femoral artery and the femoral vein

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Hemodialysis Access: Types

7

Chieh Suai Tan, Robert M. Schainfeld, and Steven Wu

Introduction

Dialysis vascular access is an important "bridge" that connects the patient to the hemodialysis machine. It is often considered the "Achilles Heel" of hemodialysis due to the potential complications that may arise. Broadly, dialysis can be performed via an arteriovenous fistula (AVF), arteriovenous graft (AVG) or a catheter (Tunneled or non-tunneled). The pro and cons of each type of dialysis vascular access are summarized in Table 7.1.

Due to the high complication rates associated with catheters (including but not limited exclusively to infection and malfunction), their routine use should not be encouraged. Compared to AVG, AVF offers superior long-term primary patency and lower infection rates and as such is the dialysis vascular access of choice. As time is required for AVF to mature after creation, patients should be referred to a surgeon for evaluation of an AVF creation by Stage 4 (glomerular filtration rate (GFR) less than 30 mL/min/1.73 m^2) Chronic Kidney Disease. This will help alleviate the need

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Table 7.1 Characteristics of different vascular access

	AVF	AVG	Catheter
Lead time between creation and utilization	Usually between 4 and 6 weeks	Depending on material used, may be used immediately or within 2 weeks	Can be used immediately
Ease of creation	Technically demanding	Technically demanding	Easy
Initial success rate	Low	High	High
Long term patency rate	High	Worse than AVF but better than catheter	Low
Infection rate	Low	Worse than AVF but better than catheter	High
Blood flow rate	High	High	Low
Overall maintenance cost	Low	High	High

for catheter placement at the time of dialysis initiation and avoid the complications associated with dialysis catheter placement [1].

Arteriovenous Fistula

An AVF is created by anastomosing a vein to the artery. However, finding optimal vessels for an AVF creation can be challenging, especially in elderly and obese patients. The usual practice of choosing the non-dominant over the dominant arm for access creation is applicable only if both arms have vessels with similar chance of success. In general, AVFs are created in the most distal vessels first to preserve the vascular "real estate". In order of preference, the radiocephalic AVF is preferred; followed by the brachiocephalic AVF and the transposed brachial basilic vein fistula: Arms ipislateral to pacemaker wires are usually not used, as there is a high risk of associated central vein stenosis from these wires. If absolutely necessary, a diagnostic contrast venogram is needed to check the patency of the central veins in patients with a pacemaker before AVF creation.

As recommended by the Fistula First Breakthrough Initiative, vessel mapping should be performed in all patients prior to access creation unless suitable vessels can be readily identified on physical examination. Mapping of the vessels can be performed using Doppler ultrasound or venogram. Doppler ultrasound has the advantage of being a noninvasive test and avoids the risk of contrast-induced nephropathy. On the other hand, a venogram permits direct visualization of the entire venous system of the limb up to the central veins.

Regardless of the modality, for vessels to be suitable for access creation, the inner diameter of the artery and veins should be more than 2.0 and 2.5 mm respectively. Measurement of the diameter of the vein should be made with a tourniquet around the arm. The veins for AVF creation should also have a minimum 8–10 cm straight segment length for cannulation and should preferably be less than 0.5 cm from the skin for easy cannulation.

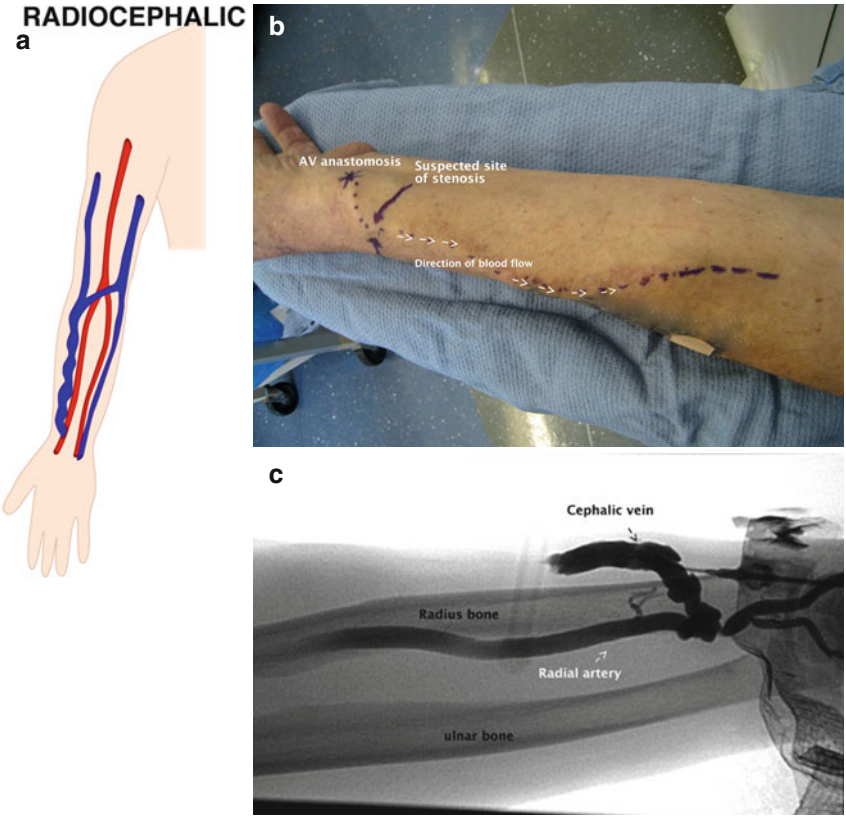


Fig. 7.1 (**a**) Radiocephalic arteriovenous fistula. (**b**) The radiocephalic fistula is created by anastomosing the cephalic vein to the radial artery at the wrist. The arteriovenous anastomosis is near the wrist and the direction of blood flow is as indicated. (**c**) "Reflux" fistulogram was performed by occluding the outflow vein while injecting contrast into the cephalic vein. The radial artery and the juxa-anastomotic segment of the left radiocephalic AVF can be clearly visualize here

Figures 7.1, 7.2, and 7.3 show the configuration of three commonly created upper limb AVFs in the United States. The characteristics, pro and cons of the four most common AVFs are summarized in Table 7.2.

Arteriovenous Graft

Although AVF is the preferred type of vascular access, some patients with small veins that have low likelihood for AVF maturation may benefit from AVG creation. An AVG is created by joining a vein to the artery using a synthetic (e.g. PTFE) or biosynthetic (e.g. Bovine vein) material. The forearm loop graft and the upper arm curved graft are the two preferred types of access. The forearm loop grafts are used to anastomose either the cephalic, antecubital or basilic veins to

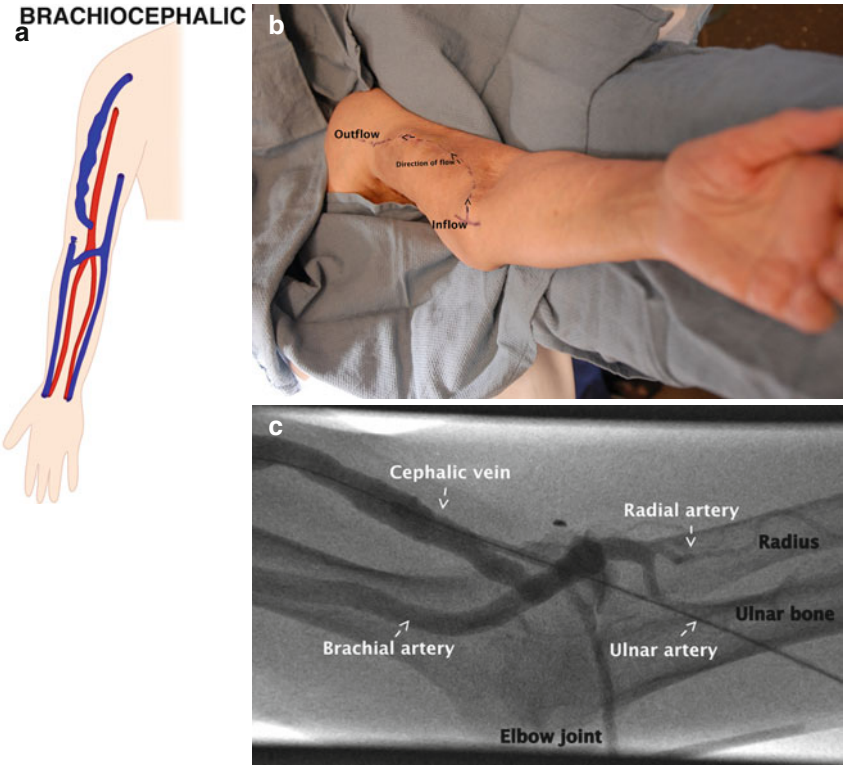


Fig. 7.2 (**a**) Brachiocephalic arteriovenous fistula. (**b**) The brachiocephalic fistula is created by anastomosing the cephalic vein to the brachial artery at the elbow. The cephalic vein runs on the lateral aspect of the arm and is usually superficial enough for easy cannulation. The brachiocephalic arteriovenous fistula can be identified by its location. The surgical scar is at the elbow where the inflow is located. It runs on the lateral aspect of the arm towards the axilla. (**c**) Appearance of the brachiocephalic fistula on fluoroscopy

the brachial artery. For the upper arm AVG, a curved graft is usually used to join the axillary or basilic vein to the brachial artery. Some examples of AVG are shown in Figs. 7.4 and 7.5.

Dialysis Catheter

Dialysis catheters are needed to provide access for hemodialysis in the absence of a functioning AVF or AVG. They can be further categorized as tunneled or non-tunneled dialysis catheter.

1. Tunneled dialysis catheter is characterized by the presence of a cuff to anchor the catheter. The presence of the cuff and the subcutaneous tunnel help decrease the risk of infection. A tunneled catheter is preferred if prolonged use (>1 week) is anticipated.

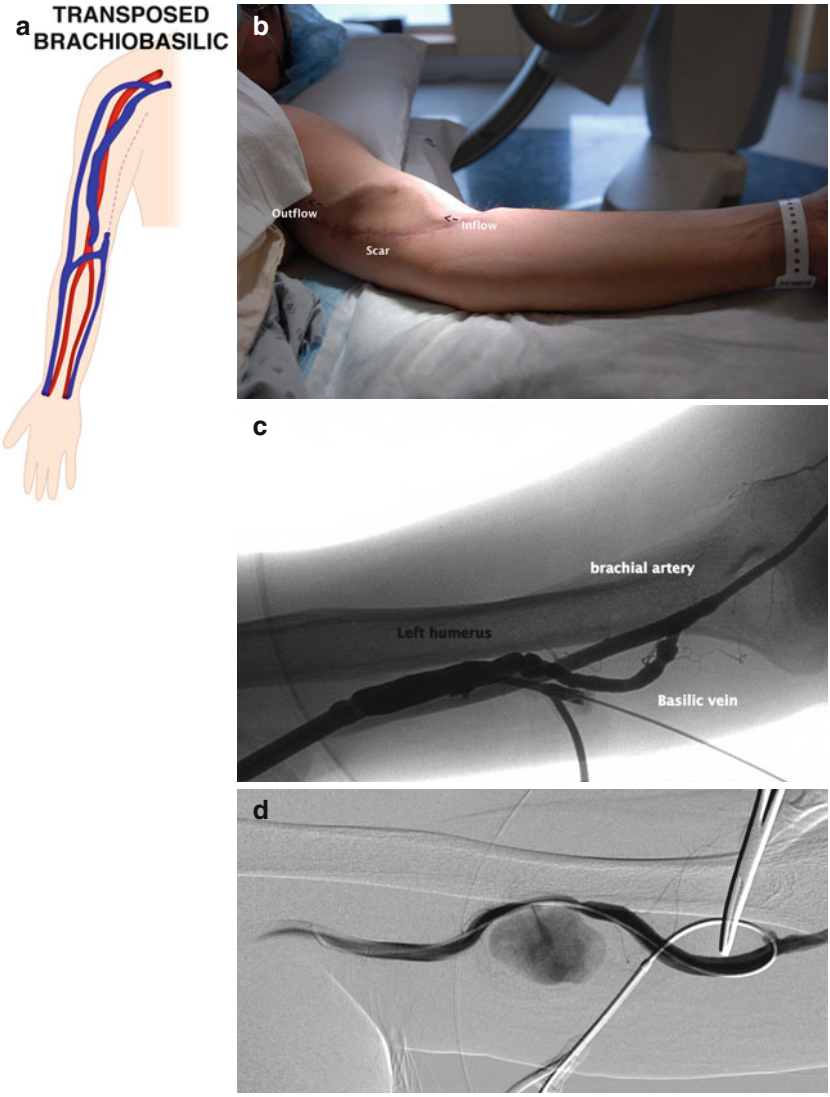


Fig. 7.3 (**a**) Brachiobasilic arteriovenous fistula. (**b**) The brachiobasilic arteriovenous fistula is created by anastomosing the basilic vein to the brachial artery at the elbow. The basilic vein lies on the medial aspect of the arm and is usually too deep and medial to be cannulated for dialysis; hence the requirement for additional "transposition" surgery to bring it nearer to the skin surface. The BBT AVF can be identified by its location and the presence of a transposition scar which runs on the medial aspect of the arm. The inflow is located near the elbow while the outflow is towards the axilla. (**c**) The basilic vein lies in close proximity to the brachial artery. Occasionally, the brachial artery may be inadvertently injured during attempts to cannulate the basilic vein for dialysis. (**d**) Pseudoaneurysm of the brachial artery as a result of inadvertent injury during placement of dialysis needle in a patient with left BBT AVF

Table 7.2 Characteristics of different upper limb AVF [2–4]

Types of AVF	Brescia-Cimino/radiocephalic (RC)	Brachiocephalic(BC)	Brachiobasilic (BB)	Gracz
Vessels used	Cephalic vein to radial artery	Cephalic vein to brachial artery	Basilic vein to brachial artery	Median cubital vein to brachial artery
Types of anastomosis	End vein to side artery or side to side	End vein to side artery or side to side	End vein to side artery	End vein to side artery
Advantage	Simple anastomosis, preserves upper arm vessels for future use, low risk of upper limb ischemia	Higher blood flow rate than RC AVF	Higher blood flow rate than RC AVF	Simultaneous arterization of both the cephalic and basilic veins, low risk of upper limb ischemia
Disadvantage	Lower blood flow rate, high primary failure rates	Increased risk of developing dialysis access steal syndrome and higher incidence of cephalic arch stenosis compared to RC AVF	Technically challenging, increased risk of developing dialysis access steal syndrome, need to transpose basilic vein	Lower flow compared to BC and BB AVF
Patency rate	1 year patency rate: 48–69 %	Mean 2 years patency rate: 70–85 %	Mean 2 years patency rate: 55–70 %	3 years patency rates: 80 %
Usual sites of stenosis	Juxta-anastomotic	Cephalic arch stenosis, Juxta-anastomotic	“Swing point” stenosis, Juxta-anastomotic	Venous outflow, Juxta-anastomotic

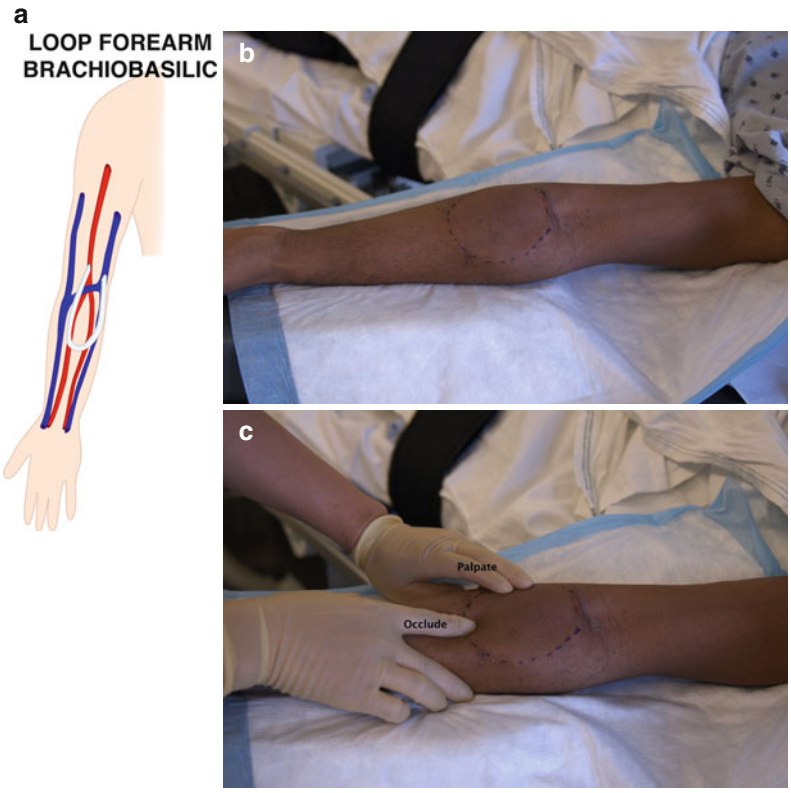
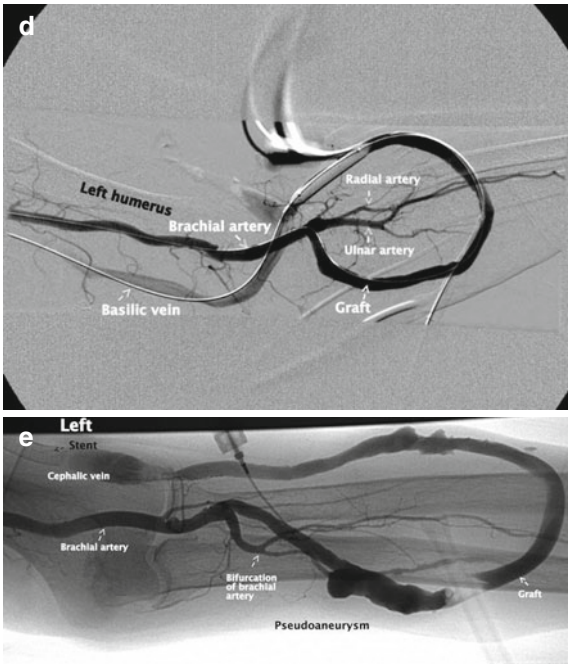


Fig. 7.4 (**a**) Forearm Brachiobasilic loop graft. (**b**) The forearm loop graft connects the brachial artery to either the cephalic, antecubital or basilic vein at the elbow. All 3 forearm loop grafts appear similar and it may be difficult to differentiate the two on physical examination. Regardless, the key point in approaching a patient with a forearm loop graft is to identify the inflow and outflow of the graft. (**c**) To determine the inflow of a forearm loop graft, occlude the apex of the loop graft with your right index finger and palpate the medial aspect of the graft. If the medial aspect of the graft becomes pulsatile, then the medial aspect of the graft is the inflow of the graft. If the thrill on the medial aspect of the graft disappears after occlusion at the apex of the graft, then the medial aspect of the graft is the outflow of the graft. (**d**) In a brachio-basilic forearm loop graft, the basilic vein is joined to the brachial artery using a loop graft in the forearm. The basilic vein runs on the medial aspect of the arm, hence, the thrill is may be palpable on the medial aspect, compared to the brachiocephalic graft where the thrill may be palpable on the lateral aspect of the arm. (**e**) A brachiocephalic forearm loop graft is created by joining the cephalic vein to the brachial artery through a loop graft in the forearm. Note the presence of a pseudoaneurysm on the graft and a stent at the graft vein junction. The cephalic vein runs on the lateral aspect of the arm

Fig. 7.4 (continued)



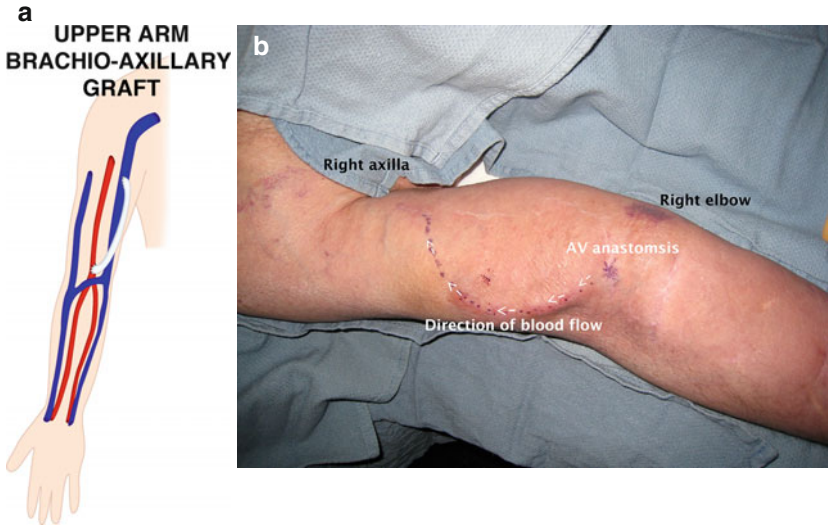
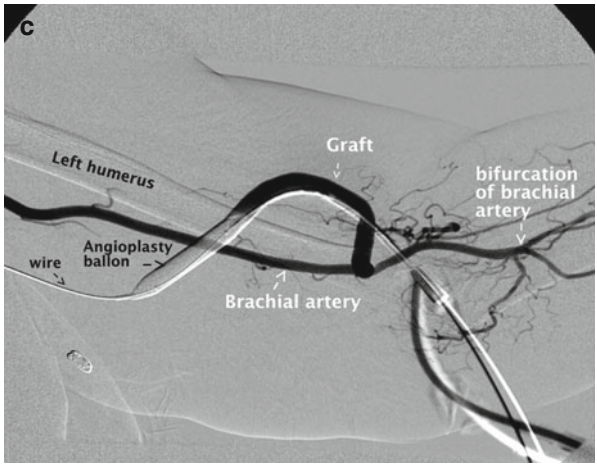


Fig. 7.5 (**a**) Brachio-axillary graft. (**b**) A right brachio-axillary arteriovenous graft is shown here. The AV anastomosis is at the elbow and the direction of blood flow is as indicated above. Note that the graft curved medially to join the axillary vein. (**c**) A left upper arm brachio-axillary arteriovenous graft is created by joining the axillary vein to the artery using a "curved" graft. Note that the graft needs to be curved medially to join the axillary vein. The wire is lying within the graft. This is a retrograde graftogram, which is performed by occluding the graft with an angioplasty balloon during contrast administration

Fig. 7.5 (continued)



2. Non-tunneled dialysis catheters have shorter extra-vascular segment and are inserted for short term (<1 week) use or when placement of a tunneled dialysis catheter is contraindicated, for example, in the presence of bacteremia.

The use of dialysis catheter is a double-edged sword. The insertion of dialysis catheter is a relatively simple procedure and the catheter can be used immediately after insertion. On the other hand, they do not last as long as AVF and AVG and are prone to infection and thrombosis. Long term use of catheters is also associated with central vein stenosis. Specifically, the use of tunneled hemodialysis catheter for chronic hemodialysis is associated with an increased hospitalization, morbidity and mortality. Hence, the use of tunneled hemodialysis catheters for chronic hemodialysis should not be encouraged.

Conclusion

Establishing a functioning vascular access is critical in the delivery of hemodialysis. Timely referral to surgeon for AVF creation by Stage 4 (glomerular filtration rate (GFR) less than 30 mL/min/1.73 m^2) Chronic Kidney Disease will alleviate the need for catheter placement at the time of dialysis initiation.

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Physical Examination of Dialysis Vascular Access and Vascular Access Surveillance

8

Chieh Suai Tan, David J.R. Steele, and Steven Wu

Introduction

As defined by the National Kidney Foundation Kidney Disease Outcomes Quality Initiative (NKF KDOQI) guidelines, vascular access monitoring is performed by physical examination to detect signs that would suggest the presence of pathology while surveillance refers to periodic evaluation by means of tests that may involve special instrumentation to detect the presence of pathology [1].

Thrombosis is a problem that can occur in both arteriovenous grafts (AVG) and in arteriovenous fistula (AVF) although it is more common in AVG. Despite the proven advantages of arteriovenous fistula (AVF) over AVG, AVF may still eventually fail and declotting of a thrombosed AVF is more time consuming, tedious and has a lower success rate than declotting of an AVG [2]. The main aims of vascular access monitoring and surveillance are prevention of vascular access thrombosis and detection of failing vascular access that may compromise the delivery of adequate dialysis.

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Vascular access thrombosis is a frequent cause of graft failure and is usually due to the presence of a flow limiting stenosis [3]. It is important to intervene before thrombosis occurs as patency rates after declotting of a thrombosed graft are reduced in comparison to angioplasty of a patent arteriovenous graft (AVG) [4]. It is postulated from population studies that through regular monitoring and surveillance to detect a decrease in flow within a dialysis access and hence the development of stenosis, vascular access patency rates can be improved by intervening before vascular access thrombosis occurs [5]. While controversies remain over the benefits of vascular access surveillance in improving long-term vascular access patency [6], we believe that surveillance, when used to supplement physical examination, as well as clinical and dialysis parameters, may be useful to identify patients who will benefit from preemptive intervention.

Physical Examination

Physical examination of the dialysis vascular access is an essential skill for the interventional nephrologist. It is easy to perform, and provides important information in the evaluation of AVF and AVG.

Inspection

Begin the physical examination by putting the patient's arms side by side on a pillow (Fig. 8.1a–d). The size of the two arms should be similar. Swelling of the arm and edema on the side of the dialysis access is suggestive of venous hypertension and possibly resistance to outflow locally or centrally. Look at the fingers and nails for any discoloration or dystrophic changes to suggest steal syndrome.

Focus your attention on the dialysis access (Fig. 8.2a–f). Determine if it is an AVF or an AVG, the type of anastomosis and the anastomotic site. Note the presence of collateral veins and look for signs of infection, hematoma or thinning of skin. Look for the presence of aneurysmal dilatation or pseudo-aneurysm (Fig. 8.3a–i) Aneurysmal dilatation or aneurysm of AVF can occur as a consequence of outflow stenosis or weakened vessel wall from repeated cannulation of the same AVF segment. It differs from pseudo-aneurysm as all layers of the vessel wall are present. Pseudo-aneurysm occurs when the leak in the vessel is contained by the surrounding tissue instead of the vessel wall. It may occur in AVG due to degeneration of the graft material or in AVF from arterial trauma.

Palpation

Begin palpation of the AVF or AVG from the anastomotic site. The AV anastomotic site is where the vein or graft is anastomosed to the artery. The direction of the blood flow within the AVF or AVG is away from the anastomosis and towards the chest.

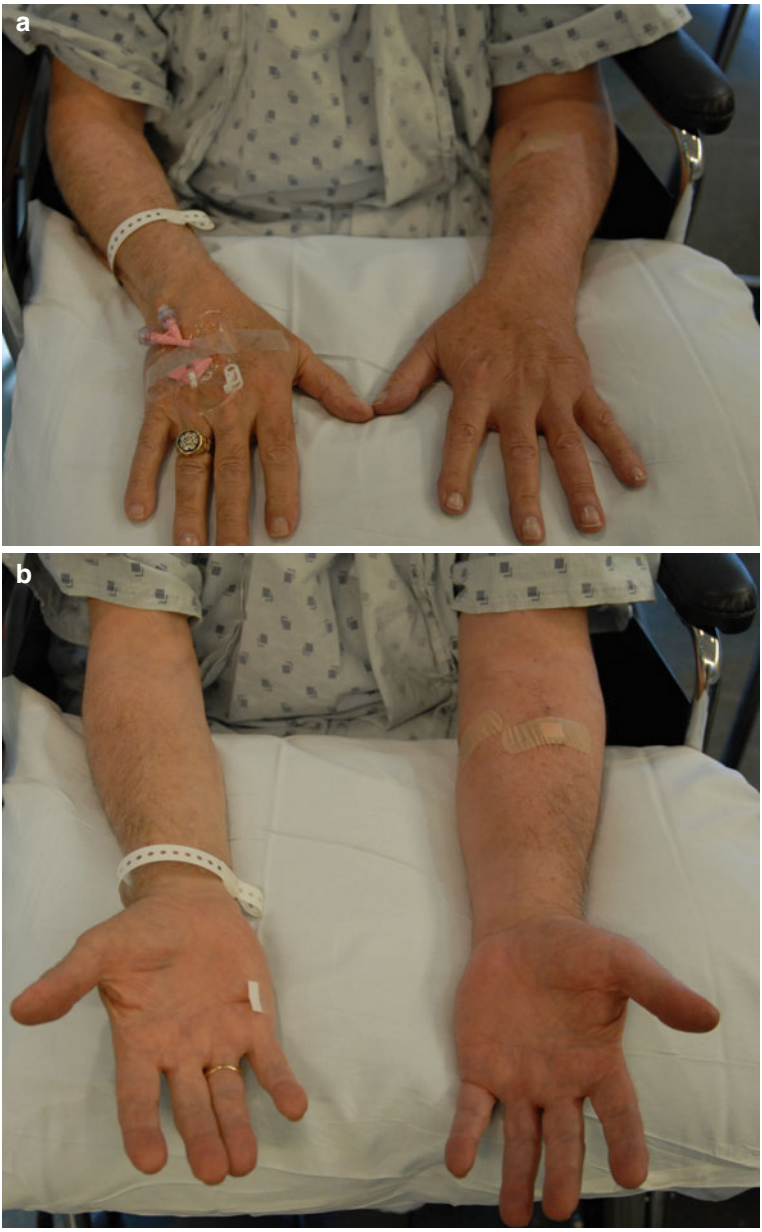


Fig. 8.1 (**a**) Inspection is a key component of the physical examination. Begin by placing both arms on a pillow. The AV access is on the left forearm and the left arm appears bigger than the right. (**b**) Turn the hand over and inspect the arm. The left arm is clearly larger then the right. The left hand also appears redder than the right. The bandaid on the forearm indicates recent cannulation of the AV access. (**c**) On closer inspection, this patient has a forearm loop graft. Note the presence of a transverse surgical scar at the elbow and the loop configuration of the graft. (**d**) The cause of the arm swelling was secondary to severe stenosis of the left brachiocephalic vein as demonstrated below

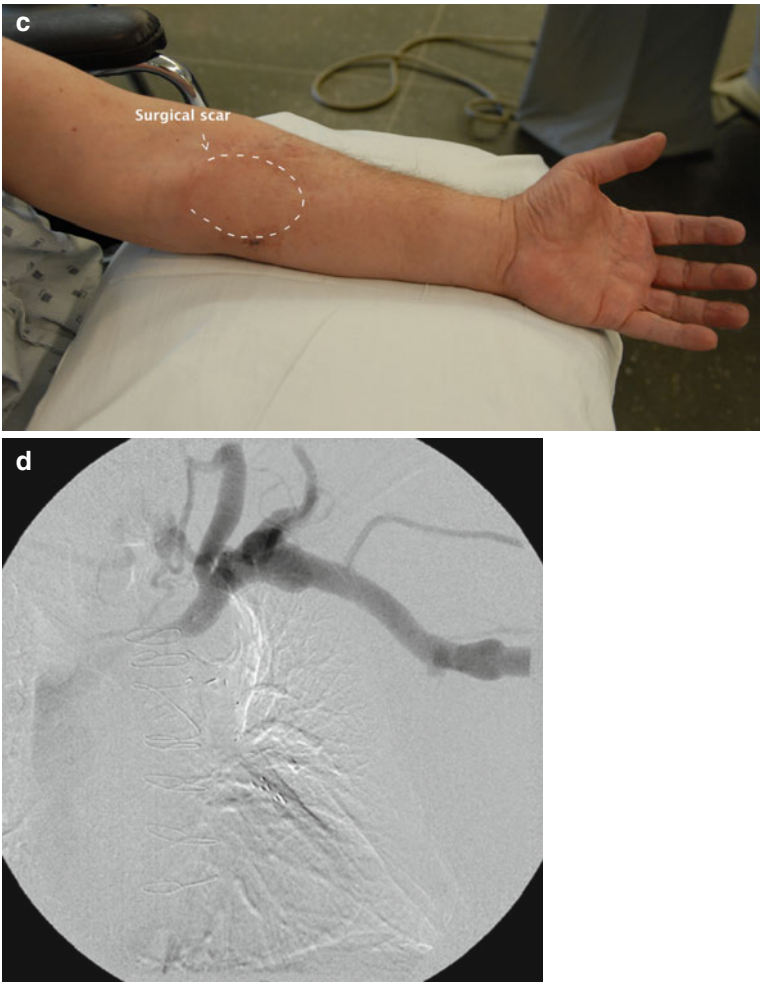


Fig. 8.1 (continued)

Place your fingers over the AV access to feel for the pulse and thrill. In general, there should be very little pulse in the AV access and it should feel soft and compressible in an AVF. In the presence of a downstream stenosis, the pulse will become strong and the AV access may feel "pulsatile". The thrill of the AV access is related to flow and is most obvious at the venous anastomosis. It has both a systolic and diastolic component and should be continuous over the entire course of the AV access. In the presence of a significant downstream stenosis, the thrill may only be felt during the systolic component. Move the finger(s) along the AV access; the pulse and thrill may suddenly disappear at the stenotic segment. For an AVF, assess the diameter and depth of the fistula to determine if it can be easily cannulated for dialysis. Specifically assess if the length of the AVF is long enough to accommodate the

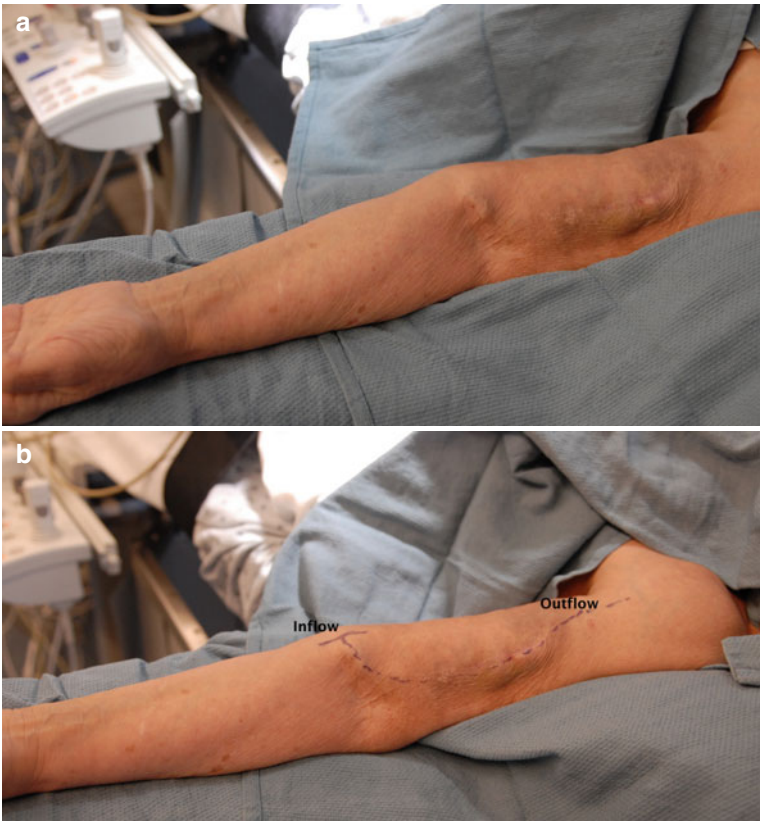
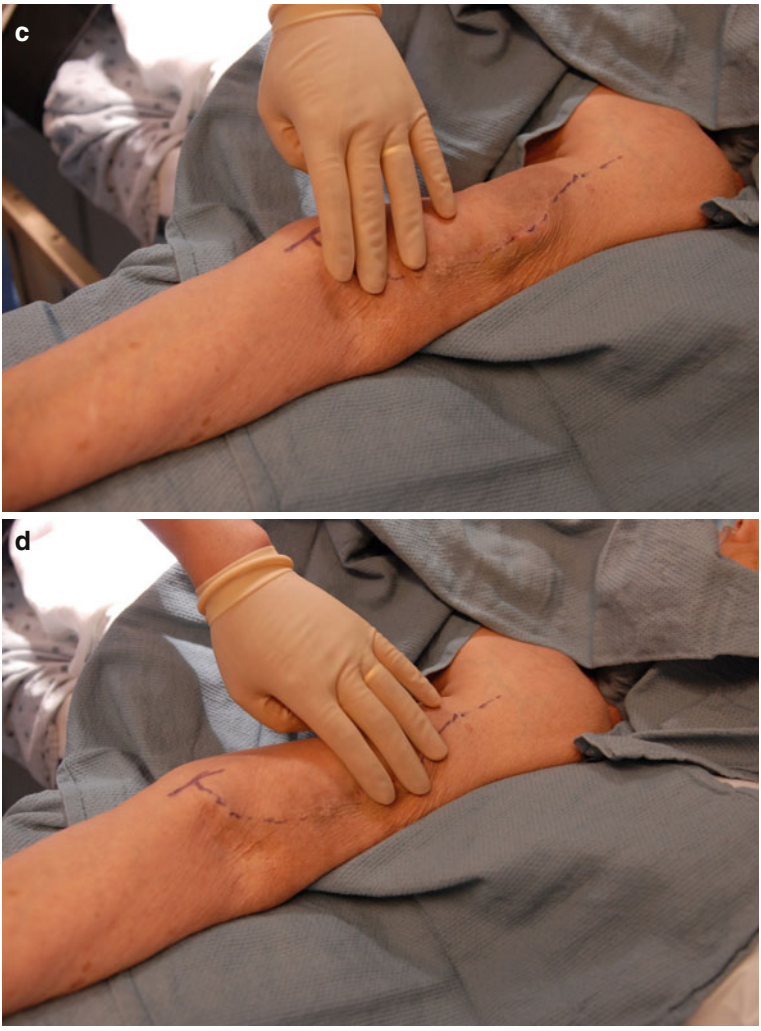


Fig. 8.2 (**a**) Identify the type of AV access that the patient has placed. This patient has a left brachiocephalic AVF. (**b**) Identify the inflow and out flow of the AVF. (**c**) Begin palpation from the inflow of the AVF. (**d**) Palpate the entire length of the AVF to feel the thrill and pulse. (**e**) Augmentation: Palpate the pulse of the AVF with your right fingers, then compress the AVF with your left index finger. The pulse intensity over the right fingers should increase. Failure to increase the pulse intensity with compression of the AVF would suggest an inflow stenosis. (**f**) Arm elevation: Raise the arm above the level of the heart and the AVF should collapse or become flaccid. In the example shown, the brachiocephalic fistula remained distended after arm elevation, suggestive of an outflow stenosis



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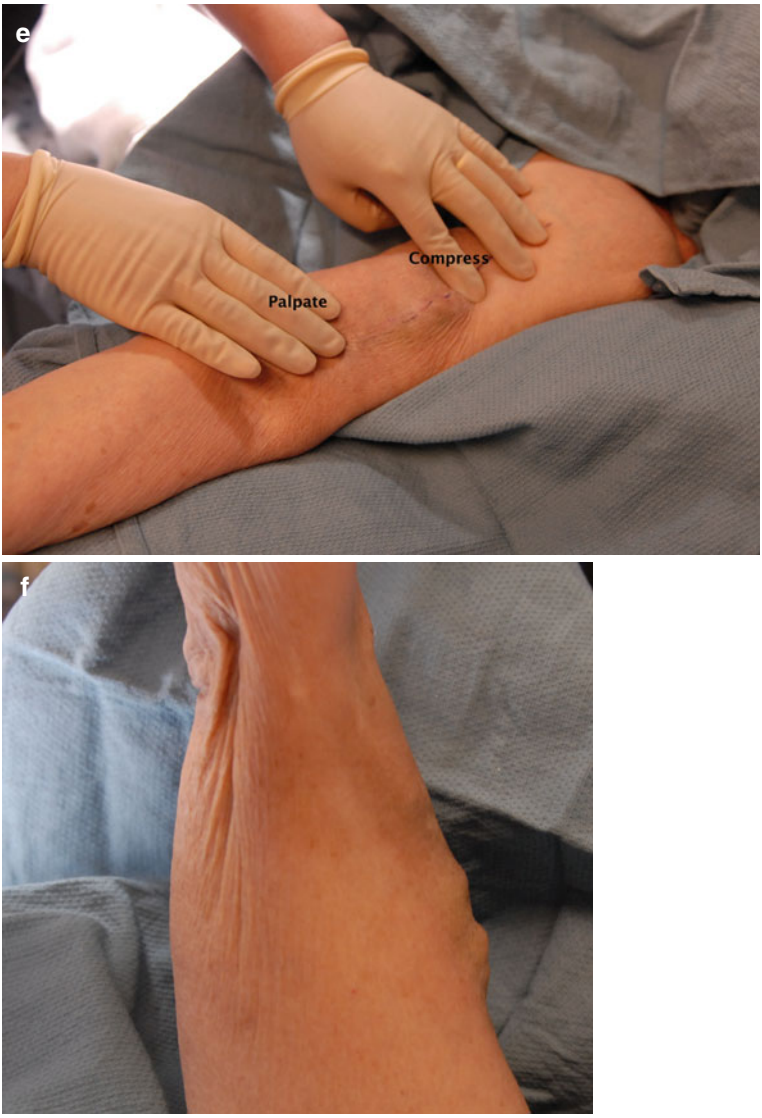

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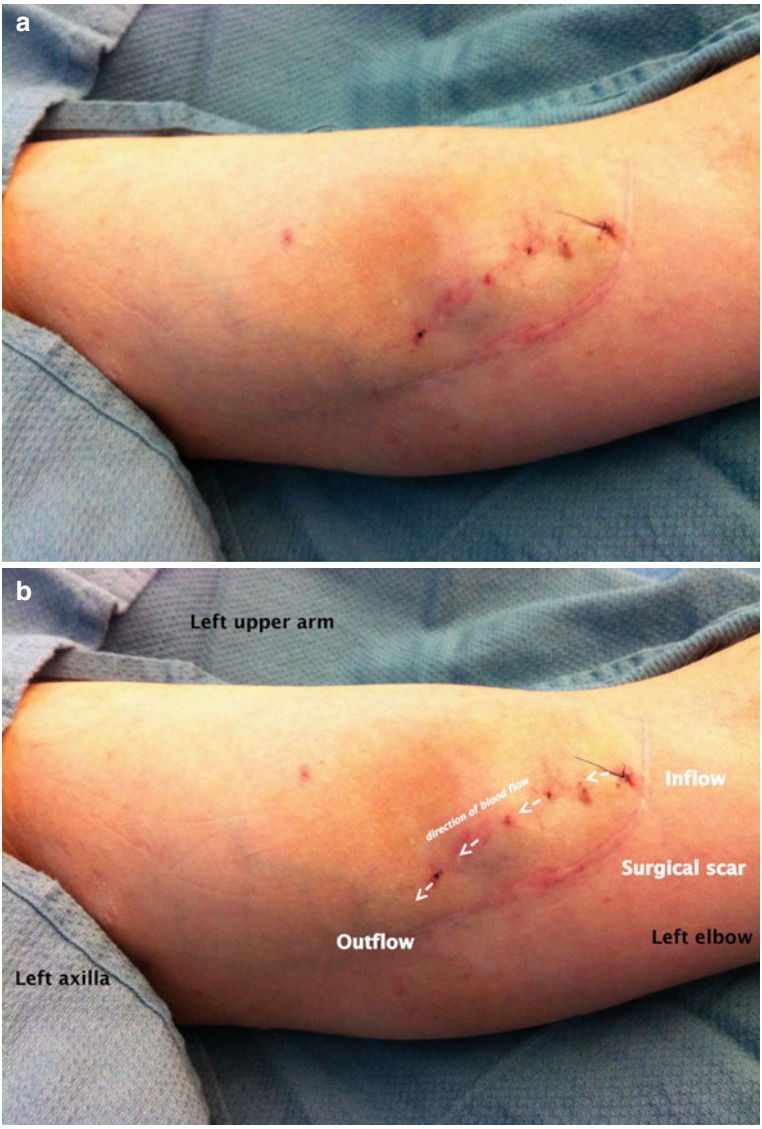
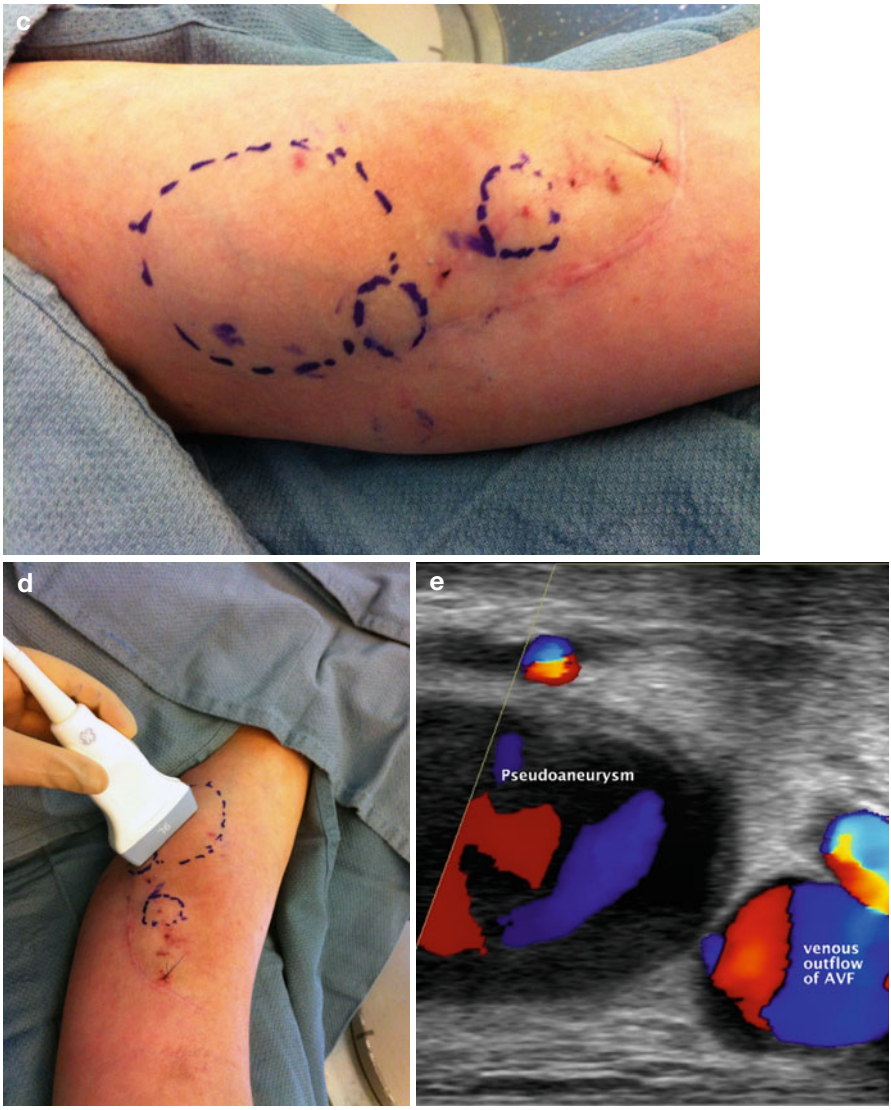


Fig. 8.3 (**a**) The patient complained of left arm pain and swelling after dialysis. (**b**) This is a left transposed brachiobasilic fistula. The direction of blood flow is as indicated below. (**c**) A large area of swelling was noted near the outflow of the fistula. (**d**) Ultrasound was performed to assess the area. (**e**) Color doppler showed flow within the area of swelling, suggestive of a pseudoaneurysm. (**f**) Doppler study of the pseudoaneursym was repeated with occlusion of the inflow of the fistula. (**g**) No flow was seen in the venous outflow of the fistula after occlusion of the inflow but flow continued within the pseudoaneurysm, suggestive that the pseudoaneurysm is arising from the arterial system. (**h**) Angiography confirmed that the pseudoaneursym was arising from the brachial artery. The basilic vein was in close proximity to the brachial artery and the brachial artery was probably inadvertently injured during placement of the dialysis needle. (**i**) The pseudoaneurysm was treated with thrombin injection with good results



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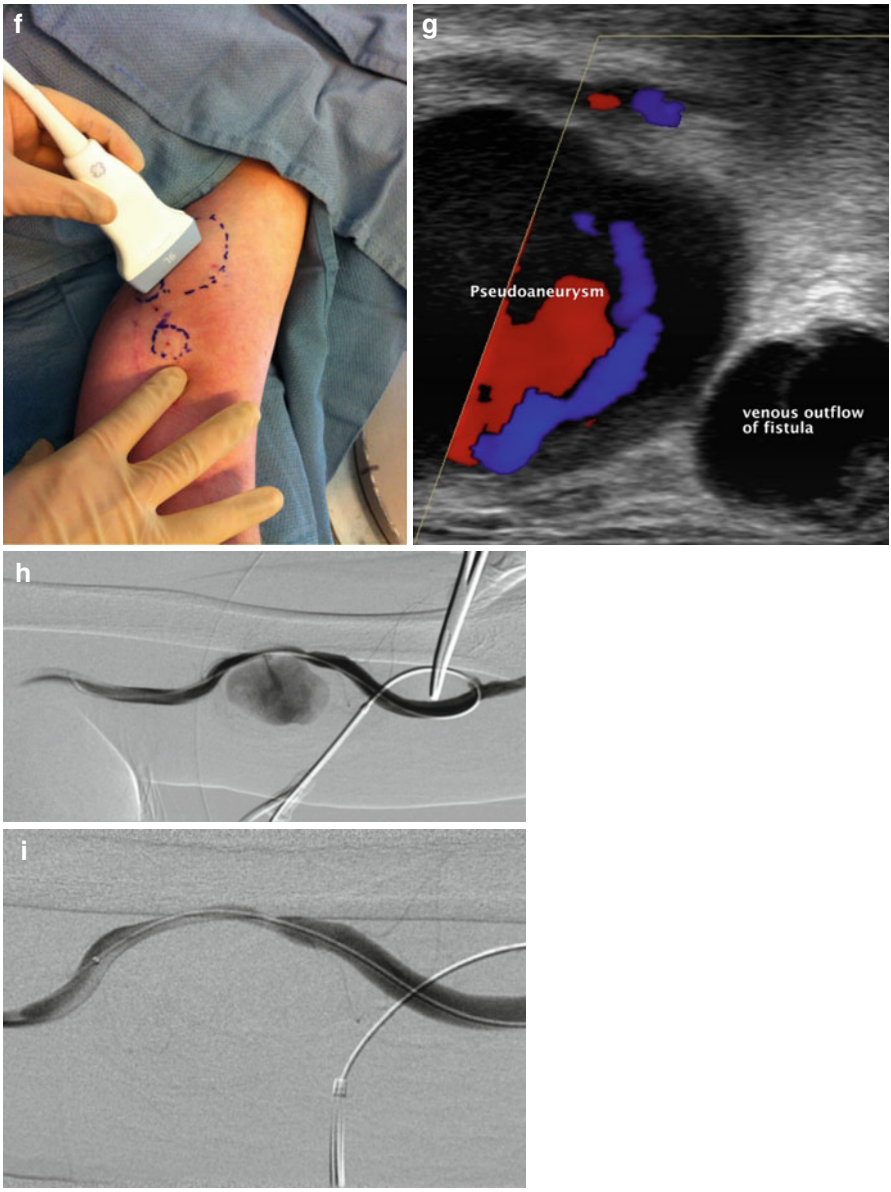

Fig. 8.3 (continued)

placement of two dialysis needles. By convention, there should be a minimum of 5 cm between the arterial and venous needles to avoid access recirculation and the arterial needle should be placed at least 1 inch from the AV anastomosis to avoid causing damage to the anastomosis.

Maneuvers

Pulse Augmentation

This maneuver works better in AVF than AVG and is useful to evaluate the inflow of the AV access. Feel the pulse of the AV access with your right fingers and occlude the AV access at some point distant from the arterial anastomosis with your left index finger. The pulse intensity should feel stronger (augmented) on the right fingers. Failure to augment suggests the presence of an inflow stenosis. If the pulse is already pulsatile before augmentation, failure to augment after occlusion is suggestive of a severe outflow stenosis.

Arm Elevation

This maneuver is useful when examining the AVF. Raise the arm above the level of the heart and the AVF should collapse or become flaccid. In the presence of a venous stenosis, the segment of the AVF before the stenosis will remain distended while the segment after the stenosis will collapse. This is a good preliminary screening test for evaluation of the access outflow.

Auscultation

The auditory manifestation of the thrill, or the bruit, can be easily auscultated over the vascular access. It has both a systolic and diastolic component and has a low pitch, rumbling character. It is especially useful to confirm the presence of flow when the thrill is not very well palpable. In the presence of a downstream stenosis, the diastolic component may be lost and the pitch becomes higher as the stenosis increases in severity.

Surveillance

Dialysis access flow surveillance is performed by using devices to measure the access blood flow (Qa) and venous pressure (VP). A detailed description of the various techniques and protocols is beyond the scope of this chapter. Briefly, Qa can be measured by using doppler ultrasound, ultrasound dilution technique using Transonics hemodialysis monitor (Transonics, Inc., Ithaca, NY), conductance or thermal dilution technique. Some dialysis machines have in-built conductivity cells to allow real time or “on-line” measurement of dialysate conductance. Propriety software and algorithm has been incorporated into these dialysis machines to

compute changes in conductance for *Qa* measurement during dialysis, therefore eliminating the need for additional access monitoring equipment.

VP is the pressure required to infuse blood back into the access and is routinely recorded during hemodialysis. It may be elevated due to malposition of the needle or the presence of outflow stenosis and is less sensitive and specific than direct measurements of access flow rates. It is only meaningful if reading is obtained at the beginning of dialysis or at low pump speed as much of the resistance arises from the needle rather than the vascular access when the blood flow rate is high. On the other hand, intra-access pressure (IAP), which is a component of VP, can be sequentially measured for surveillance of AVG. IAP can be measured directly as static IAP using a pressure measuring device or indirectly calculated using computerized algorithm as an equivalent IAP from the VP recorded using dialysis. The IAP is usually less than 50 % of the mean arterial blood pressure in an AVG and the ratio increases with the development of outflow stenosis.

For Qa surveillance, the KDOQI guidelines recommend an intervention referral when the Qa of an AVG is less than 600 mL/min or when Qa has decreased by more than 25 % and falls below 1,000 mL/min. For AVF, the recommendation is when Qa is less than 400–500 mL/min. This discrepancy is because an AVF may remain patent at a lower blood flow rate than an AVG. An IAP /MAP ratio of greater than 0.5 may be due to the presence of an outflow stenosis and may warrant further evaluation and treatment.

It is important to monitor trends and correlate with clinical findings rather than relying on a single measurement. Specifically, a decrease in Qa is usually accompanied by other signs and symptoms such as decreased thrill, or increase pulsatility of the AV access, difficulties in cannulation or recurrent triggering of the arterial alarm (from low pressure) during dialysis. On the other hand, an increased VP may be accompanied by prolonged bleeding from the cannulation sites after dialysis; enlarging AV access, arm swelling or recurrent triggering of the venous alarm (high pressure) during dialysis. Location and positioning of the needle on the AV access can affect the readings and noting changes in cannulation sites when there is a sudden variation in the Qa and VP trends may be helpful.

Hemodialysis Dose and Adequacy

The advent of hemodialysis therapy has converted end stage renal disease from a terminal illness to a chronic disease state. Similar to the management of many other chronic diseases, it is essential to monitor adequacy of treatment to ensure the well being of patients.

To monitor adequacy of dialysis, blood investigations are done at least once a month. While the presence of persistent hyperkalemia, or metabolic acidosis is suggestive for insufficient clearance, urea has always been used as the conventional marker for dialysis clearance.

To monitor dialysis adequacy either the urea reduction ratio (URR) or the Kt/V of urea (Clearance of Urea) can be used. For the purposes of access surveillance it should be noted that there are “variants” of Kt/V of urea such as the single pool Kt/V (spKt/V), double pool kt/V(spKt/V) and equilibrated Kt/V (eKt/V); therefore,

one should use the same formula for assessment each time when computing trends in an individual patient.

Access Dysfunction and Recirculation

When the delivered dialysis dose is much lower than what is prescribed, vascular access dysfunction and recirculation should be considered as a possible cause. Assessment of recirculation can be performed using the ultrasound based dilution technique or blood based urea measurement. A recirculation value that is greater than 10 % should be considered abnormal and warrants consideration for a diagnostic angiogram.

Hemodialysis access recirculation occurs when dialyzed blood returning through the venous needle reenters the dialysis circuit through the arterial needle instead of the systemic circulation (Fig. 8.4a–c). This is commonly due to the presence of a

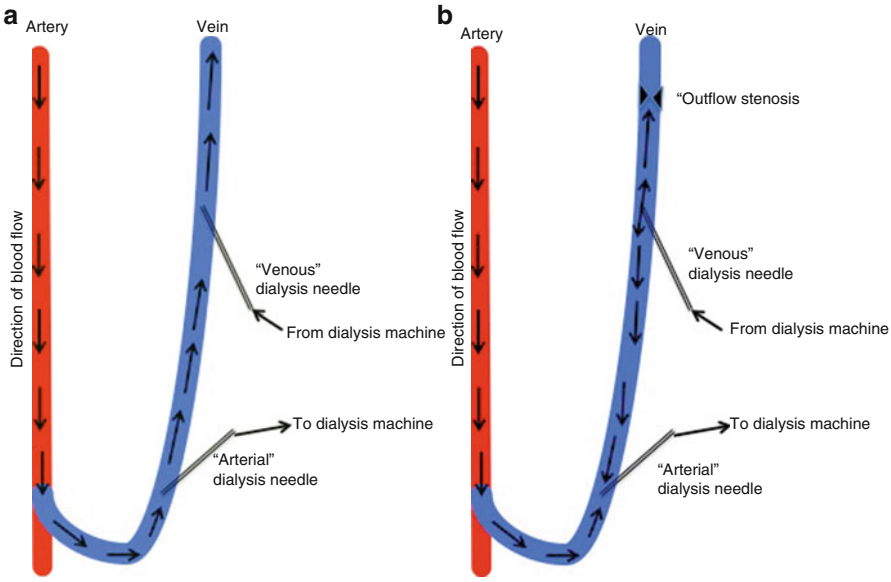

Fig. 8.4 (**a**) The direction of blood flow is shown by the arrows. The "arterial" dialysis needle is typically placed against the direction of blood flow while the "venous" dialysis needle is placed in the opposite direction to minimize access recirculation. The typical blood flow rate within an AV access is usually above 600 mL/min. The blood pump of the dialysis machine will generate a negative pressure to pull blood into the dialysis circuit. The usual blood flow rate within the dialysis circuit is around 300 mL/min. (**b**) In the presence of an outflow stenosis, the venous pressure within the AV access will increase and obstructs the return of blood from the dialysis circuit. This may cause the back flow of blood into the arterial needle, resulting in an increase in recirculation. (**c**) In the presence of an inflow stenosis, blood flow rate within the AV access will decrease. The inflow of blood into the AV access may not be able to meet up with the demands of the dialysis machine. The negative pressure generated by the arterial blood pump of the dialysis machine will "pull" blood from the venous limb into the dialysis circuit to maintain the flow, causing an increase in re-circulation

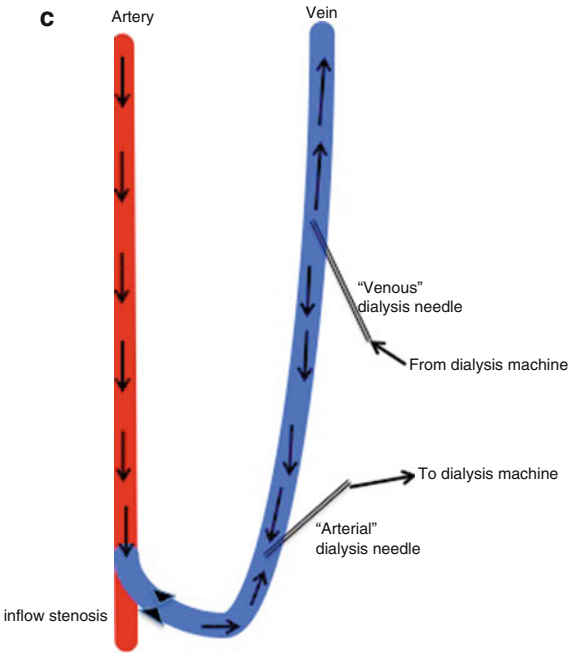

Fig. 8.4 (continued)

high-grade venous stenosis, which obstructs the venous outflow and causes the backflow of blood into the arterial needle. Occasionally, it may also be caused by an inflow stenosis, which results in the backflow of blood from the venous limb of the access to meet up with the demand generated by the arterial blood pump of the machine.

Recirculation may also be caused by inadvertent reverse placement of the arterial and venous needles on the AV access. In particular, the direction of blood flow in a loop graft needs to be determined accurately to ensure correct needle placement. One easy way to determine the direction of flow is to temporarily occlude the loop AVG at its apex and palpate the graft at either side of the occlusion. The thrill on the venous limb should diminish while the arterial limb will become more pulsatile.

The consequence of mixing dialyzed or cleansed and undialyzed/uncleansed blood within the dialysis circuit is a lower solute concentration within the blood compartment of the dialyzer and hence a lower diffusion gradient across the dialyzer membrane and decreased dialysis efficiency. Therefore, regular monitoring and surveillance protocols are important as inadequate dialysis from access recirculation can affect the well being of dialysis patients and results in life threatening electrolyte imbalances such as hyperkalemia and metabolic acidosis.

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Hemodialysis Access: Imaging Diagnosis

9

Mark Reddick and Sanjeeva P. Kalva

Introduction

A well functioning dialysis access is the lifeline for patients with end stage renal disease (ESRD) on hemodialysis. Dialysis access circuits include both arterio-venous fistulas (AVF) and arterio-venous grafts (AVG). An AV fistula is created by connecting a vein to an artery, resulting in one anastomosis. An AV graft is created when a biologically acceptable tube is connected to an artery at one end and to a vein at the other end, resulting in two anastomoses. The upper extremities are preferred over the lower extremities for dialysis access creation and fistulas have been shown to out-perform grafts in terms of durability and infection rates [1]. Maintaining a given dialysis access requires early detection of access dysfunction. The goal is to keep the dialysis access functioning such that adequate dialysis is achieved, as well as to prevent thrombosis of the access. Once dialysis access thromboses, its lifespan declines dramatically [1–3].

Duplex Doppler ultrasound continues to be the mainstay imaging modality for evaluation of dialysis access circuits. Dialysis access circuits are typically superficial and allow excellent evaluation by ultrasound. Ultrasound imaging can augment the physical exam in detecting dialysis circuit problems by characterizing and localizing problem areas within the access circuit and help identify patients at high risk for future circuit thrombosis [4]. The use of pre-operative ultrasound for mapping

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Table 9.1 Common indications for ultrasound evaluation of dialysis access circuits and their associated ultrasound findings

Indication for ultrasound study	Common findings on ultrasound
Low flow, poor maturation, diminished, absent thrill, collapse	Stenosis of inflow artery, arterial anastomosis, or juxta-anastomotic segment peripheral to the cannulation zone
Difficult cannulation	Cannulation zone too deep (>6 mm), short segment of superficial cannulation zone, immature fistula (<4 mm, flow <500 mL/min), tortuosity
Clot aspiration	Non specific
Elevated venous pressure, prolonged bleeding, pulsatility	Stenosis central to the cannulation zone (outflow or central veins)
Elevated recirculation time, diminished urea reduction rate	Competing outflow, stenosis peripheral or central to cannulation zone
Suspected infection	Perigraft fluid collection, soft tissue edema, aneurismal degeneration of anastomosis
Perigraft mass	Abscess, hematoma, pseudoaneurysm
Steal symptoms	High flow in graft/fistula with augmentation of plethysmographic waveform in digits with graft/fistula compression

prior to access has been shown to improve patency of dialysis access and identify situations in which alternative access sites should be utilized [5–7]. The use of routine surveillance ultrasound of already existing dialysis access circuits remains controversial but is typically done in conjunction with some evidence of access dysfunction from parameters measured at dialysis or from clinical exam findings [8]. The information gathered from a thorough ultrasound evaluation of a dialysis circuit is unique relative to other vascular beds. This is because the creation of a graft or fistula results in unique flow dynamics including increased peak systolic and end diastolic velocities, high flow rates, turbulence and spectral broadening. A thorough understanding of these unique flow dynamics is therefore critical when interpreting these studies.

Indications

Indications for dialysis access ultrasound include: low flow, difficult cannulation, clot aspiration, elevated venous pressures, prolonged bleeding, elevated recirculation time, and diminished urea reduction rate. These indications are encountered during dialysis. There are several clinical indicators of fistula/graft dysfunction that can also be used to initiate an ultrasound evaluation including: poor maturation, evidence of infection, perigraft mass (hematoma, pseudoaneurysm), symptoms of distal limb ischemia or "steal", loss of thrill or diminished thrill, pulsatility and collapse of the fistula/graft. Some of these indications suggest a problem within a particular segment within the circuit (Table 9.1). For example, a history of low flow

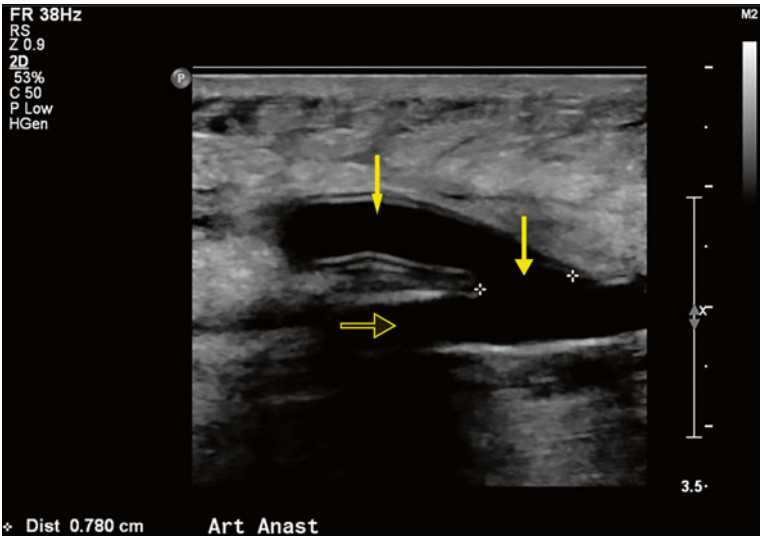


Fig. 9.1 Gray scale image demonstrating the arterial anastomosis of a dialysis access graft. The anastomosis can be accurately measured in gray scale imaging. *Open arrow* points to the inflow artery. *Thick arrow* points to the anastomosis which measures 7.8 mm as indicated by the calipers. The *thinner arrow* points to the arterial limb of the synthetic graft

suggests an inflow or arterial anastomotic or juxta-anastomotic stenosis peripheral to the cannulation zone. A history of elevated venous pressure, however, suggests a stenosis that is central to the cannulation zone.

Ultrasound Acquisition, Display and Transducers

In addition to acquiring excellent anatomical images, modern ultrasound machines are also capable of acquiring important hemodynamic information such as the presence, direction and location of flow, as well as the velocity of blood flow and the presence of turbulence. Also, quantitative flow measurements can be obtained with the use of appropriate software packages that can be incorporated into the ultrasound unit.

There are a few key terms regarding the modes of ultrasound data acquisition and display that are fundamental to understand when interpreting dialysis access ultrasound studies. B-mode or gray scale ultrasound generates a two dimensional image of anatomical structures in shades of gray. This mode is useful to evaluate the anatomy of the circuit, measure vessel diameters and depths (Fig. 9.1) and to assess the presence and extent of perigraft hematomas, abscesses, and pseudoaneurysms (Fig. 9.2).

Pulse wave Doppler is a technique in which the transducer emits ultrasound in pulses. Blood flow velocity measurements are limited to those in the physiological range, but the depth of the recorded velocity measurement can be determined. Color

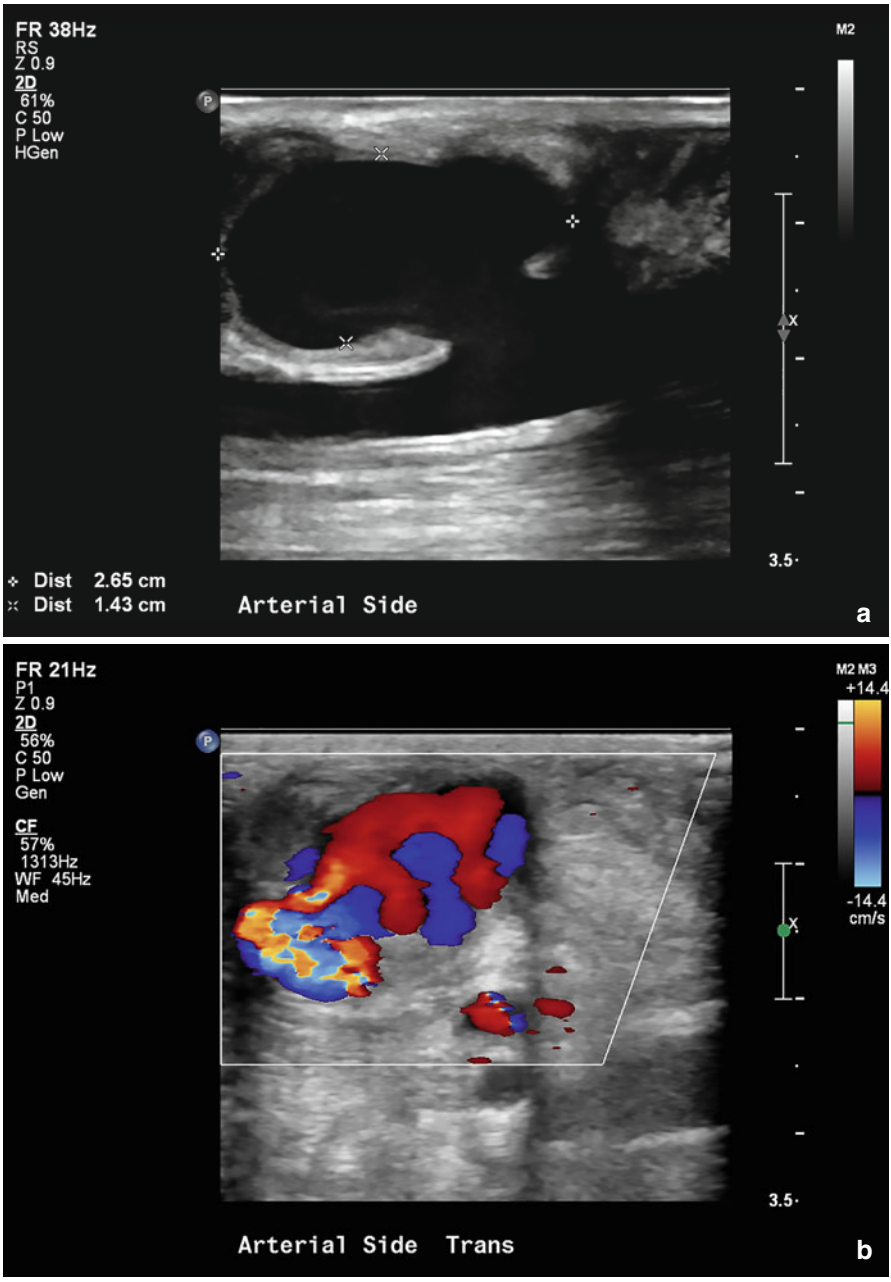


Fig. 9.2 Gray scale or B-mode ultrasound image of an access site pseudoaneurysm. The aneurysm is lobulated and measures 2.7 cm × 1.4 (**a**). This pseudoaneurysm demonstrates flow within it on color Doppler in a different scan plane (**b**)

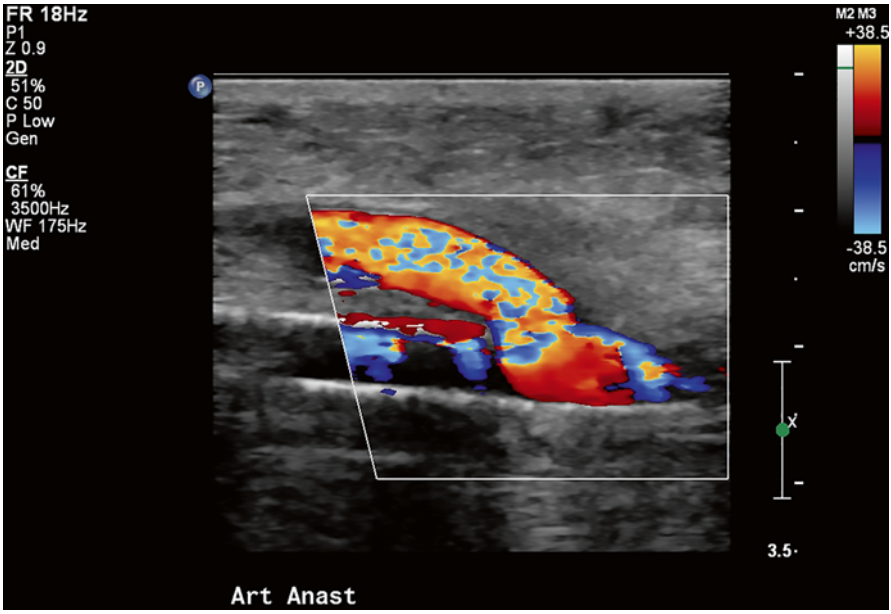


Fig. 9.3 Color Doppler image of the same arterial anastomosis as in Fig. 9.1 demonstrating turbulent flow within the arterial limb of the graft. Note that there are areas of both blue and red, indicating turbulence. This is a normal finding at a dialysis access arterial ansatomosis but would be considered abnormal in a native artery

flow Doppler is a type of pulsed Doppler that adds information regarding the direction of flow (Fig. 9.3). In general, flow towards the transducer is assigned a red color while flow away from the transducer is assigned a blue color. Turbulent flow can be detected by the presence of admixing of red and blue indicating that flow is going both toward and away from the transducer at such a location.

Another important mode of ultrasound acquisition and display is spectral Doppler. This mode of ultrasound displays flow velocities as a spectrum on the Y-axis along a time line on the X-axis. The term spectral broadening refers to a greater range of flow velocities. This often correlates with turbulent flow detected with color flow Doppler and can be seen at sites of stenosis.

Finally, duplex Doppler refers to a form of image display in which both color flow and spectral Doppler waveforms are displayed simultaneously. This allows for accurate localization of velocity information (Fig. 9.4).

The types of transducers that can be used for dialysis access evaluation include curved, phased array and linear transducers. Frequencies range from 2 to 10 MHz. In general, curved and phase array transducers are helpful in evaluating deeper structures while linear transducers are better for superficial structures. Higher frequency transducers are more sensitive for detecting low flow and have better spatial resolution whereas low frequency transducers allow better penetration. Aliasing is an artifact that occurs when the sampled blood is flowing too fast for the system to

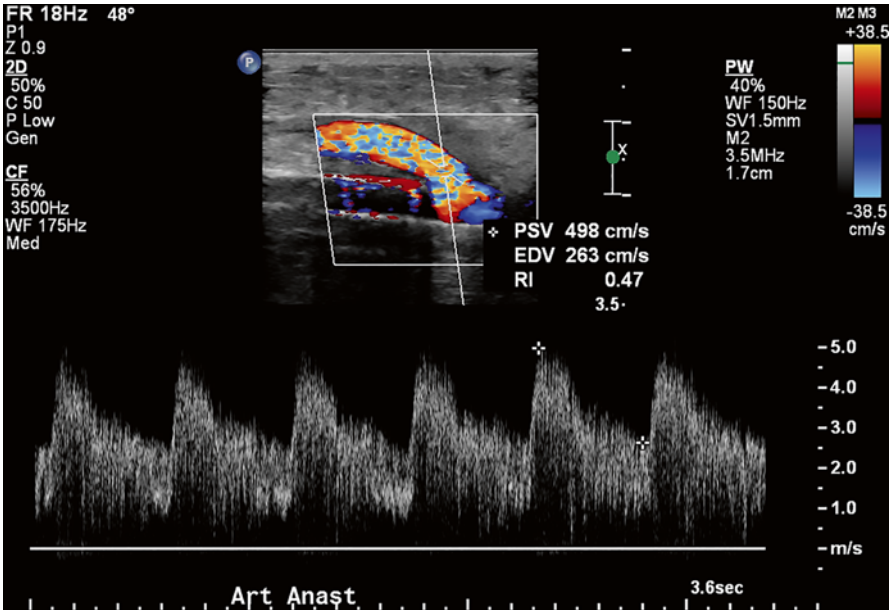


Fig. 9.4 Duplex Doppler image of the same arterial anastomosis as seen in Figs. 9.1 and 9.3. The waveform is velocity on the Y-axis and time on the X-axis. Note the spectral broadening or filling in of the waveform. This correlates with the mixing of the blue and red colors on color Doppler. The angle of incidence is 48° as indicated in the upper left hand corner and the sample volume is very small and within the central flow lumen of the sampled area. The peak systolic velocity and end diastolic velocities are 498 and 263 cm/s, respectively

accurately obtain its velocity. This happens more commonly with higher frequency transducers.

It is usually possible to gather the appropriate information necessary to make access management decisions based on a thorough physical exam and ultrasound evaluation of a given dialysis access. However, there are occasionally patient-specific factors that can limit the study. These factors include the presence of catheters or lines, edema, hematoma, wounds, surgical dressings, contractures and calcification.

Doppler Imaging

In order to interpret the velocity and waveform information obtained from Doppler evaluation of dialysis access circuits, it is important to understand the Doppler shift equation, the angle of incidence, and the Doppler sample volume, and how these are interrelated. One critical part of interpreting these studies is to ensure that the angle of incidence and sample volume parameters are appropriately selected.

The Doppler equation is as follows:

$$\Delta f = 2 f 0 v \cos \theta / c$$

Delta f is the Doppler frequency shift
f0 is the ultrasound emission frequency
V is the mean velocity of blood flow
c is the speed of sound in tissue (1,450 m/s)

This equation demonstrates that the Doppler shift is proportional to the frequency of the probe that is used, the velocity of the blood flow, and the cosine of the Doppler angle. The Doppler angle is the angle between the central flow lumen of the vessel and the ultrasound beam. This angle can be manipulated by the ultrasound user. The cosine theta portion of this formula dictates the optimum angle of incidence when measuring velocity. Since Cos 90 equals 0, there will be no detectable velocity when the transducer is perpendicular to the direction of flow. Since Cos 0 equals 1, the highest velocity will be acquired when the ultrasound beam is parallel to the direction of flow. However, gray scale image quality is compromised at this angle and such an angle is often not technically feasible. Angles above 60° result in increasing magnification of velocity error. In order to standardize and optimize the acquisition and reporting of Doppler velocities, an angle of incidence as close to 60° is used. If the Doppler angle is improperly set, it can manifest as an apparent stenosis when there is not a stenosis present (Fig. 9.5).

Another important parameter to consider is the sample volume. This sets the volume of flowing blood from which the velocity data and waveforms are obtained. In the Doppler equation, v is the mean velocity of blood flow. This mean velocity changes with the size of the sample volume. This is due to the normal distribution of velocities within a vessel where centrally there is more uniform laminar flow and the velocities drop off with distance from the central flow lumen to the vessel wall. In general, the sample volume should be as small as possible and as central as possible (Fig. 9.4).

The longitudinal plane allows for greater ease of setting the Doppler angle at 60°. Areas of stenosis will demonstrate characteristic decreased lumen diameter on gray scale imaging, increased peak systolic velocity, spectral broadening and turbulence, as well as decreased velocity downstream from the stenosis (Fig. 9.6).

The typical range of blood flow velocity shifts is from approximately 0.2 to 8 KHz, which is in the audible range. This allows the imager to simultaneously listen to the flow dynamics and correlate this important aspect of vascular ultrasound imaging with the data that is acquired.

Another useful capability of Doppler ultrasound is calculation of flow volume. This is accomplished by the use of a mathematical software package that is incorporated into the ultrasound unit. To measure flow volume, the imager places the sample volume gate as done with velocity measurements, however, the gate is extended to include the entire vessel lumen. The diameter of the vessel is also demarcated with cursors. It is important for the diameter to be demarcated in gray scale as this eliminates any overestimation of diameter caused by bleed through on color Doppler (Fig. 9.7). Flow rates within dialysis fistulas/grafts are typically in the range of 500–1,500 mL/min. At these flow rates, adequate dialysis is usually achieved. In patients with peripheral arterial disease, however, higher flow may result in vascular steal symptoms (see Chap. 10).

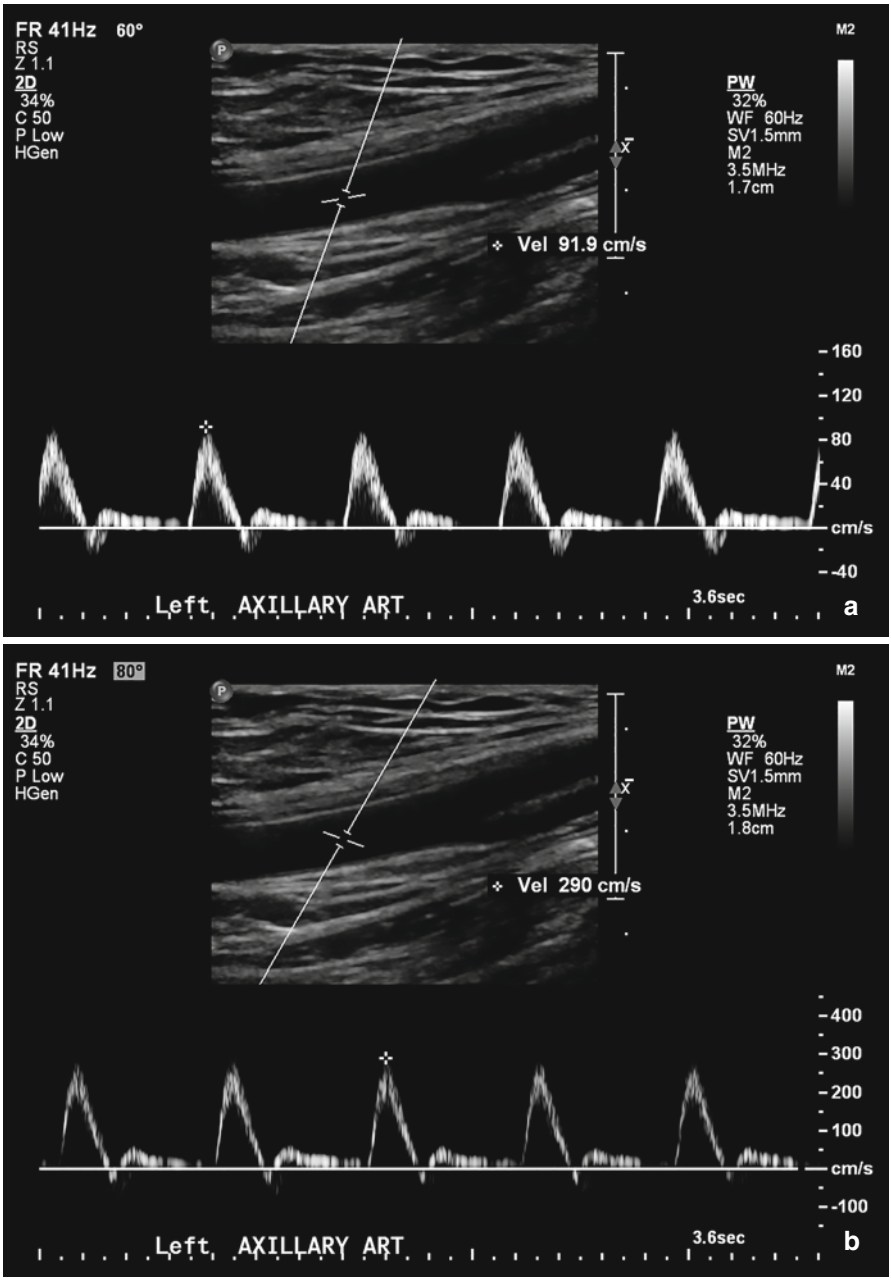


Fig. 9.5 The Doppler angle can be chosen by the ultrasound user. In (**a**), the Doppler angle is set to 60° (upper left corner). This gives a velocity measurement of 91.9 cm/s. In (**b**), the Doppler angle is incorrectly chosen at 80°. This gives a velocity of 290 cm/s which suggests a possible stenosis in the axillary artery that is being interrogated. In order to optimize and standardize vascular ultrasound reporting, an angle as close as possible to 60° is chosen

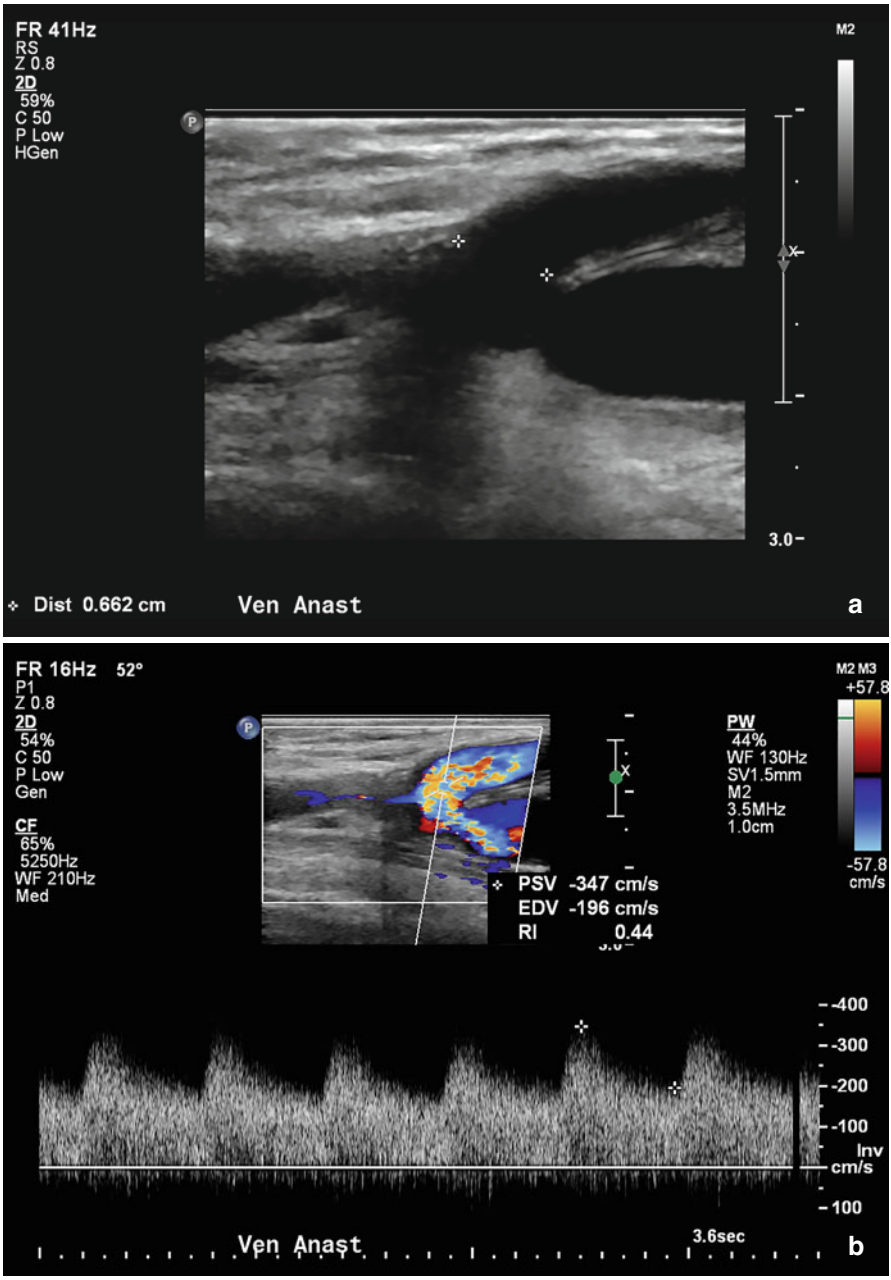


Fig. 9.6 (**a**) Gray scale image demonstrating the venous anastomosis measuring 6.6 mm, as well as a high grade juxta-anastomotic stenosis with marked reduction of luminal diameter. (**b**) Duplex Doppler image of the venous anastomosis demonstrating PSV of 347 cm/s and EDV of 196 cm/s. (**c**) Magnified color Doppler image demonstrating the high grade juxta-anastomotic stenosis with only a trace of color flow through the stenosis along with elevated velocity of 450 cm/s. Note the neointimal hyperplasia seen as a smudgy gray area on either side of the stenotic flow lumen (*yellow arrow*) and elevated velocity at the site of stenosis of 450 cm/s (**d**). (**e**) Duplex Doppler image of the outflow vein immediately central to the stenosis demonstrating a marked reduction in velocity of 50 cm/s

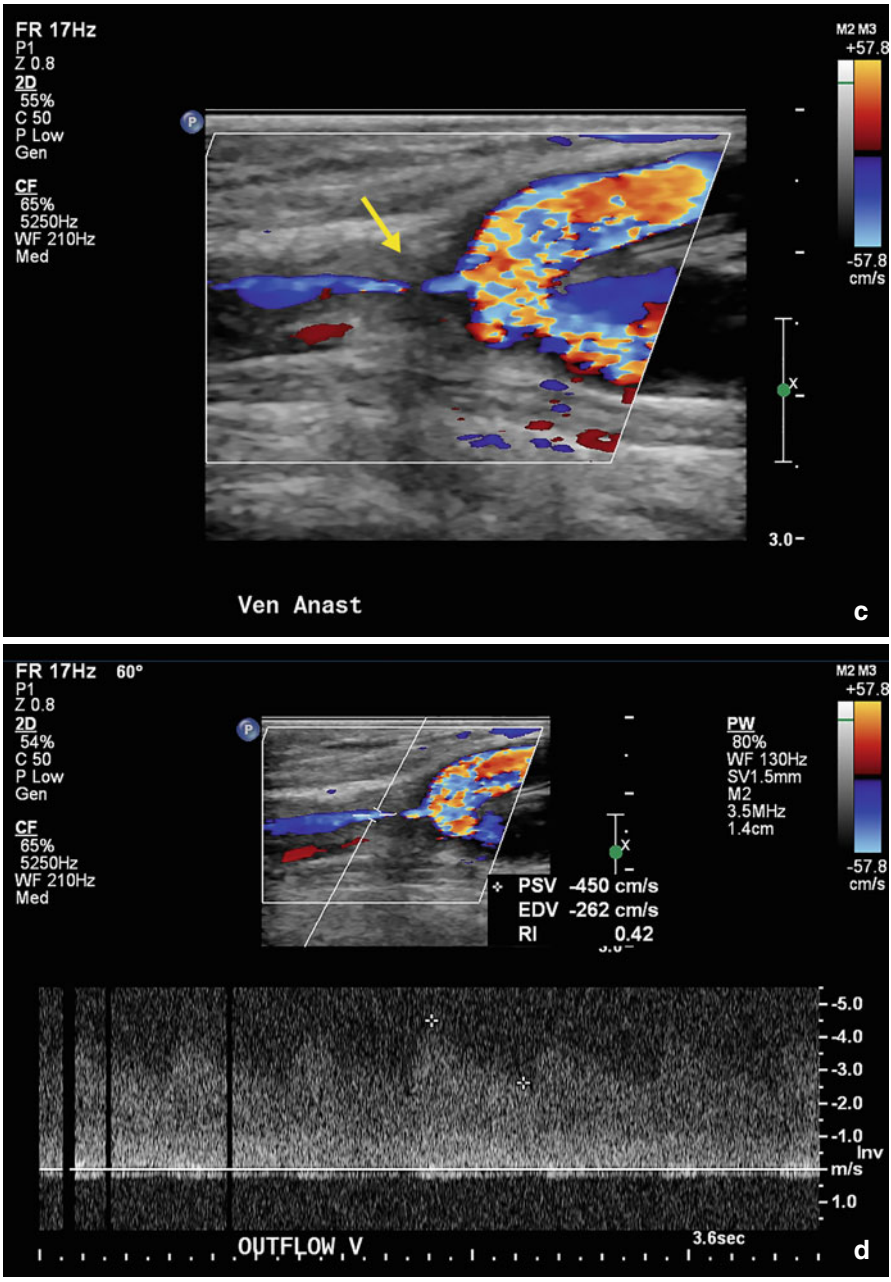
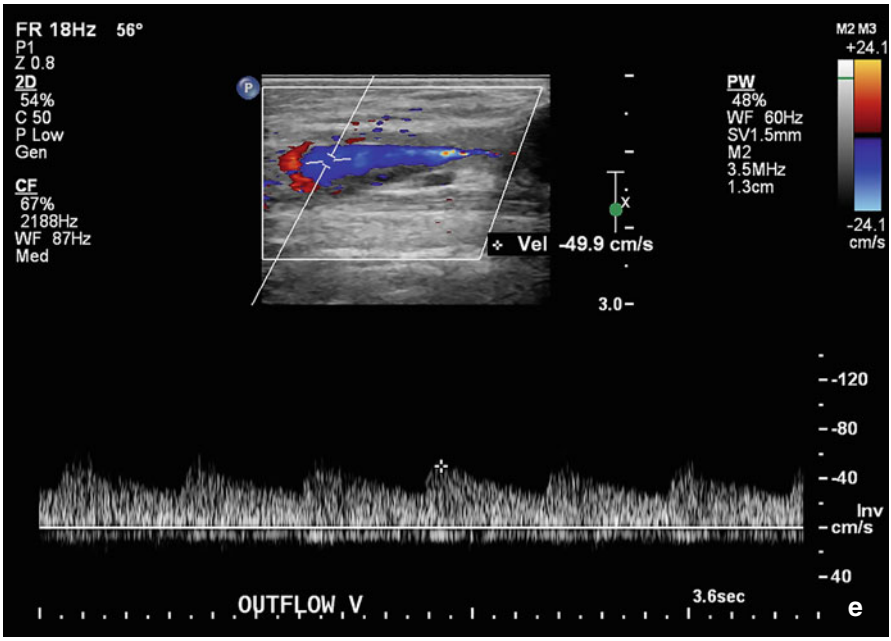


Fig. 9.6 (continued)



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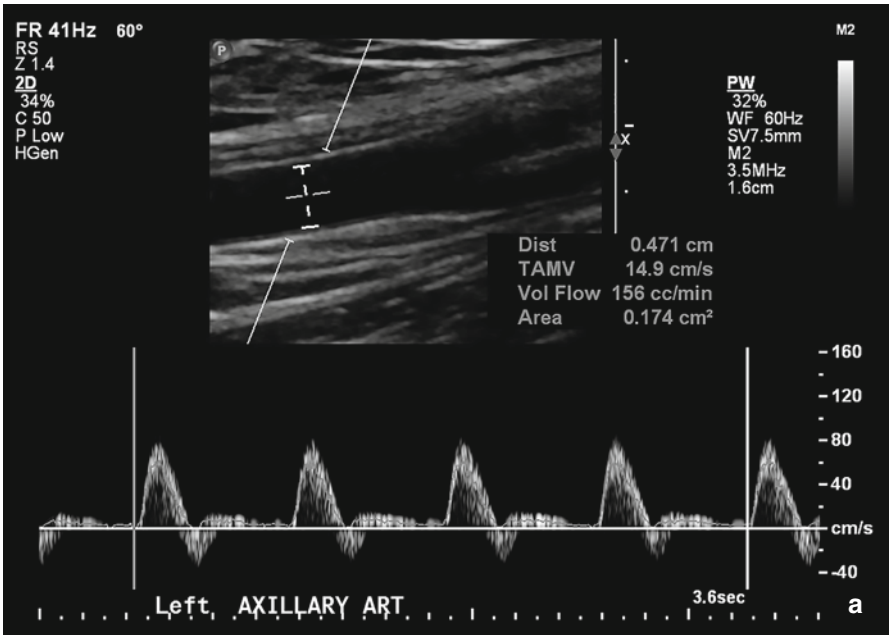

Fig. 9.7 (**a**) Calculation of flow volume in the axillary artery. This requires the diameter of the vessel to be demarcated which is most accurately done on gray scale imaging. The angle of incidence is set at 60° as indicated in top left hand corner. Mathematical software calculates the flow volume based on a prescribed formula utilizing the mean velocity and vessel diameter. (**b**) Segment of dialysis access circuit in a different patient from (a). Note the "bleed through" in the color image (*yellow arrow*). This could result in overestimation of flow by demarcating too large of a diameter

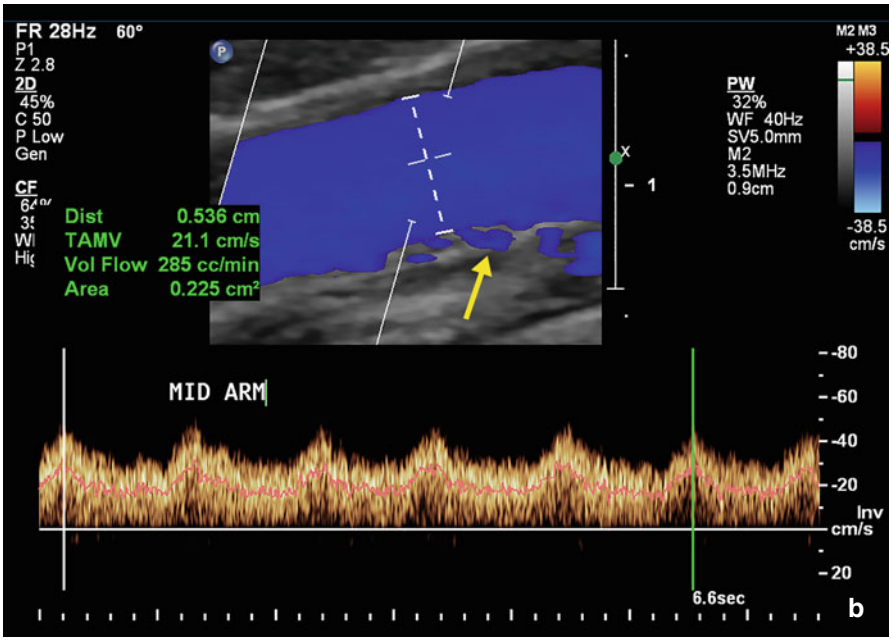

Fig. 9.7 (continued)

Procedure

When performing ultrasound dialysis access circuit evaluation, the patient should be in the supine position, slightly reclined, with the access extremity extended approximately 45° and externally rotated. A detailed protocol for Duplex Doppler evaluation of hemodialysis access circuits was published in 2012 by Teodorescu et al. [9]. We concur with this protocol, which starts with evaluation of the entire circuit in the transverse plane from the inflow artery to the outflow veins and central venous structures if they are amenable. This gives the imager an overview of the anatomy of the circuit and preliminarily identifies potential areas of stenosis. Next, the inflow artery is evaluated in the longitudinal plane using pulsed color and spectral (duplex) Doppler. The PSV, EDV and flow volume should be recorded. The proximal anastomosis is then interrogated. Gray scale diameter measurement, color Doppler and spectral PSV, EDV and waveforms should be recorded. If the access is a graft, the venous anastomosis should also be interrogated with similar imaging documentation. PSV, EDV and flow volume should be measured within the cannulation zone. The remainder of the access should then be scanned in the longitudinal plane using color flow Doppler to identify areas of turbulence. Once identified, an area of turbulence should be further evaluated with color and spectral Doppler documenting PSV, EDV and waveforms. For any stenosis, the same imaging data should be acquired at an area 2 cm upstream and 2 cm downstream. The axillary, subclavian and innominate veins should be imaged in gray scale, color and spectral Doppler (Fig. 9.8). It is often not possible to image the central veins. Normal

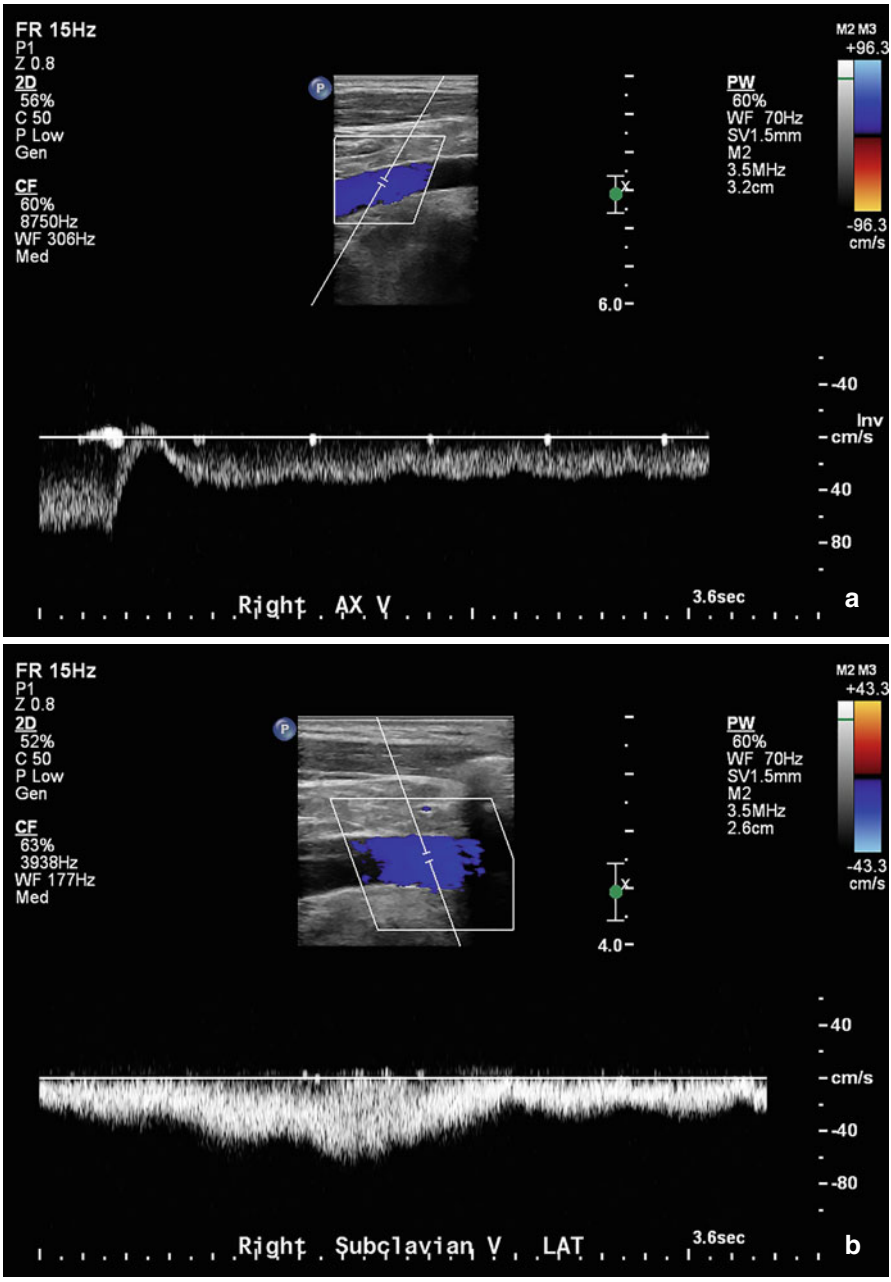

Fig. 9.8 Normal duplex Doppler images of more central venous structures including the axillary (**a**), subclavian (**b**, **c**) and inominate veins (**d**). These are frequent areas of stenosis in patients with a history of prior dialysis access or other chronic indwelling catheters

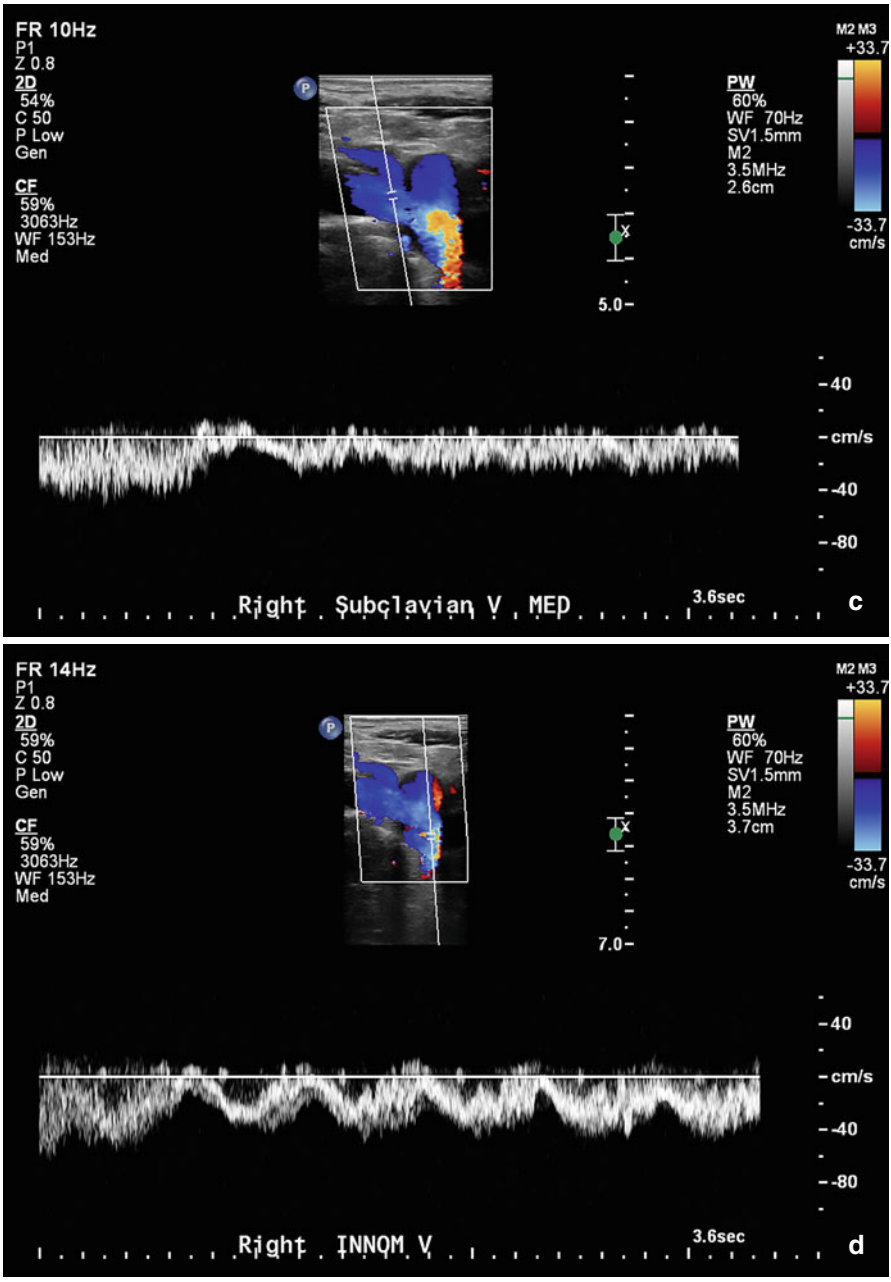

Fig. 9.8 (continued)

findings in the central veins include: continuous flow with mild phasicity in the axillary and subclavian veins and respiratory phasicity in the more central innominate veins. There should be increased flow towards the heart during inspiration and decreased flow during exhalation. Abnormal findings in the central veins include lack of flow in keeping with acute or chronic occlusion. In chronic central venous occlusive disease, the parent veins will demonstrate lack of flow, absence of respiratory phasicity in the peripheral veins and presence of numerous tortuous, dilated collateral vessels (Fig. 9.10).

Other important images and measurements should be obtained depending on the indication. For example, if the problem is difficult cannulation, then the depth of the access from the skin surface should be documented. In general this should be 6 mm or less. If only a small segment of the access is superficial, measurement of the length of this segment should be documented. If the problem is poor maturation, then the diameters of the anastomosis and cannulation zone should be measured. If this measurement is less than 4 mm or the flow is less than 500 mL/min, there is a high likelihood that the access will not mature [10].

In addition to assessing the adequacy of the access for dialysis, other things to consider and document are the presence of perigraft hematomas, pseudoaneurysms or other perigraft fluid collections (Fig. 9.2). These findings alert the dialysis team and treating physicians to additional problems with patient's access beyond the adequacy for dialysis.

Diagnostic Criteria

Normal findings as well as findings associated with moderate and severe stenosis are listed in Table 9.2. Also, those findings that are associated with inflow and outflow stenosis and access occlusion are listed.

Pitfalls

Several potential pitfalls can limit the integrity of the ultrasound study. These include chronic occlusion of outflow or central veins that are well collateralized, low systemic blood pressure, and poor Doppler angle or sample volume selection. Also, discrepancies can arise such as a focal velocity >300 cm/s with no apparent luminal diameter reduction or absent velocity acceleration in the presence of a flow lumen diameter reduction. This can be seen with inflow disease (see Chap. 10) or low systemic blood pressure. In these situations, a correlative study such as CTA or catheter based angiography may be useful.

Table 9.2 Classification of stenoses and their associated ultrasound imaging findings

Classification	Velocity (cm/s)	Imaging characteristics
Normal	Mid graft PSV > 150 cm/s Anastamosis PSV > 300 cm/s, chaotic, disorganized flow	No visible narrowing Distended outflow veins Aneurysms, puncture sites, perigraft fluid may be visible
Moderate stenosis	Ratio of PSV at stenosis to PSV at 2 cm beyond anastamosis if normal-appearing <3	Decrease in lumen diameter Echogenic narrowing Wall abnormalities
Severe stenosis	Marked velocity acceleration at stenotic area Ratio of PSV at stenosis to PSV 2 cm beyond anastamosis if normqal-appearing >3	Intraluminal echogenicity with <2 mm lumen or >50 % diameter reduction Marked reduction in lumen diameter with color Doppler
Inflow stenosis	Increased PSV at the site of the stenosis with monophasic and diminished waveforms distally Flow acceleration with graft compression at the outflow anastamosis	Intraluminal echogenicity <2 mm lumen at velocity acceleration
Outflow stenosis	Mid graft PSV < 100 cm/s Distal vein PSV > 300 cm/s Velocity at the proximal anastamosis will diminish in proportion to severity of venous outflow stenosis	Intraluminal echogenicity with <2 mm lumen at velocity acceleration Prominent collateral veins around outflow
Occlusion	No Doppler signal	Intraluminal echogenicity Graft walls collapsed Occluded vein may not be visible

From Teodorescu et al. [9]
PSV peak systolic velocity

Computed Tomography Angiography

Axial imaging such as computed tomography angiography (CTA) may be useful when there is discrepant data acquired from ultrasound. Also, CTA is useful if there is concern for graft infection or abscess, aneurismal degeneration of an anastomosis, or an extensive fluid collection. In this setting, the graft may be extracted and the CT will also document the patency of the central venous structures prior to creation of a new circuit access.

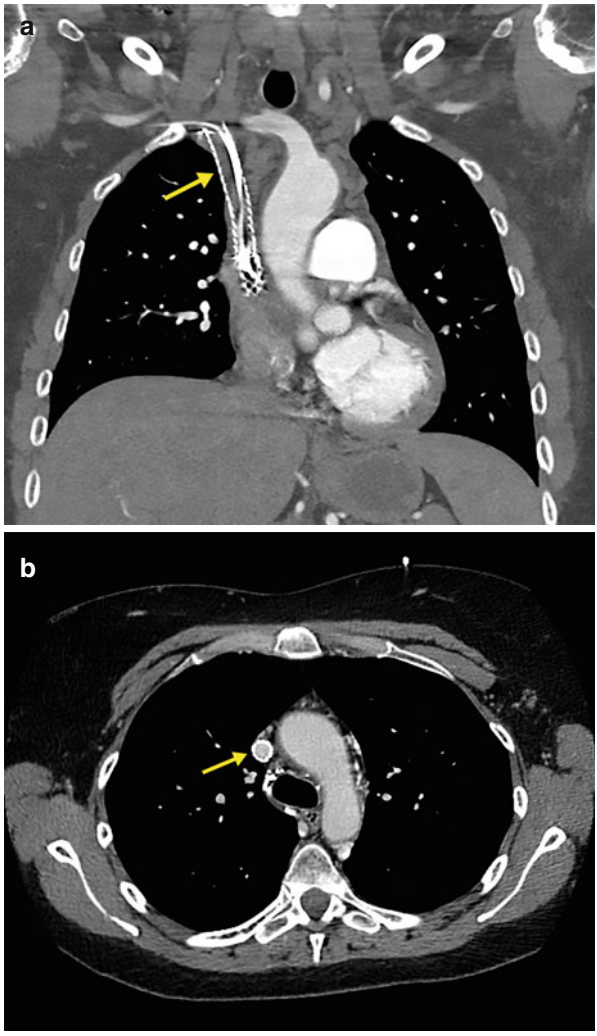

Fig. 9.9 (**a**) CTA demonstrating an occluded SVC stent (*yellow arrow*). Very little artifact is seen related to the stent. Most of the artifact is related to the mediport catheter occupying a large portion of residual flow lumen in this undersized stent performed at an outside institution. In (**b**), the patency of the stent is well established with CTA (*yellow arrow*). This is after mediport removal and recanalization of the SVC

A few studies have been done evaluating the efficacy of CTA for evaluation of the failing dialysis access [11–15]. These studies include a relatively small number of patients. CTA was shown to have a relatively low sensitivity for detecting central venous stenoses, particularly in veins that are in close proximity to osseous structures such as the subclavian vein. This study also showed that all plane evaluation resulted in greatest sensitivity in detection of venous stenoses [13]. Dialysis circuits containing stents are generally not amenable for evaluation by MRI/MRA due to associated artifact. CTA, however, gives relatively minimal associated artifact (Fig. 9.9). One area where CTA has been shown to be of value is in the assessment of aneurysms. Unlike conventional angiography, CTA shows both the flow

lumen through the aneurysm as well as areas of thrombosis. CTA was also shown to demonstrate the existence, extent and anatomy of venous collaterals (Fig. 9.10) [13].

At this time, we recommend the use of CTA in instances where there is discrepant data from the physical exam and/or ultrasound. It may also be used to evaluate the central venous structures prior to access creation or planned recanalization and to evaluate aneurysms and extent of venous collaterals.

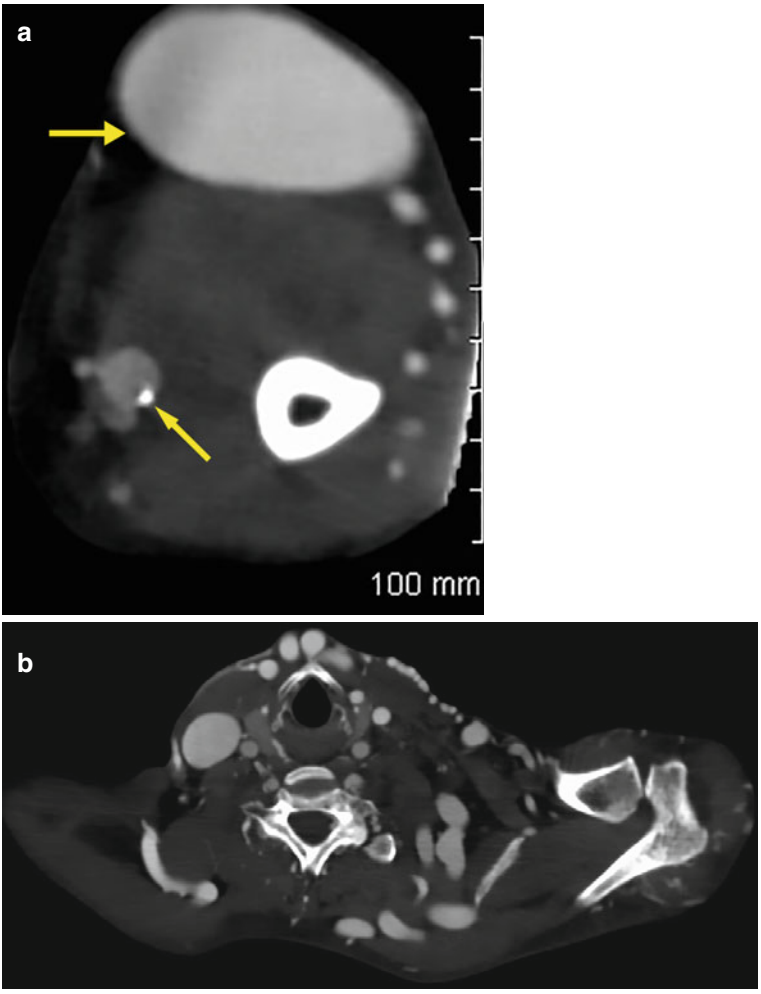

Fig. 9.10 (**a**) CTA showing a brachial artery catheter (*thin yellow arrow*) placed for CTA evaluation of a failing left arm radio-cephalic dialysis access circuit. Note the large, aneurismal outflow vein (*thick yellow arrow*). (**b–d**) Extensive collaterals in the upper arm, axilla, chest wall, mediastinum due to bilateral subclavian vein chronic occlusion

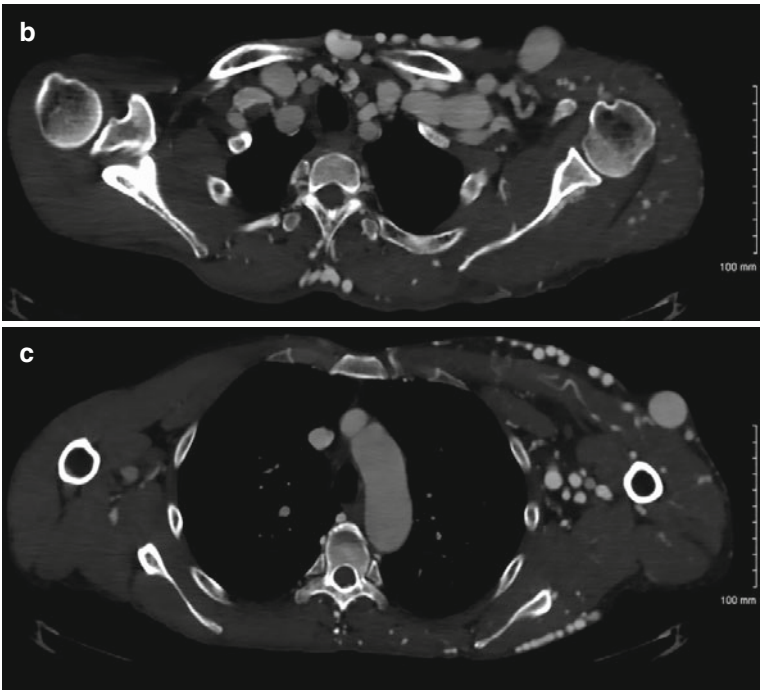

Fig. 9.10 (continued)

Magnetic Resonance Imaging and Magnetic Resonance Angiography

Magnetic resonance imaging (MRI) and magnetic resonance angiography (MRA) play a limited role in the evaluation of dialysis circuits. Adequate evaluation of dialysis circuits requires the use of Gadolinium as contrast material. The use of Gadolinium based contrast materials in this population has been linked to the development of nephrogenic systemic sclerosis (NSF). NSF is a devastating diffuse sclerosing disease that affects the skin, eyes, joints and internal organs. The use of Gadolinium based contrast materials is now contraindicated in patients with a glomerular filtration rate (GFR) of less than 60 mL/min and especially under 30 mL/min. Newer Gadolinium-based contrast materials have promising safety profiles in this population and with more research, may be available for use in the future. Non-contrast MR imaging of dialysis access circuits is challenging and not routinely performed. One significant advantage of MRA over CTA is that signal is obtained only from vascular structures. This limits the effect of bone and calcium related artifact. However, unlike CTA, artifact related to graft material and/or circuit stent limits evaluation of graft/stent patency and may overestimate or underestimate stenoses [16].

Conclusions

Dialysis access ultrasound evaluation is useful for early detection of access problems. This chapter discussed the indications for dialysis access evaluation using ultrasound. We provided a brief overview of ultrasound, a detailed protocol for performing dialysis access ultrasound studies, as well as the diagnostic criteria for access dysfunction and some pitfalls. The utility and limitations of axial imaging such as CTA and MRA were discussed.

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Part III

Hemodialysis Vascular Access Management: Interventions

Angiogram and Angioplasty

10

Chieh Suai Tan, Steven Wu, and Arif Asif

Introduction

It is important to use the correct terminology for radiological procedures. An angiogram is a diagnostic procedure to visualize blood vessels using contrast material. Hence, angiograms of arteriovenous fistula (AVF) and arteriovenous graft (AVG) are called fistulogram and graftogram respectively.

Angioplasty is a term used to describe a procedure to dilate stenosed or occluded blood vessels. In radiology context, it is synonymous with percutaneous transluminal angioplasty (PTA), which involves entry through the skin (percutaneous) and going through the vessels (transluminal) to the site of the lesion and dilate the narrowed or occluded blood vessel (angioplasty).

These two techniques (angiogram and angioplasty) are valuable in the management of arteriovenous (AV) access as stenosis secondary to neointimal hyperplasia is often the cause of access thrombosis and failure in a dialysis patient.

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Table 10.1 Differences between venous and arterial interventions during dialysis access management

	Venous intervention	Arterial Intervention
Heparin	Usually not required	Usually required
Complications	Rupture, thrombosis, pulmonary embolism	Dissection, thrombosis, rupture
Balloon length	Oversize	Cover lesion and little beyond
Balloon diameter	Oversize	Do not oversize
Duration of inflation	Long, minimum 3 min	Short
Type of balloon	High pressure balloon	Choice depends on type of lesion

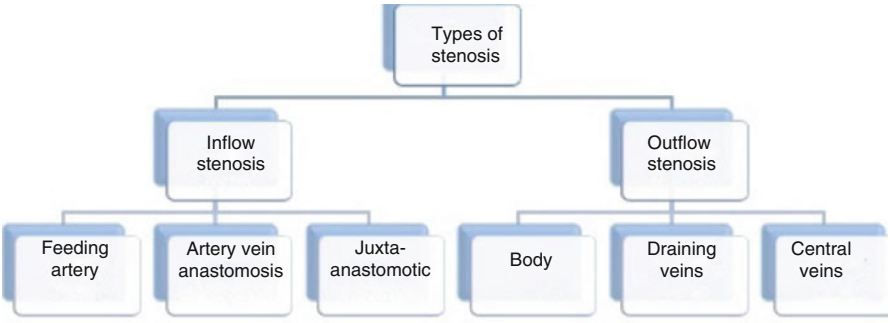

Fig. 10.1 The juxta-anastomotic (JA) segment is defined as the first 2 cm of the vein after the artery vein anastomosis. The body of the AVF is defined as the segment of the venous limb where cannulation for dialysis is made while the draining veins (inclusive of the cephalic arch) are segments that drain the AV access. The central veins include the axillary, subclavian, brachiocephalic veins and the superior vena cava

Venous Intervention

Although both arterial and venous interventional procedures require similar endovascular skill set, there are distinct dissimilarities between the two procedures and knowledge of these differences is crucial to ensure successful endovascular interventions. The differences are summarized in Table 10.1.

The site of lesion in an AVF is broadly divided into "inflow" or "outflow" stenosis as summarized in Fig. 10.1. The stenosis may occur at the arterial, artery-vein anastomosis, juxta-anastomotic site, body (sites of needling), draining and central veins. It is often possible to delineate the site of stenosis based on the clinical findings and physical examination. These are as summarized in Table 10.2.

AVFs have a primary non-functional rate [1] of about 20 % (range, 10–50 %) that varies among centers and requires a maturation time between 1 and 4 months. Failure of maturation may be due to the presence of an inflow stenosis caused by neointimal hyperplasia at the juxta-anastomotic site [2], which can be treated with angioplasty. Late fistula failure is caused primarily by neointimal hyperplasia that results in venous stenosis. The most common site of stenosis in the radiocephalic

Table 10.2 Summary of possible sites of stenosis in an AVF in relation to symptoms and physical examination

Clinical findings	Physical examination	Possible sites of stenosis
High dynamic or static venous pressure	Pulsatile AVF	Outflow stenosis
Prolonged bleeding after removal of dialysis needle	Pulsatile AVF	Outflow stenosis
Upper limb swelling	Swollen arm	Central vein stenosis
Decrease thrill	Flat AVF	Inflow stenosis and body
Difficult cannulation	Flat or difficult to palpate Good thrill	Inflow stenosis and body No stenosis, AVF may be too deep for cannulation
"Failure to mature"	Flat AVF Multiple dilated veins	Inflow stenosis Presence of accessory veins or collaterals

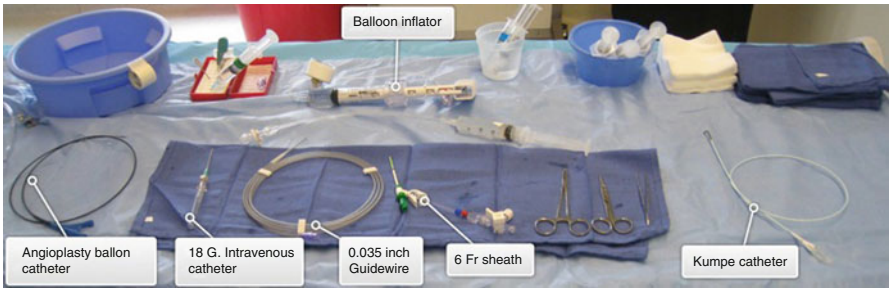

Fig. 10.2 Equipment for fistulogram and angioplasty

fistula is at or around the anastomotic region; for upper arm fistula, most stenoses occur in the draining and central veins [3].

AVG has lower primary failure rates but inferior long term patency when compared to AVF. The site of stenosis is usually at the graft-vein anastomosis or within 6–10 cm of the anastomosis [1].

Equipment

Prepare the following equipment on a sterile trolley (Fig. 10.2)

1. Normal saline for flushing of sheaths and catheters
2. Lidnocaine
3. 18 Gauge (G) intravenous catheter
4. X1 0.035 in. wire
5. X1 6 Fr or 7 Fr 4 cm sheath
6. X1 Kumpe catheter

7. X1 angioplasty balloon
8. X1 balloon inflator
9. X1 2/0 non absorbable suture (Ethilon)
10. Gauze
11. Hemostat
12. Needle holder
13. Syringes and needles

Fistulogram and Angioplasty

1. Review the indication for the procedures. Specifically, the indications for the procedure often provide clues to the site of stenosis.
2. Examine the AVF to identify (Fig. 10.3a, b)
   (a) "Parts" of the AVF,
   (b) Needling sites for dialysis,
   (c) Direction of flow,
   (d) Presence of pseudoaneurysm,
   (e) Contraindication to intervention such as the presence of infection,
   (f) Thrills, pulsatility, bruit of the AVF as baseline for comparison after the procedure.
3. Determine the site of placement of the sheath
   (a) Place it close to the stenotic site and direct it towards the site of stenosis.
   (b) Avoid placing it over the pseudoaneurysm or directly over the stenotic segment as it will impede angioplasty.
4. Anesthetize the skin with 1 % lidocaine (Fig. 10.4).
5. Cannulate the AVF with a 18G angiocath. In this case example, the suspected lesion is at the JA junction. Hence, the angiocath is placed in a retrograde direction towards the inflow (Fig. 10.5).
6. Advance the needle till you feel a "give" and see "flashback".
7. Hold the needle in position while pushing in the cannula (Fig. 10.6).
8. Do an initial diagnostic fistulogram using the cannula (Fig. 10.7).
9. Inject the contrast material through the cannula to visualize the AVF and draining veins all the way through the superior vena cava.
10. Note any stenotic lesions (Fig. 10.8a–d).
11. Do a "reflux" fistulogram by occluding the outflow vein while injecting the contrast material (Fig. 10.9a, b).
12. The stenosis in this case example is around the JA region.
13. Insert a 0.035 in. wire into the 18 G cannula. Remove the cannula and insert a 6 Fr sheath over the guide wire (Fig. 10.10a–d).
14. Manipulate the guidewire tip across the JA stenosis into the feeding artery with the help of a Kumpe catheter under fluoroscopy (Fig. 10.11a, b).
15. After crossing the stenosis, remove the guide wire and inject the contrast material via the Kumpe catheter to visualize the site of stenosis (Fig. 10.11c).

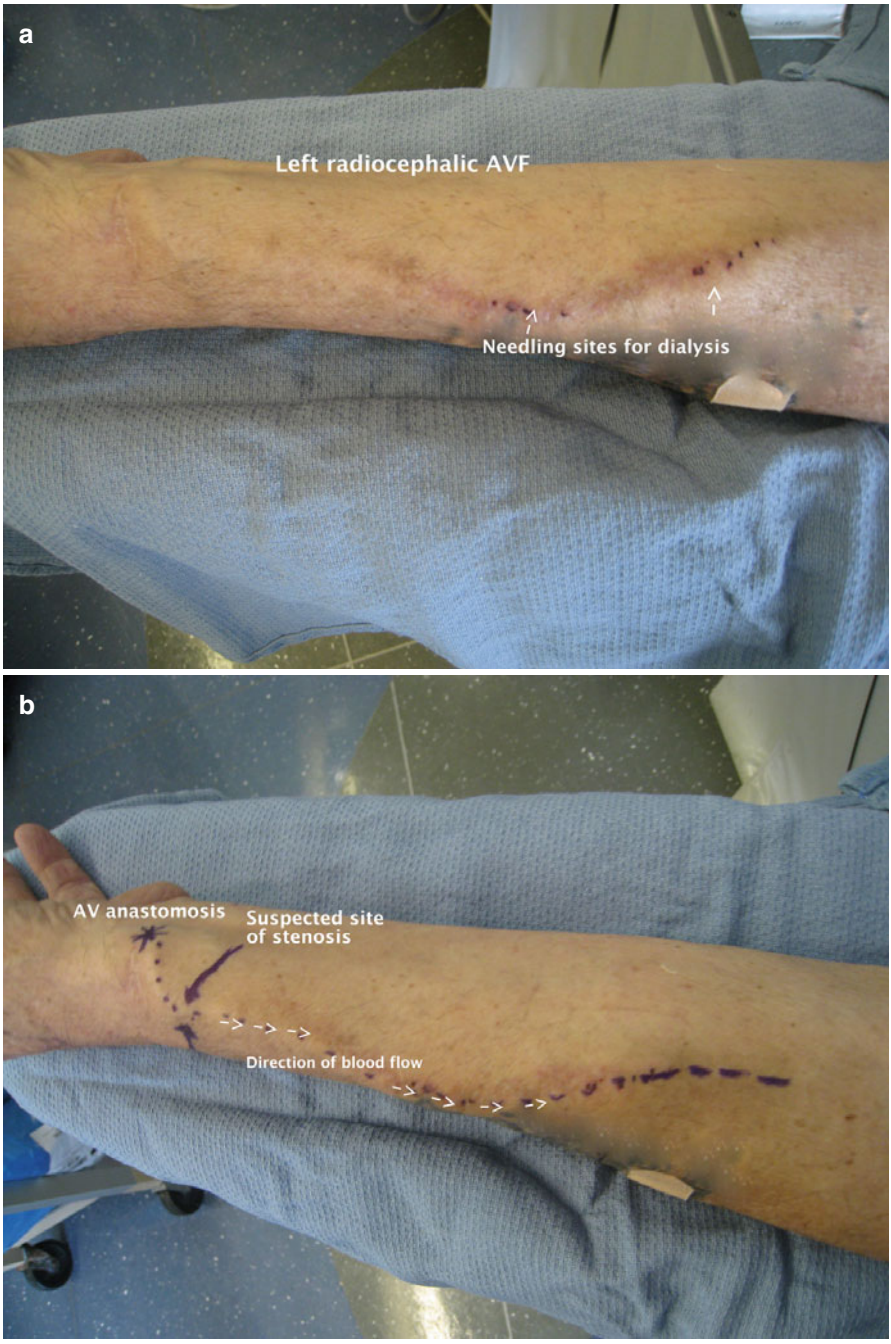

Fig. 10.3 (**a**) Physical examination of the AVF. (**b**) Identify the area of stenosis

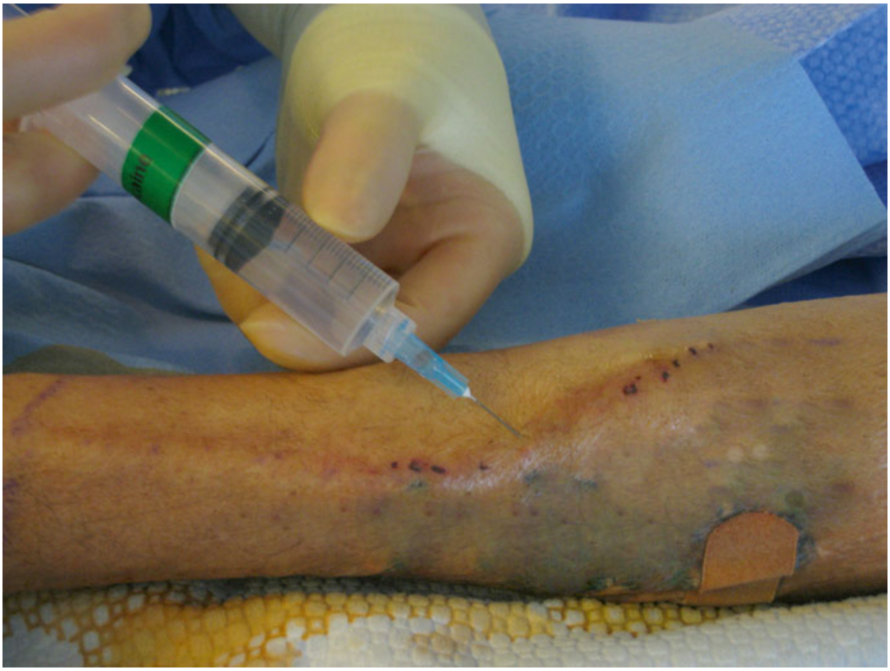

Fig. 10.4 Anesthetize the skin

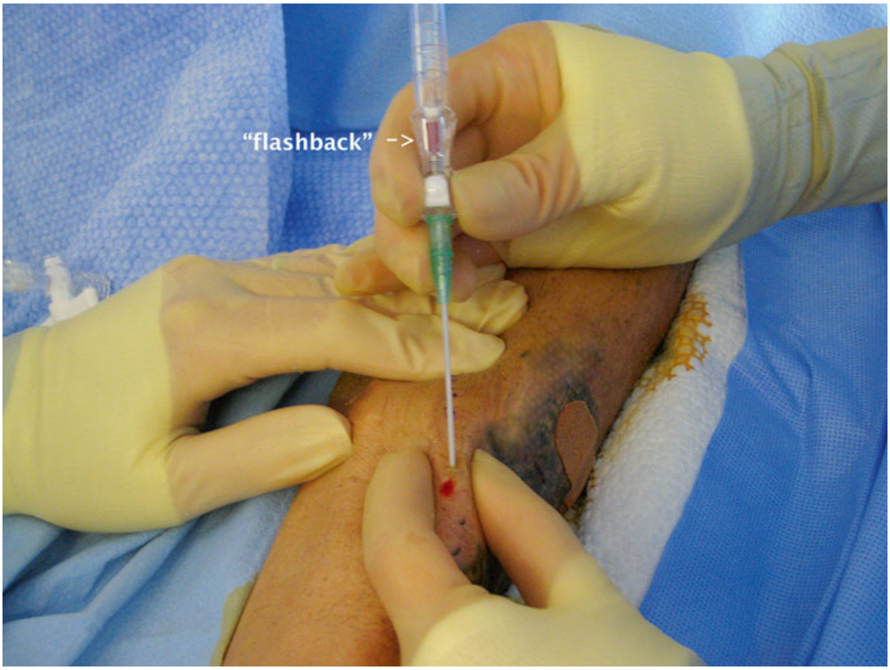

Fig. 10.5 Push in the IV catheter till "flashback" is seen

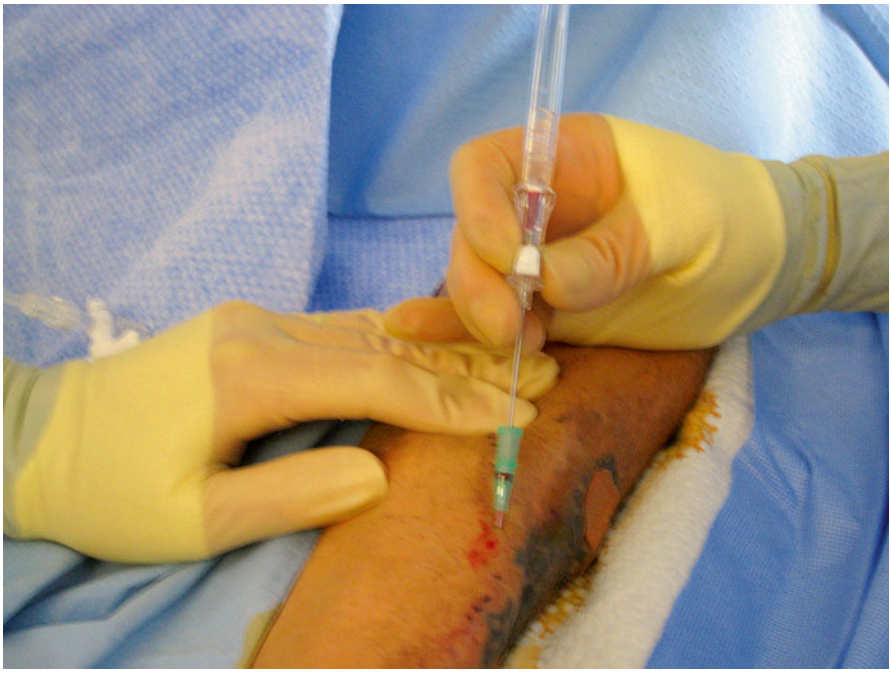

Fig. 10.6 Remove the needle and push in the cannula

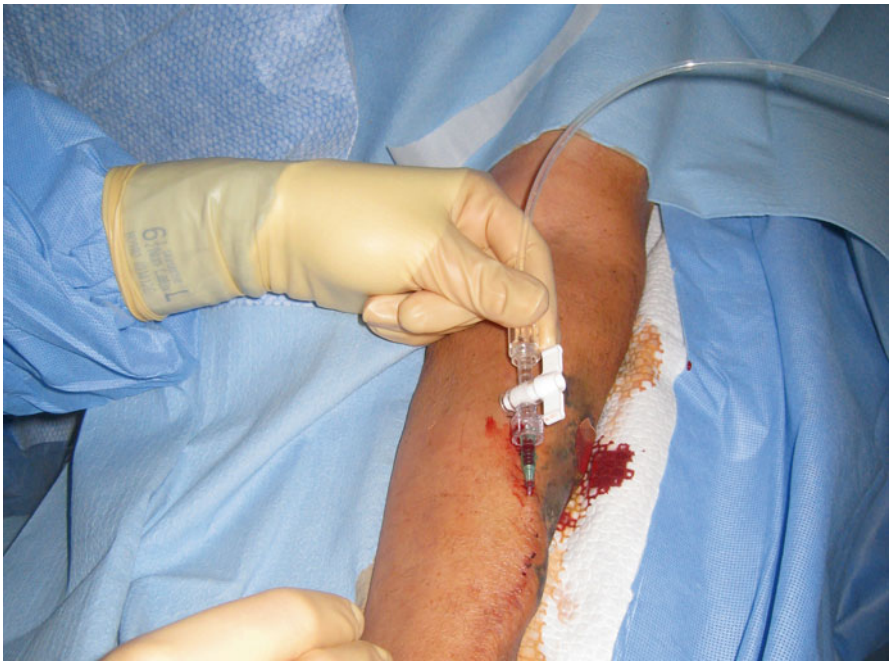

Fig. 10.7 Inject contrast via the cannula

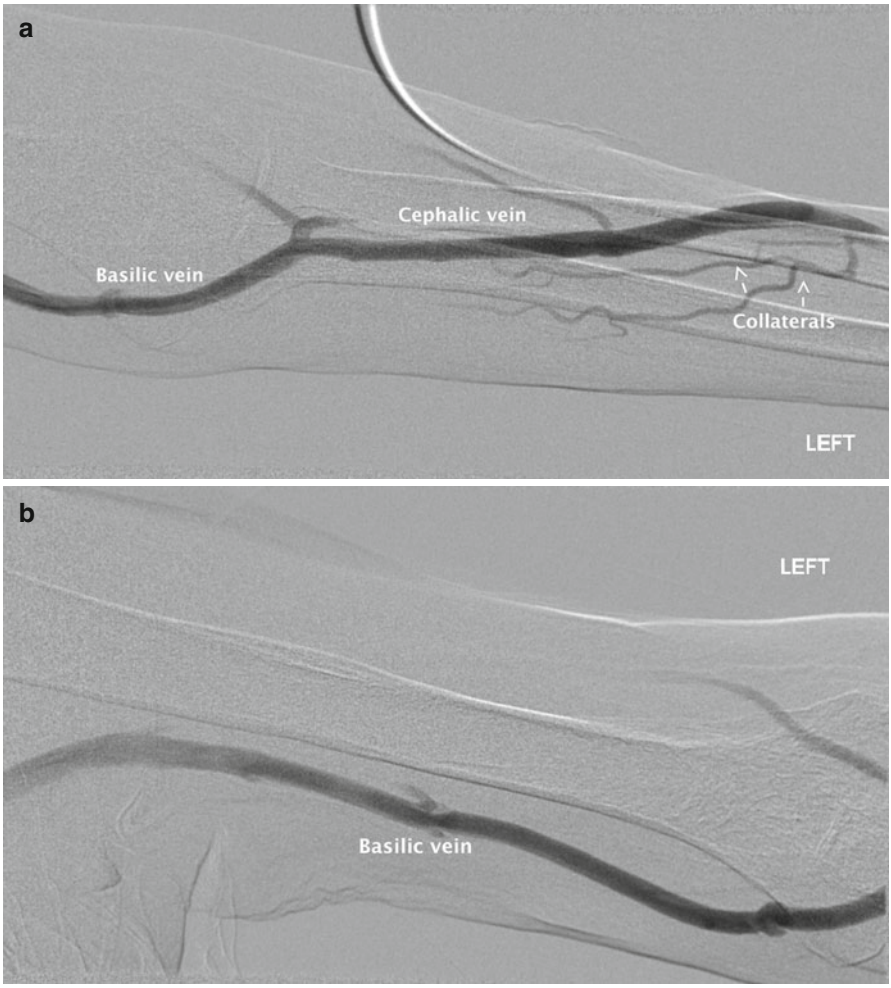

Fig. 10.8 (**a**) Free flow of contrast within the AVF. (**b**) No evidence of stenosis in the basilic vein. (**c**) Possible stenosis seen during imaging of the central veins. (**d**) No stenosis was seen after adjusting the imaging angle

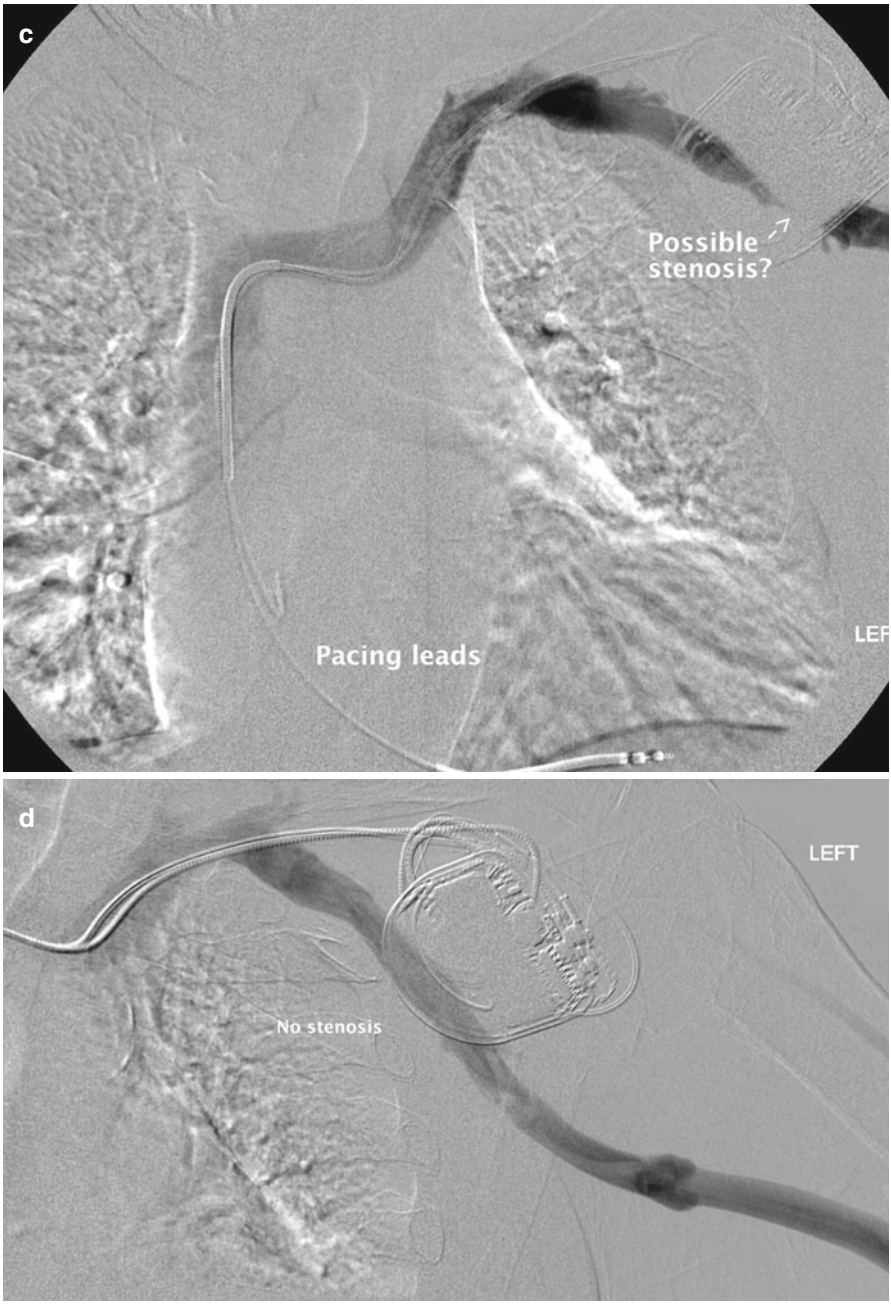

Fig. 10.8 (continued)

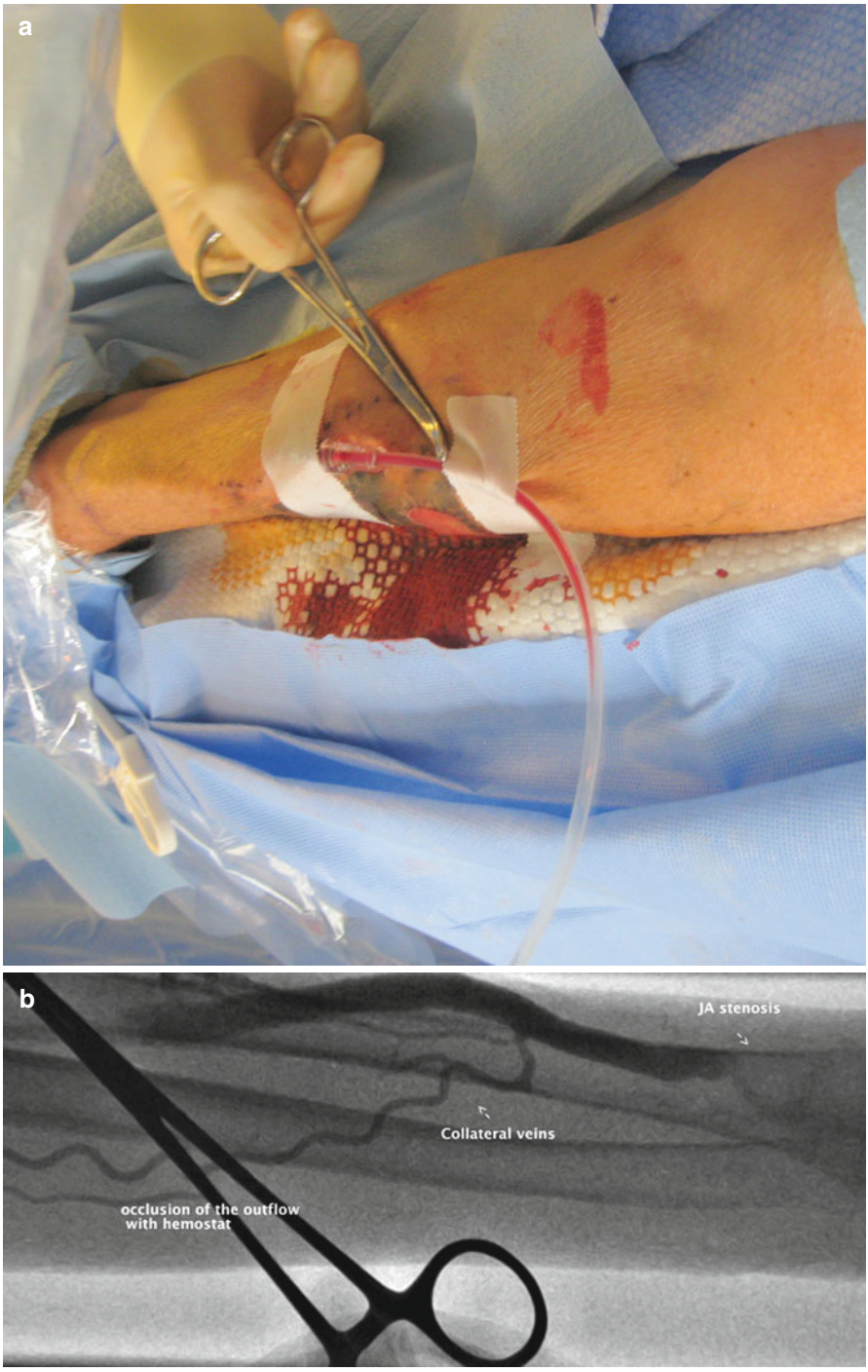

Fig. 10.9 (**a**) Compress the AVF with a hemostat to "reflux" the contrast material to demonstrate the inflow. (**b**) Poor flow of contrast material, demonstrating stenosis of the Juxa-anastomotic area (JA)

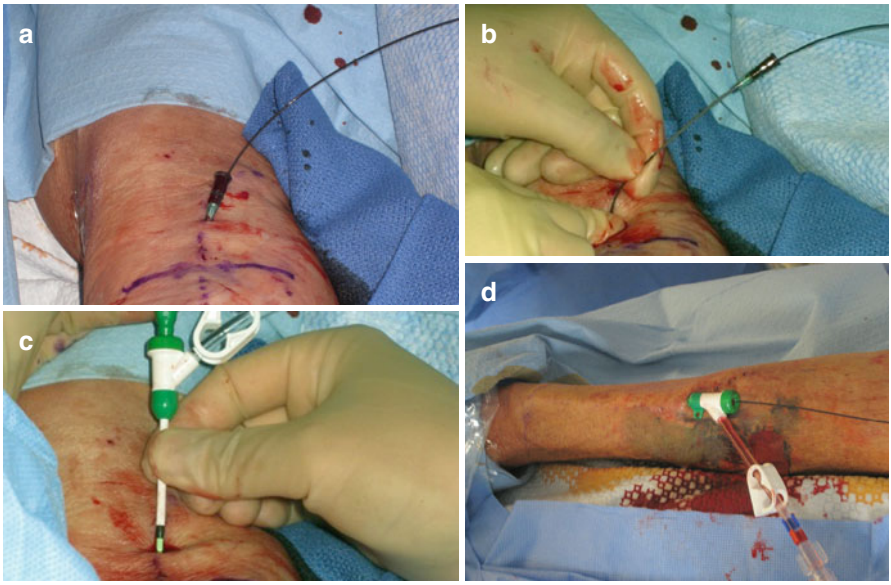

Fig. 10.10 (**a**) Insert the guide wire into the cannula. (**b**) Remove the cannula while pressing on the venotomy site. (**c**) Insert the sheath via the guidewire. (**d**) Sheath is placed over the guide wire

16. After confirming the position, reinsert the guide wire and remove the Kumpe catheter.
17. Review the images to decide on the size of angioplasty balloon.
18. Prime the balloon catheter by aspirating back on the inflation port with a balloon inflation device.
19. Insert the angioplasty balloon catheter over the guide wire. The inflatable portion of the balloon catheter is marked with radio-opaque markers. Position the balloon across the lesion (Fig. 10.12a, b).
20. Balloon inflation (Fig. 10.12c–f)
    (a) A balloon inflation device is often used for this purpose.
    (b) The pressure rating for each angioplasty balloon is listed on the package label. This pressure rating indicates the amount of pressure that the balloon will tolerate before rupture.
    (c) Within the balloon inflator, contrast material is used to permit visualization of the balloon during inflation and deflation.
    (d) Inflate the balloon while maintaining traction on the shaft of the balloon catheter to prevent it from slipping off the lesion. Inflation is stopped when the lesion is completely effaced or when the pressure rating is reached. Keep the balloon inflated for at least 3 min.
    (e) Deflate the balloon completely and move it to the next downstream lesion if any. If not, remove the balloon catheter but leave the guide wire in situ.

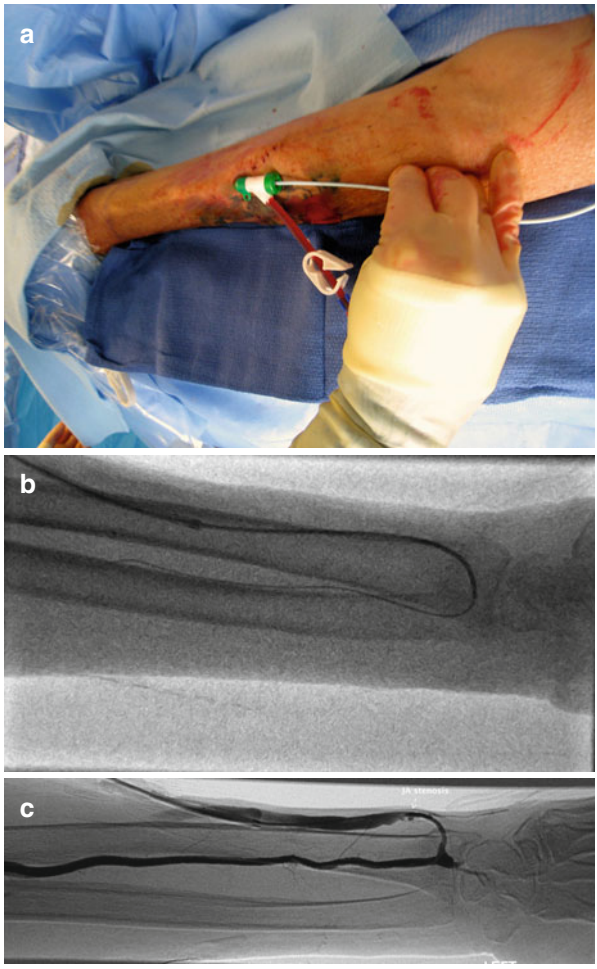

Fig. 10.11 (**a**) Insert Kumpe catheter over the guide wire. (**b**) Steer the guide wire across the stenosis into the feeding artery with the help of the Kumpe catheter. (**c**) After removing the guide wire, inject contrast material through the Kumpe catheter to assess the stenotic area well

21. Reinsert the Kumpe catheter over the guide wire and remove the guide wire.
22. Inject contrast material through the Kumpe catheter to determine the effectiveness of treatment and presence of any complications such as extravasation (Fig. 10.12g).
23. Once all the lesions are treated, remove the Kumpe catheter and examine the AVF for thrill and the hands for any complications.
24. Apply a purse string suture around the sheath and tighten it immediately after pulling out the sheath (Fig. 10.13).

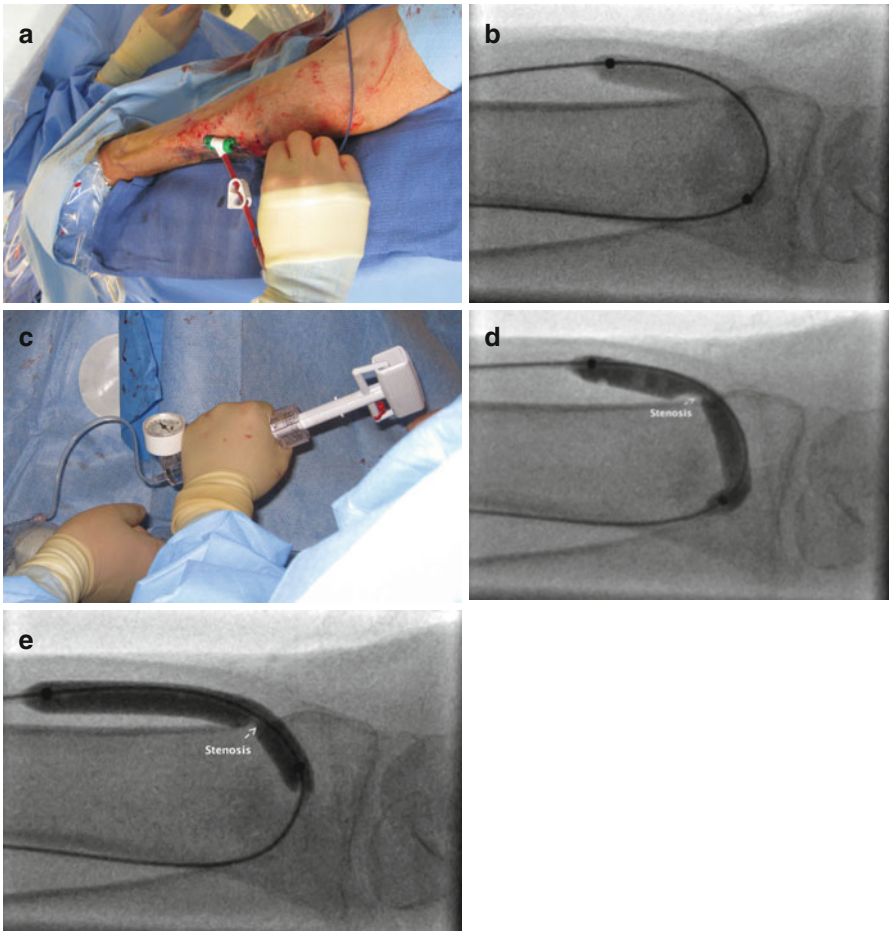

Fig. 10.12 (**a**) Insert the balloon catheter over the guide wire. (**b**) Position the balloon catheter across the stenosis and inflate the balloon. (**c**) Inflate the balloon using an inflator. (**d**) Stenotic lesion demonstrated during balloon inflation. (**e**) Repositioning of the balloon may be necessary. (**f**) Complete effacement of the stenosis. (**g**) Fistulogram showed a decrease in severity of stenosis

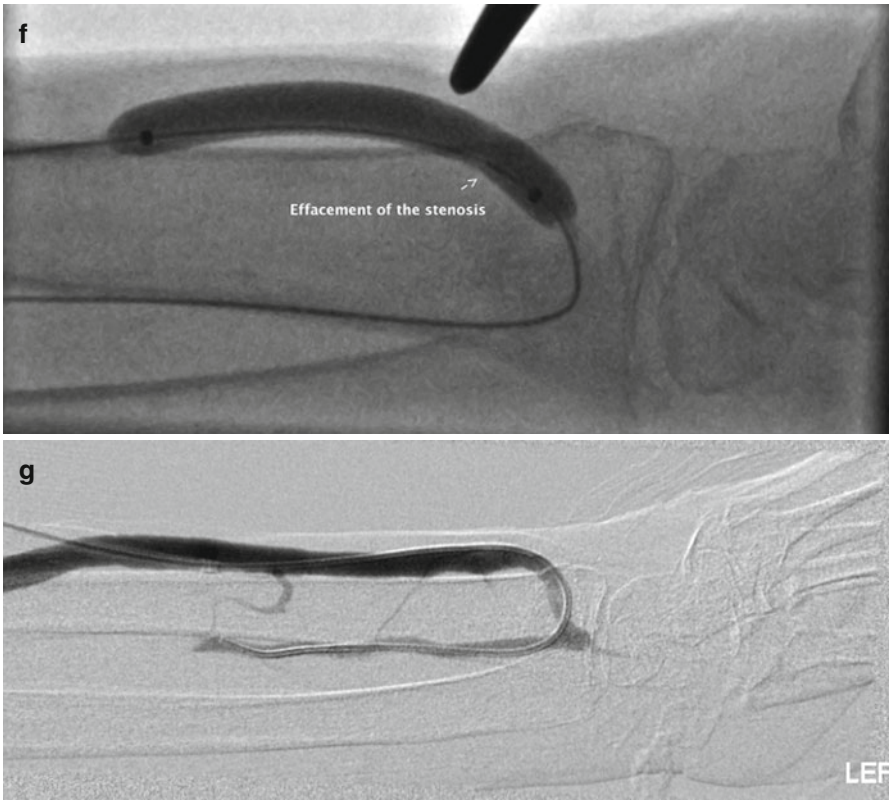

Fig. 10.12 (continued)

Graftogram and Angioplasty

The procedure for a graftogram is similar to that of a fistulogram. The stenotic lesion is usually in the outflow compared to the inflow in an AVF. Before puncturing the graft, it is important to find out the direction of blood flow and cannulate the graft in the correct direction. To determine the inflow and outflow of the AV graft, temporarily occlude the mid section of the graft with your fingers. The inflow should become pulsatile after occlusion while the "thrill" should disappear in the outflow segment of the AV graft.

1. Examine the AVG to identify the site of stenosis (Fig. 10.14a, b).
2. Clean and drape the patient.
3. Anesthetize the skin.
4. Cannulate the AVG with an 18G intravenous catheter and direct it towards the suspected site of stenosis. In this case example, the suspected site of stenosis is within the central veins. Hence, the angiocatheter is placed in an antegrade direction, towards the central veins (Fig. 10.14c).

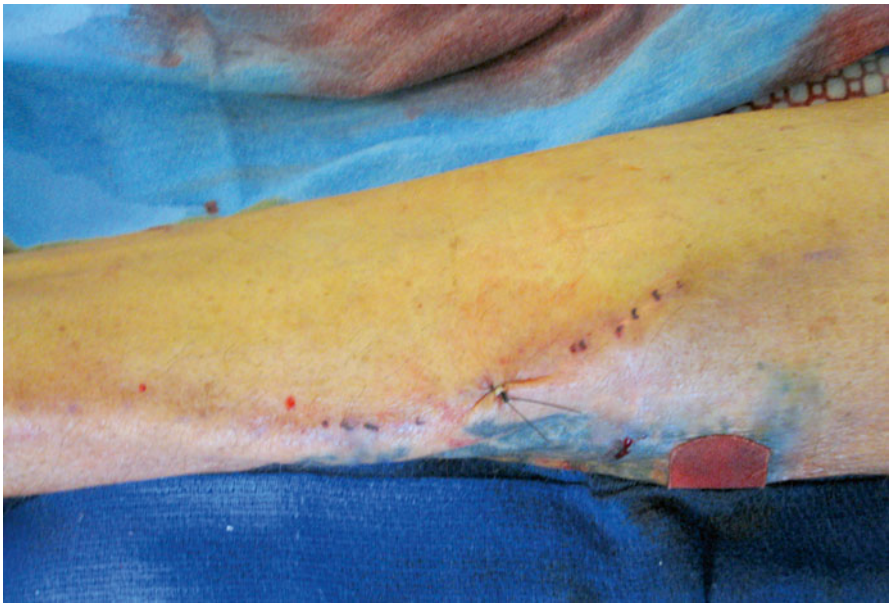

Fig. 10.13 Final appearance of the AVF after completion of the procedure

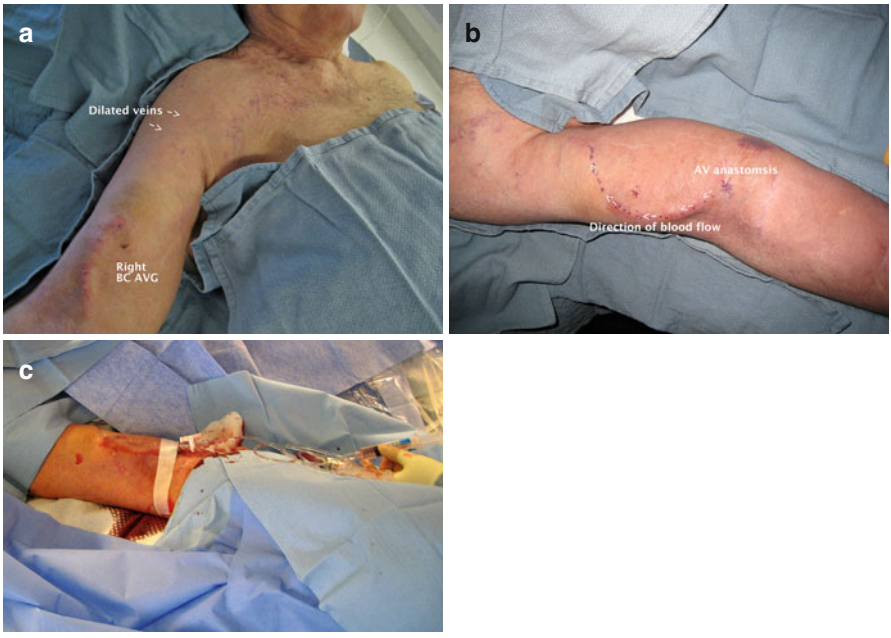

Fig. 10.14 (**a**) Examine the AVG. The presence of dilated arm and chest veins suggest the presence of a central vein stenosis. (**b**) Note the direction of blood flow and plan the site of sheath placement. (**c**) Do an initial graftogram using a 18G cannula

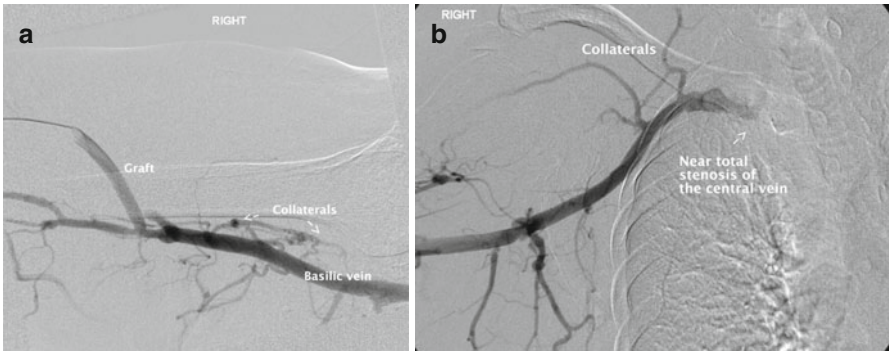

Fig. 10.15 (**a**) Initial graftogram showed multiple collaterals, suggestive of outflow stenosis. (**b**) Central venogram showed near total stenosis of the central vein

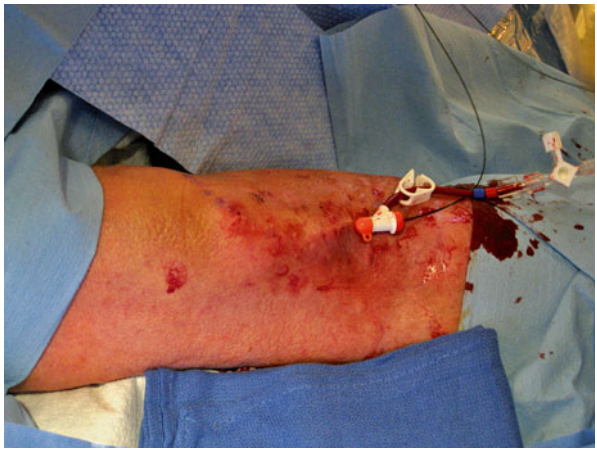

Fig. 10.16 Exchange the cannula for a sheath over the guide wire

5. Do a graftogram to delineate the site of stenosis.
6. Check the outflow and central veins (Fig. 10.15a, b).
7. Insert the guide wire into the intravenous cannula. Exchange the cannula of the intravenous catheter for a sheath over the guide wire (Fig. 10.16).
8. Navigate the wire tip across the stenosis into the inferior vena cava. A kumpe catheter may be used to steer the wire into the inferior vena cava if needed (Fig. 10.17a).
9. Insert the angioplasty balloon to the site of stenosis and inflate the balloon to treat the stenosis (Fig. 10.17b–d).
10. Assess the outcome of angioplasty by doing a DSA run (Fig. 10.17e).
11. Check the inflow of the graft by doing a "reflux" angiogram by injecting contrast material via the sidearm of the vascular sheath while occluding the outflow of the graft with either the angioplasty balloon or by manual compression with a hemostat.
12. Remove the guide wire.
13. Apply purse string suture and remove the sheath (Fig. 10.18a, b).

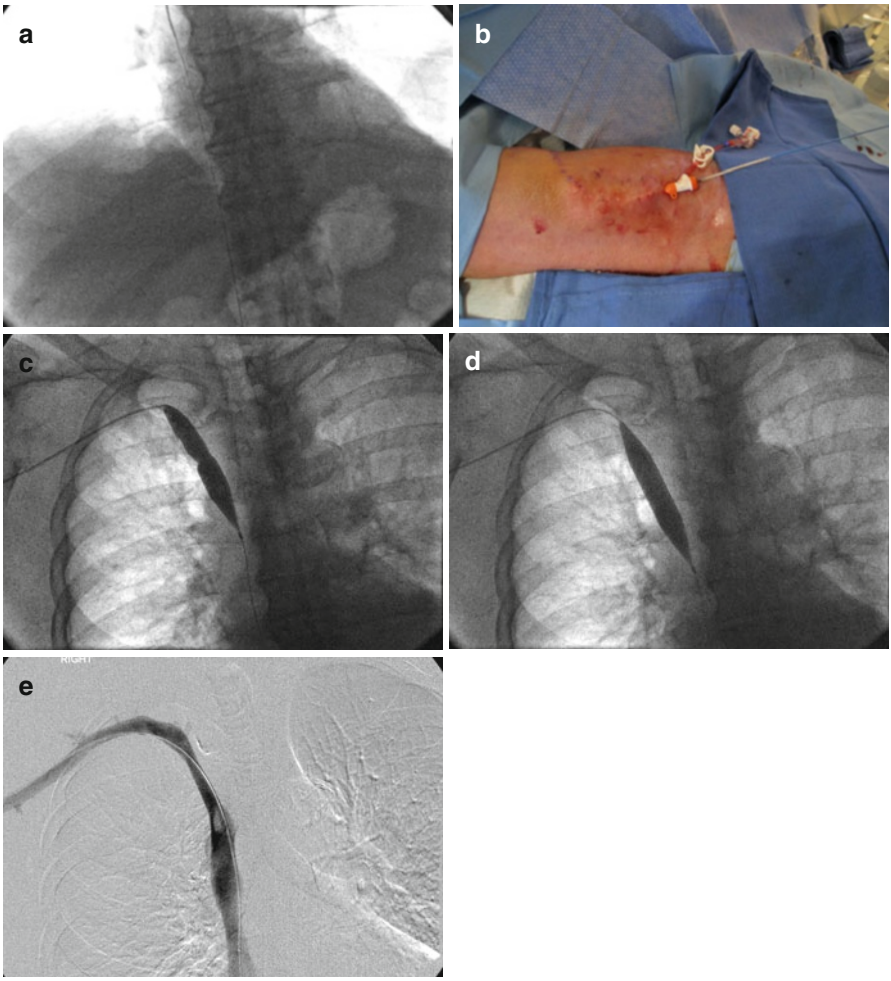

Fig. 10.17 (**a**) Steer the guide wire tip across the stenosis into the inferior vena cava. (**b**) Insert the balloon catheter over guide wire. (**c**) Inflate the balloon. (**d**) Complete effacement of the stenosis with balloon inflation. (**e**) Improvement in flow after balloon angioplasty

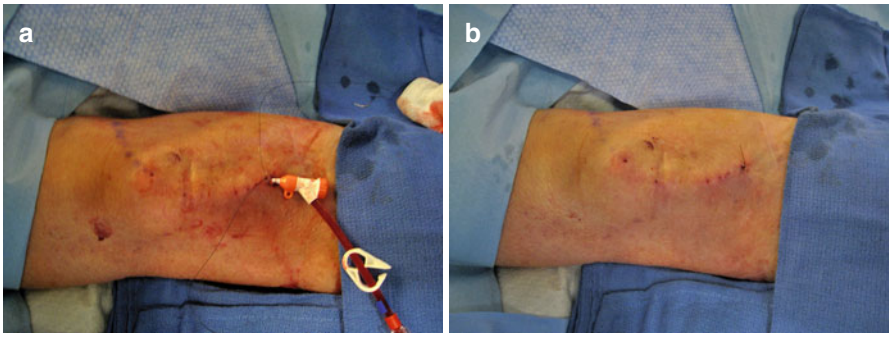

Fig. 10.18 (**a**) Apply a purse string suture around the sheath. (**b**) Remove the sheath and tighten the purse string suture

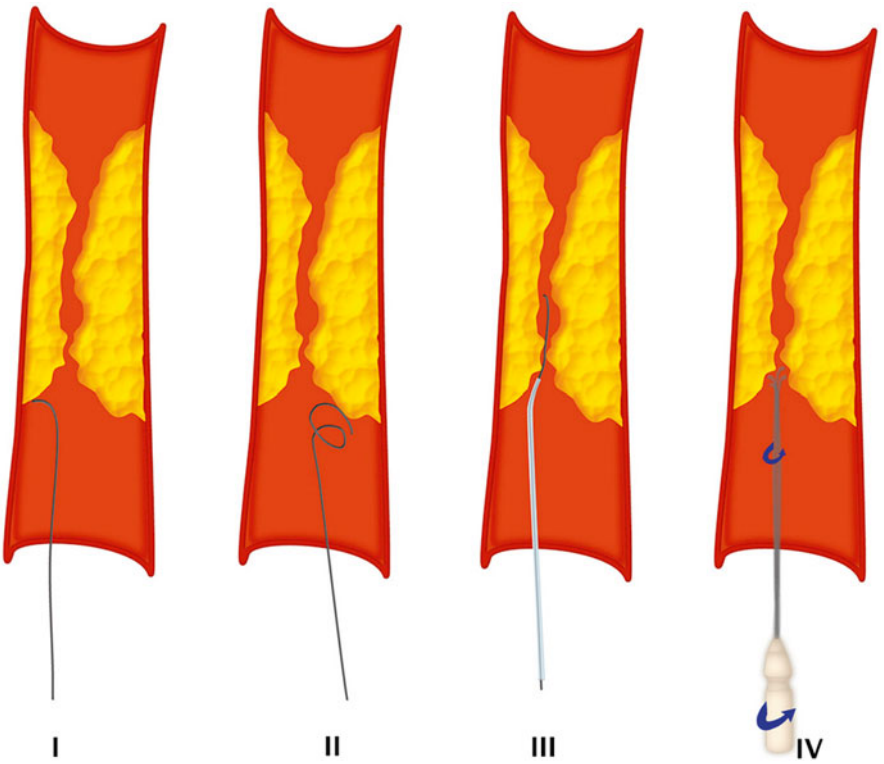

Fig. 10.19 Difficulties may be encountered while trying to cross a stenotic lesion. The wire may tangle up when you try pushing the wire forward (**I**, **II**). An angled catheter may be passed over the wire to stiffen and rotate the tip of the wire across the lesion (**III**). A Torque device may also be attached to the wire to "spin" it across the lesion (**IV**)

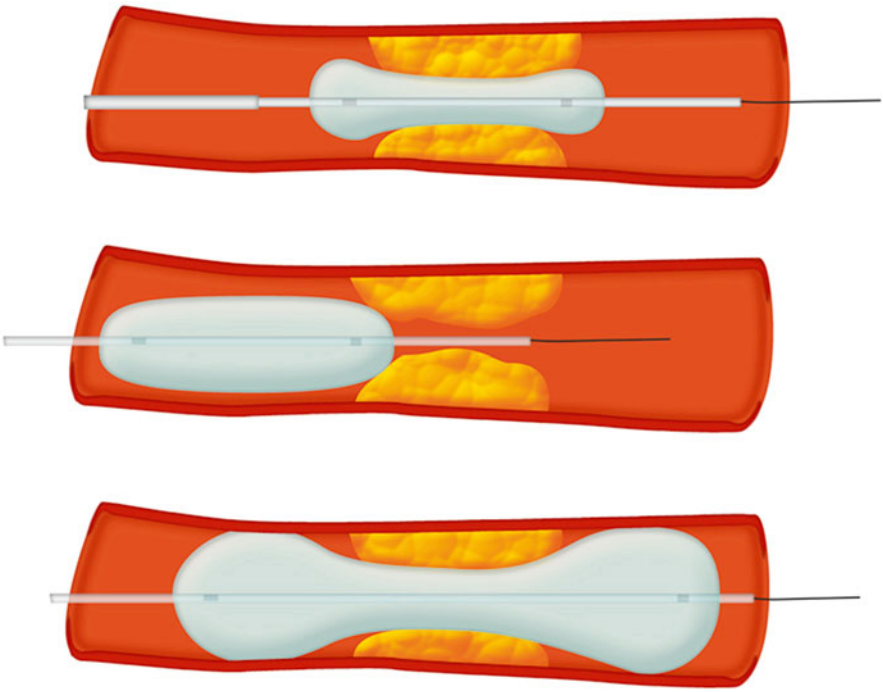

Fig. 10.20 The angioplasty balloon may slip off the site of stenosis during inflation. This can be managed by repositioning the balloon and holding on to the balloon catheter (near the sheath) during inflation to keep it in position. A longer balloon may be needed if the length of stenosis is long

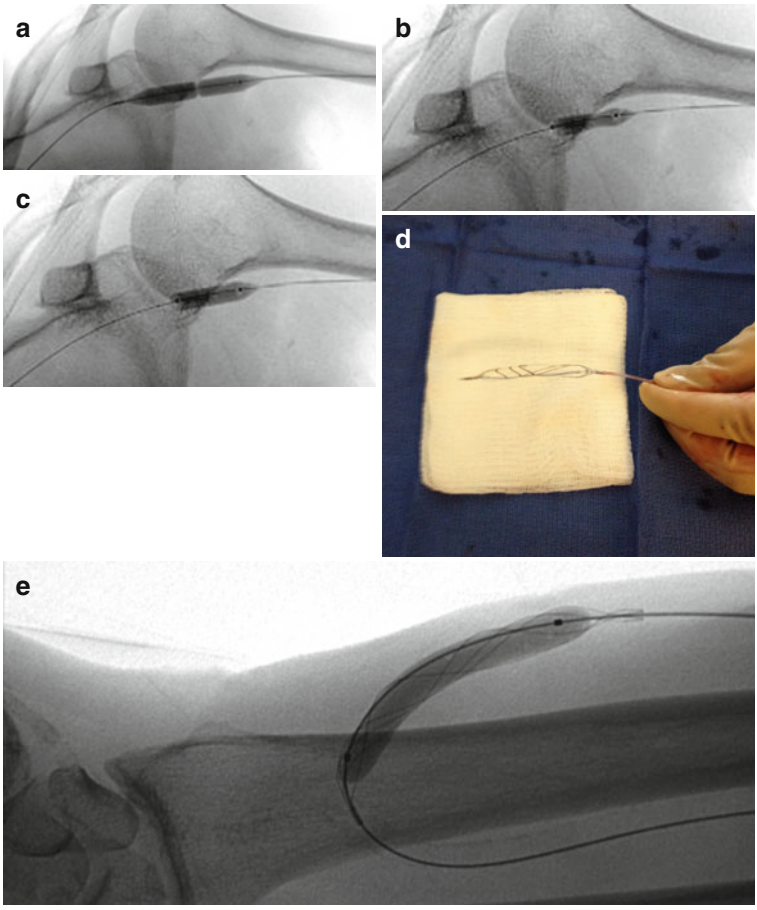

Fig. 10.21 (**a**) Persistent "waisting" at using a high pressure balloon at maximal balloon inflation. (**b**) Same lesion treated with a cutting balloon. (**c**) Effacement of the stenosis with cutting balloon. (**d**) An Angiosculpt balloon has three or four flexible nitinol spiral struts attached to a semi-compliant balloon. (**e**) Inflation of the balloon will create a radial force to push the edges of the nitinol struts into the target lesion to "score" it

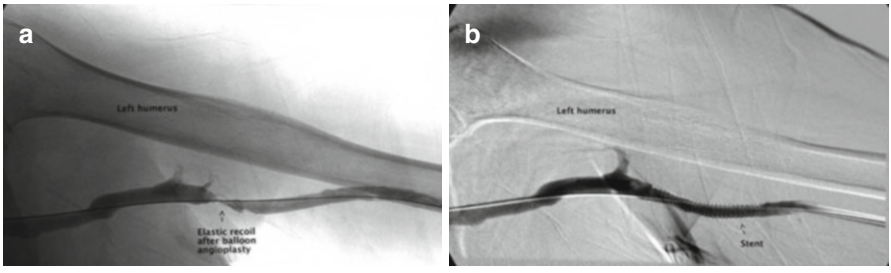

Fig. 10.22 (**a**) Stenotic lesion at the graft vein junction "recoiled" after balloon angioplasty. (**b**) A stent was placed to maintain the patency of the AVG

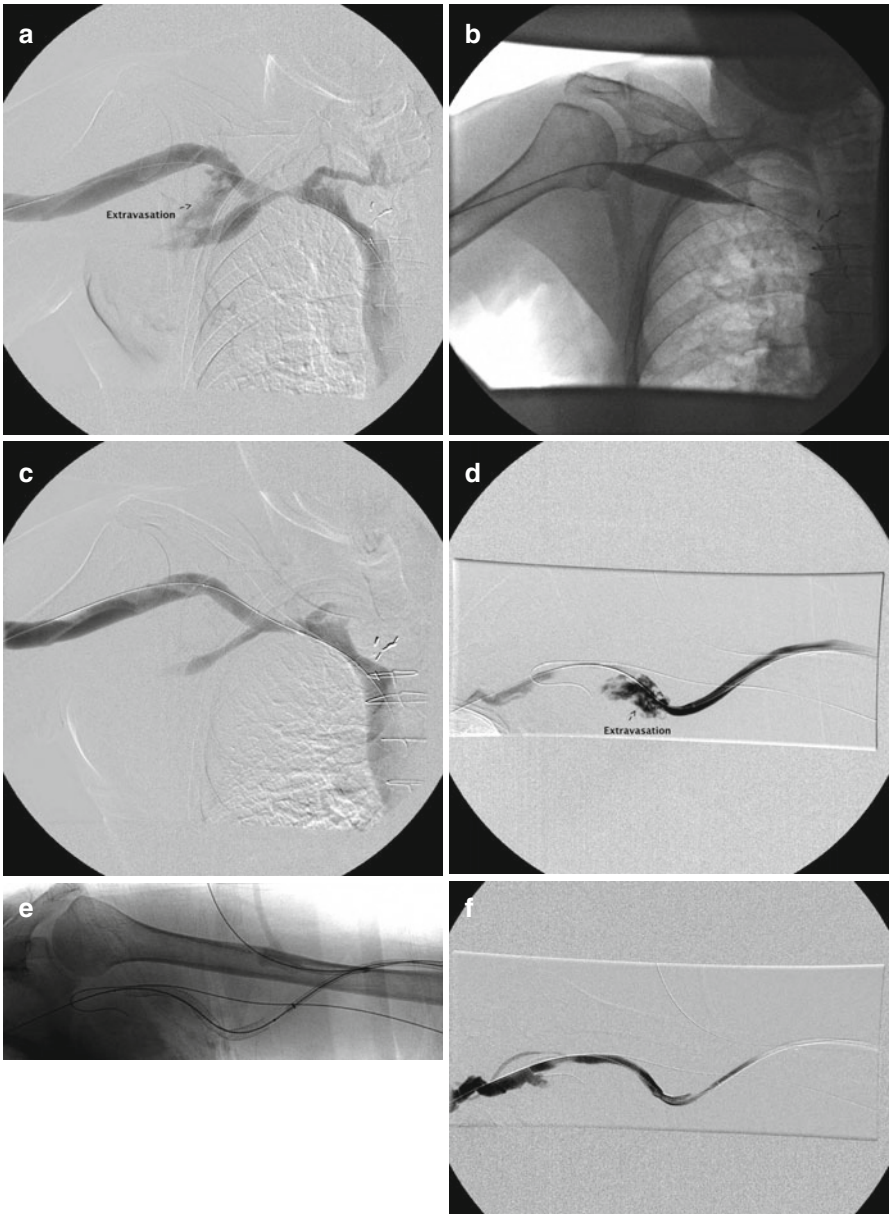

Fig. 10.23 (**a**) Extravasation of contrast after angioplasty of the cephalic arch. (**b**) The angioplasty balloon was gently re-inflated at lower pressure to tamponade the site of bleeding for 3–5 min. (**c**) Extravasation of contrast material stopped. (**d**) Venous rupture after balloon angioplasty of the graft vein junction of a left upper arm BB AVG. (**e**) Covered stents were deployed to control the bleeding. (**f**) Extravasation of contrast material stopped after stent deployment

Tips and Troubleshooting

Some of the common problems and complications that you may come across while performing a fistulogram and angioplasty are covered in Table 10.3.

Table 10.3 Common problems and complications

Problem	Suggestions
Inability to cannulate AV access	1. Occlude the venous outflow to engorge the veins 2. Cannulate the AV access under real time ultrasound guidance 3. Find an alternative site which may be remote from dialysis cannulation sites
Inability to pass guide wire through a stenosis (Fig. 10.19)	1. Use an angled catheter to "stiffen" the wire and rotate the wire across the stenosis 2. Use a curved tip guide wire or modify the curvature of the wire tip by running a hemostat over the top while holding the guidewire between the hemostat and thumb 3. Change to a smaller caliber guidewire 4. Apply external compression to the site of stenosis using a hemostat to change the configuration of the stenosis
Inability to advance the balloon catheter over the guide wire at the site of stenosis	1. Change to a smaller angioplasty balloon to pre-dilate the lesions before using a larger balloon 2. Use a balloon catheter that has a better trackability 3. Wedge the balloon catheter into the lesion and gently inflate it repeatedly to dilate the lesion till it passes through
"Watermelon seed" effect: Balloon repeatedly slipping off site of stenosis during inflation. (Fig. 10.20)	1. Hold onto the balloon catheter during inflation 2. Reposition the balloon catheter to "center" it at the site of stenosis 3. Use a longer balloon to cover the length of stenosis 4. Use a smaller balloon to pre-dilate the stenosis
Persistent "waist" at maximal pressure inflation (Fig. 10.21)	1. Change to an ultrahigh pressure balloon 2. Use a scoring balloon, e.g. AngioSculpt (AngioScore, Fremont, CA) 3. Use a cutting balloon, e.g. Peripheral Cutting Balloon (Boston Scientific, Natick, MA) 4. Extend balloon inflation time
"Recoil": lesions effaced during pressure inflation but recur after deflation of balloon (Fig. 10.22)	1. Exclude external compression 2. Reassess hemodynamic significance, if intervention is necessary, (a) Prolong the balloon inflation time, or (b) Use larger balloon, or (c) Use an ultrahigh pressure balloon, or (d) Use an angioscoring balloon, or (e) Use a cutting balloon, or (f) Consider using a stent

Table 10.3 (continued)

Problem	Suggestions
Venous rupture (Fig. 10.23)	1. Control the extravasation by compressing the inflow of the AV access 2. It is critical to maintain the wire across the site of rupture at all time 3. Reposition the balloon to the rupture site and gently re-inflate the angioplasty balloon at lower pressure to tamponade the bleed for 3–5 min 4. To prevent thrombosis of the AV access during the prolonged tamponade, periodically deflate the balloon for a few seconds to allow flow to continue 5. Most of the bleeding will stop. If persistent, deploy a stent graft across the ruptured segment 6. If stent deployment is necessary, the sheath would need to be upsized to allow the passage of the stent
Rupture of angioplasty balloon	1. Exclude venous rupture which may have occurred concurrently 2. Gently withdraw the balloon through the sheath to prevent further fragmentation of balloon material 3. If balloon is stuck while pulling it out from the sheath, exchange the sheath for a larger sheath or apply a purse string suture around the sheath and remove the sheath together with the balloon 4. After removal, check the balloon to ensure that all fragments are removed
Wire fragments or foreign body is inadvertently created during procedure	1. Remove the fragments with a snare device (EN snare or Goose neck snare)
Sheath is dislodge during procedure	1. Re insert the inner dilator into the sheath before replacing the sheath, do not push in the sheath without the inner dilator in place
Hematoma after sheath removal	1. Tends to occur more frequently in non matured AVFs 2. Compress the puncture site 3. Redo the purse string

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Declotting of Dialysis Vascular Access

11

Chieh Suai Tan, Steven Wu, and Sanjeeva P. Kalva

Introduction

Thrombosis of arteriovenous (AV) access can be considered a renal "emergency" that requires urgent intervention. With the advent of interventional nephrology as a subspecialty, declotting of the AV access can now be performed swiftly with minimal disruption to the dialysis schedule of the patients.

Thrombosis of an AV access is usually secondary to the development of flow restricting stenoses within the circuit. Therefore, treatment of a thrombosed AV access requires thrombolysis, as well as angioplasty of the underlying stenosis. In arteriovenous grafts (AVG), the sites of stenosis are most commonly at the graft-vein junction or in the draining vein. On the other hand, the site of stenosis may be within an outflow vein for an upper arm arteriovenous fistula (AVF) or the inflow vessels for a lower arm AVF [1, 2].

Although similar techniques are employed for declotting of AVF and AVG, there are some subtle differences in the approach and etiology. In particular, declotting of

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Table 11.1 Differences between declotting of an AVF and AVG

	AVF	AVG
Configuration	Native vein to artery	Vein to synthetic material to artery
Flow requirement for patency	Usually remain patent at low blood flow	Likely to thrombose at low blood flow
Incidence of thrombosis	Low	High
Etiology	Inflow stenosis more than outflow stenosis	Graft vein junction stenosis
Urgency of intervention	High (within hours to few days)	Lower than AVF (within days to weeks)
Clot burden	Variable, usually low but can be high in the presence of aneurysm	Moderate, usually confined within the graft
Technical difficulties	High, may be difficult to cannulate the main outflow vein	Low. Graft is visible and can be cannulated easily
Success rate	Lower than AVG	Higher than AVF

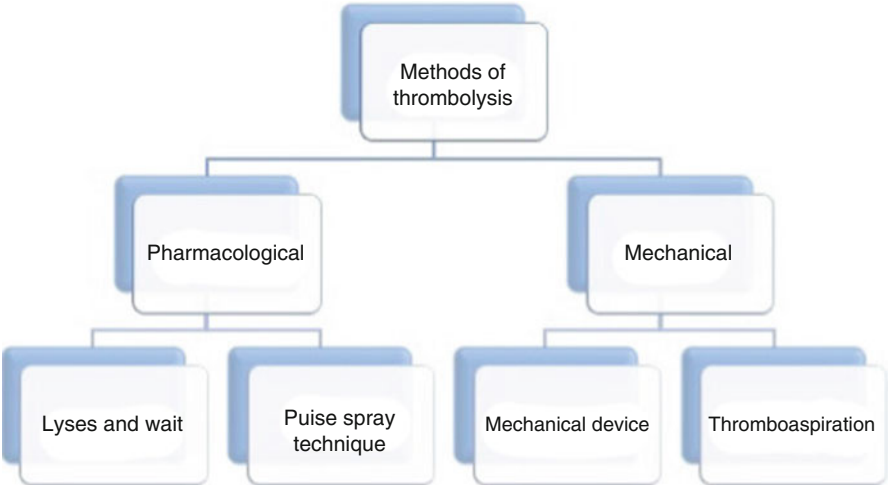

Fig. 11.1 Methods of thrombolysis

a thrombosed fistulas requires more time and expertise than declotting of a graft. The differences are as summarized in Table 11.1.

Methods of Declotting

Broadly, the two methods of declotting as summarized in Fig. 11.1. The differentiation is arbitrary as most of the time, a combination of both pharmacological and mechanical thrombolysis are needed to ensure technical success.

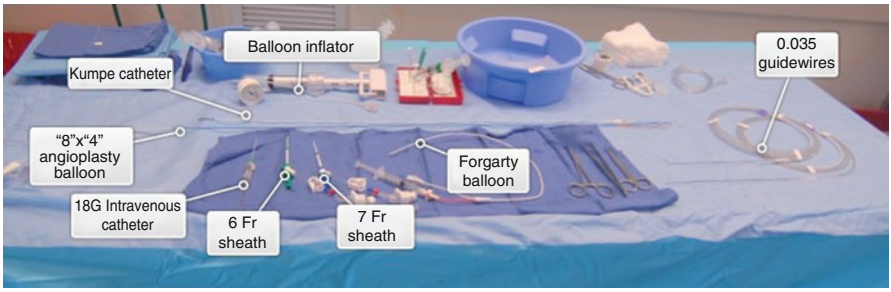

Fig. 11.2 Equipment for declotting

Equipment (Fig. 11.2)

1. Normal saline for flushing of sheaths and catheters
2. Lidocaine
3. Two 18 Gauge (G) intravenous catheters
4. Two 0.035 in. guide wires
5. One 6 Fr 4 cm sheath
6. One 7 Fr 4 cm sheath
7. One Kumpe catheter
8. One Angioplasty balloon
9. One 5.5 Fr Forgarty balloon
10. One balloon inflator
11. 4 mg of Tissue plasma activator (tPA) in 4 mL of sterile water
12. 2,000 units of heparin (1,000 units/mL concentration)
13. Two 3/0 non absorbable sutures (Ethilon)
14. Gauze
15. Hemostat
16. Needle holder
17. Syringes and needles

Declotting of AVG

1. Two puncture sites are required to access the entire circuit to remove all the clots and the "arterial plug" (Fig. 11.3a).
2. The first puncture should be placed closed to the arterial anastomotic site in an antegrade direction towards the venous outflow. The direction of blood flow can be determined by:
   (a) Physical examination: Palpate for arterial pulsations along the graft. It should get more distinct as you approach the AV anastomosis.

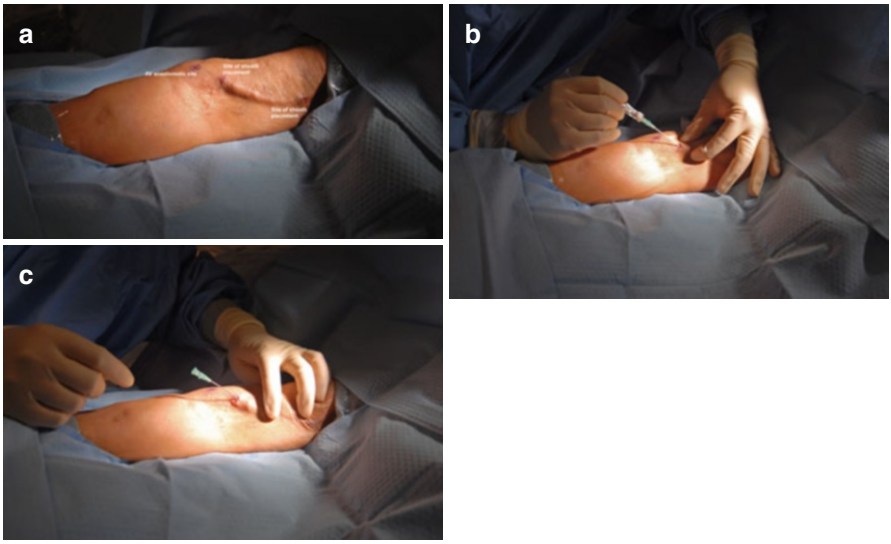

Fig. 11.3 (**a**) Note the AV anastomotic site and mark the site of sheath placement. (**b**) Hold the IV cannula like a pencil with your right hand and advance it gentle while feeling for a "give". (**c**) Stale blood should be seen in the cannula if it is in the right position

(b) History: Enquire about the placement of needles during dialysis. The "A" needle is directed towards the inflow while the "V" needle is directed towards the outflow.
(c) Surgical notes.
(d) Images from previous access intervention.

3. Cannulate the AVG with a 18G angiocath (Fig. 11.3b, c).
   (a) Advance the needle till you feel a "give". "Flashback" is usually not seen as the blood is clotted within the AVG.
   (b) Hold onto the needle while pushing in the cannula.
4. Gently instill 2 mg of tPA into the thrombosed AVF via the cannula (Fig. 11.4a).
5. Insert a 0.035 in. wire into the 18G cannula (Fig. 11.4b) and push the tip of the wire up to the subclavian vein.
6. Remove the cannula over the guide wire (Fig. 11.4c) and thread a 4 cm long 6 Fr sheath along with its dilator over the guide wire to insert the sheath into the cannulation site. Remove the dilator from the sheath (Fig. 11.4d).
7. Pass a 5 Fr Kumpe catheter up to the level of the thoracic cage. Remove the guide wire and perform a venogram to check the central veins via the Kumpe catheter (Fig. 11.5a).
8. Pull back the catheter towards the AVF while injecting the contrast to image the draining veins (Fig. 11.5b, c).
9. Treat significant stenotic lesions with balloon angioplasty: Reinsert the guide wire over the Kumpe catheter, then remove the Kumpe catheter and insert the balloon catheter over the guide wire (Fig. 11.6a–c).

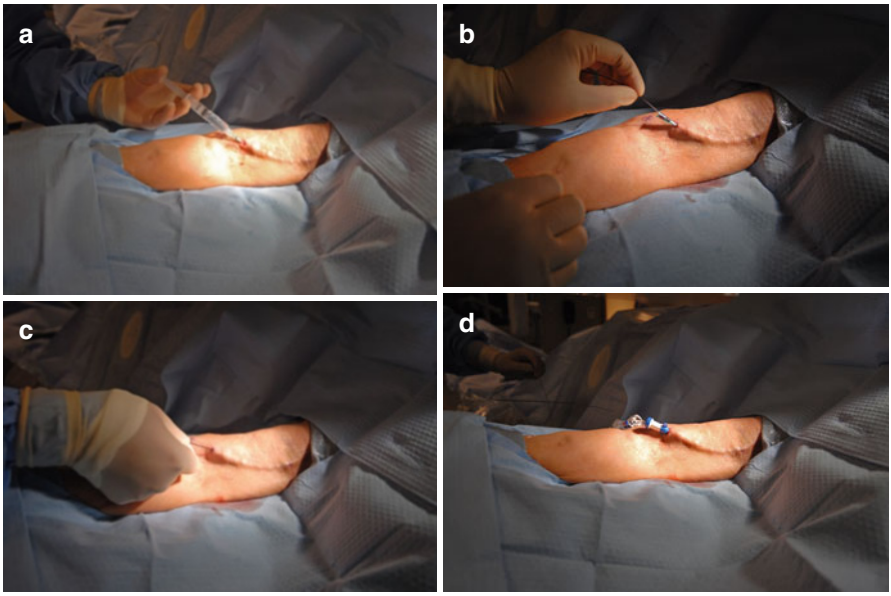

Fig. 11.4 (**a**) Instill tPA into the graft via the cannula. (**b**) Pass the guide wire into the graft via the cannula. (**c**) Remove the cannula from the graft but leave the wire in situ. (**d**) Insert the sheath into the AVG over the guidewire of the sheath in the AVG

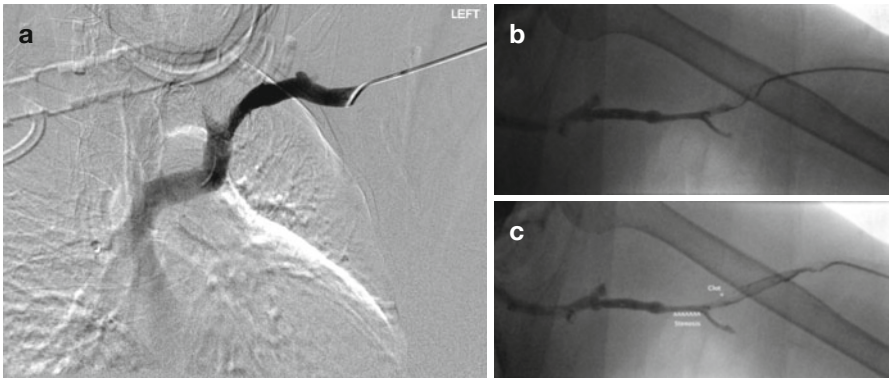

Fig. 11.5 (**a**) Do a central venogram with the catheter placed just outside the thoracic cage. (**b**) Inject the contrast material while pulling the catheter towards the sheath. (**c**) Stenosis of the graft vein junction and a thrombus within graft

10. After treatment of the stenotic segment, the next step is to declot the AVG mechanically.
11. Pull back the deflated angioplasty balloon into the thrombosed AVG and inflate the balloon (Fig. 11.7a). The aim is to "macerate" the thrombus within the AVG. There is no need to keep the balloon inflated for 3 min. Deflate the balloon and move it towards the sheath before inflating it again. Repeat these till you reach the tip of the sheath (Fig. 11.7b, c).

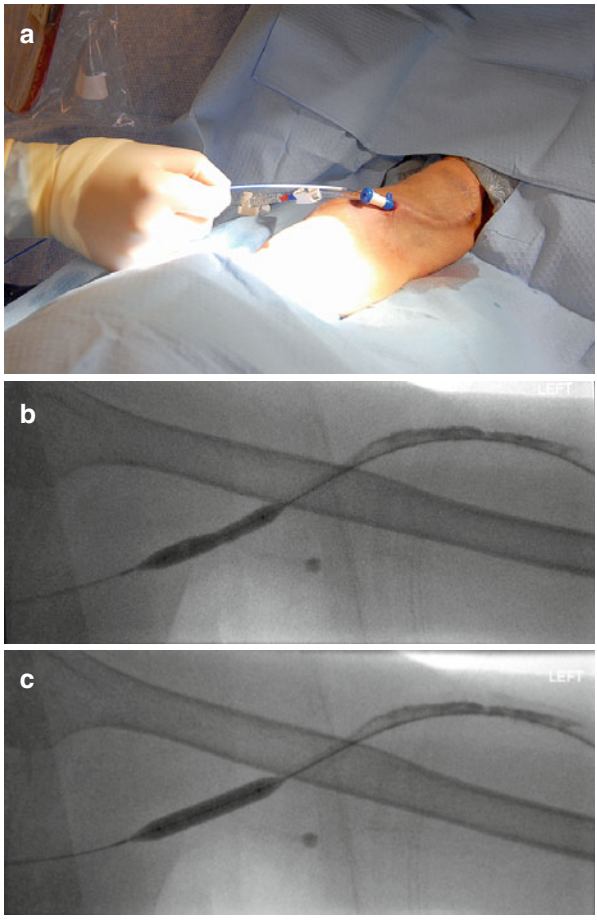

Fig. 11.6 (**a**) Insert the angioplasty balloon catheter over the guide wire. (**b**) Stenosis causing "waisting" of the balloon during inflation. (**c**) Complete effacement of stenosis at maximal balloon inflation

12. Aspirate clots from the side-port of the sheath and perform a graftogram to check the results of thrombolysis (Fig. 11.7d–f). If necessary, repeat the step 11 and 12.
13. Once the venous outflow is cleared, make a second puncture on the venous limb and direct it in a retrograde direction towards the arterial inflow (Fig. 11.8a–c). Ensure there is sufficient distance between the first and second puncture for sheath placement so that the two sheaths do not overlap. Instill 2,000 units of heparin intravenously.
14. Gently pass the guide wire tip into the feeding artery (Fig. 11.9a). Do not use excessive force as it might push the "arterial plug" or thrombus into the artery and result in distal embolisation.
15. Insert a 5.5 Fr Fogarty balloon catheter over the guide wire into the artery. Inflate the Fogarty balloon with 1.5 mL of air (Fig. 11.9b–d). Pull back the balloon towards the sheath to dislodge the arterial plug (Fig. 11.9e). Repeated attempts may be needed to clear the arterial plug.

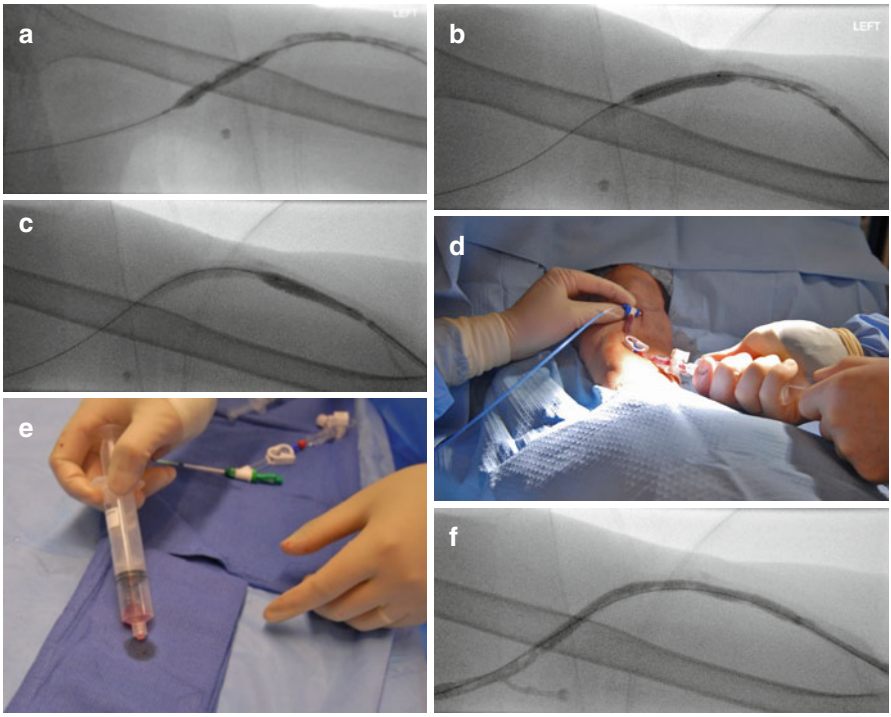

Fig. 11.7 (**a**) Inflate the angioplasty balloon to macerate the thrombus. (**b**) Deflate, pull back and re-inflate the balloon. (**c**) Repeat the steps still you reach the tip of the sheath. (**d**) Aspirate from the side port of the sheath. (**e**) Look for the presence of clots that are aspirated. (**f**) Graftogram to check the result of thrombolysis

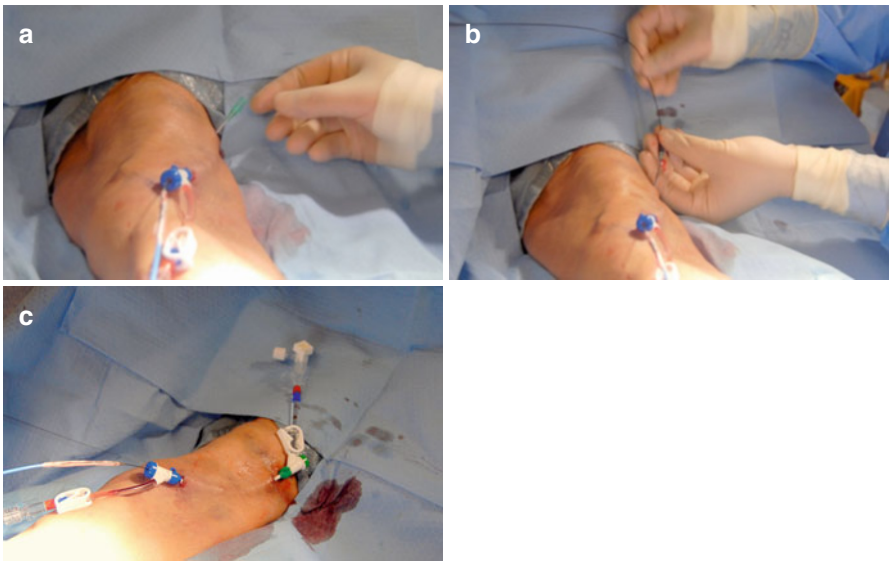

Fig. 11.8 (**a**) Cannulate the AVG using the IV cannula as described previously. (**b**) Insert the wire through the cannula. (**c**) Remove the cannula and insert the sheath into the graft over the guidewire

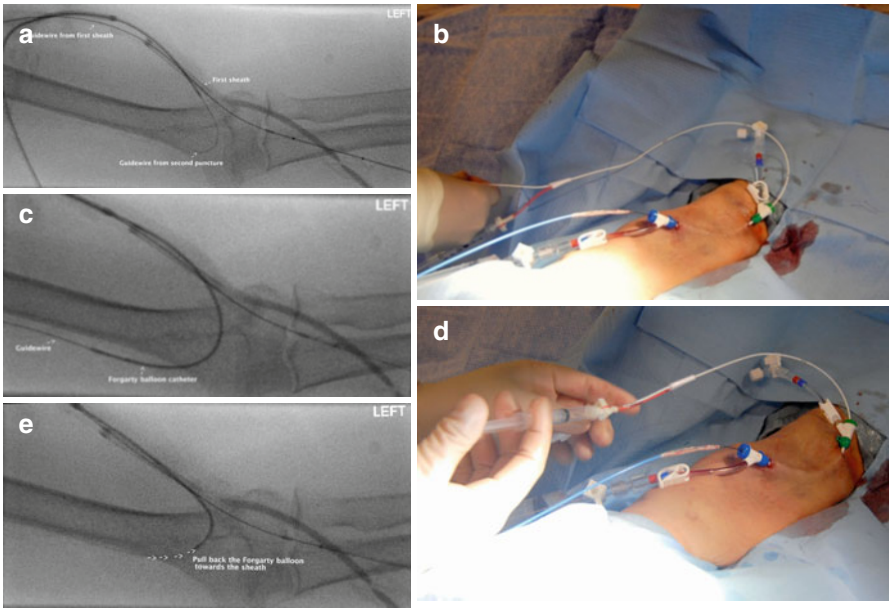

Fig. 11.9 (**a**) Insertion of guidewire into the feeding artery. (**b**) Insert the Fogarty balloon catheter over the guide wire. (**c**) Ensure that the guide wire is within the feeding artery. Insert the Forgarty balloon catheter into the feeding artery under fluoroscopy. (**d**) Inflate the Fogarty balloon with 1.5 mL of air. (**e**) The balloon is not well visualized as it is inflated using air. Pull back the inflated balloon catheter towards the sheath to dislodge the "arterial plug"

16. Perform a check angiogram to ensure adequacy of thrombolysis (Fig. 11.10a).
17. A retrograde graftogram can be performed by compressing the graft while injecting contrast via the sidearm of first sheath (Fig. 11.10b).
18. Do a final run of the outflow veins. Any significant stenosis that is discovered after thrombolysis should be treated with balloon angioplasty.
19. Apply purse string suture around the sheath (Fig. 11.10c).
20. Pull out the sheath and immediately tighten the purse string suture (Fig. 11.10d, e).
21. Apply dressing over the wound.
22. Check the distal pulses.
23. Watch out for any hematoma formation.
24. Stitches can be removed after 1–2 days.

Declotting of AVF

The steps for thrombolysis in an AVF are similar to that of an AVG. However, compared to the AVG, declotting a thrombosed AVF can be more challenging because of the following reasons:

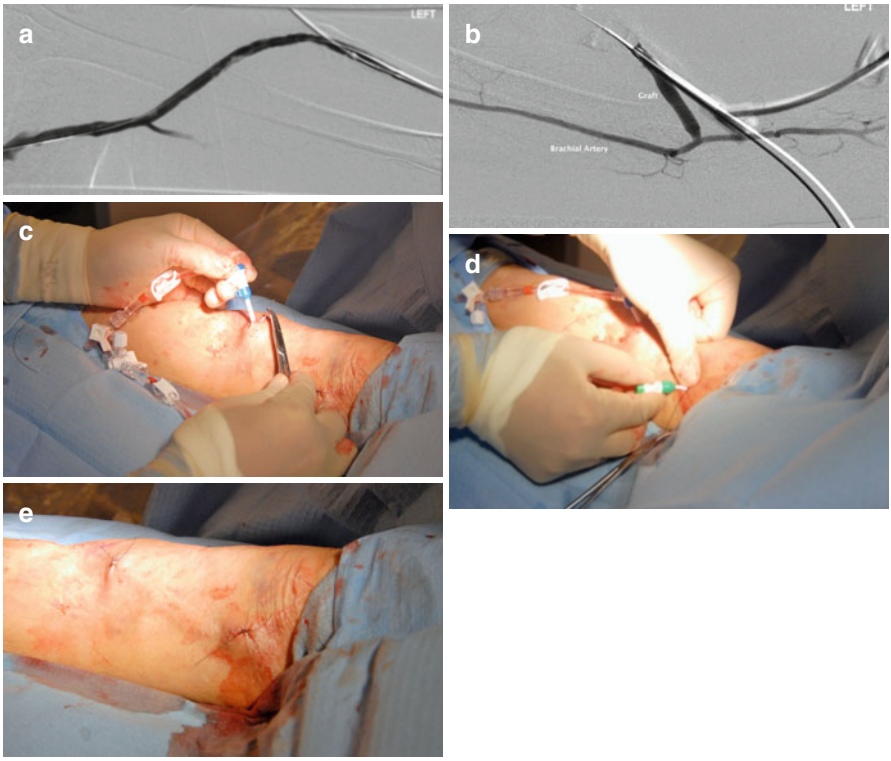

Fig. 11.10 (**a**) Check adequacy of thrombolysis. Note the free flow of contrast through the graft. (**b**) Retrograde graftogram to visualize the inflow of the AVG. (**c**) Apply purse string suture around the sheath. (**d**) Tighten the purse string while pulling out the sheath. (**e**) AVG after sheath removal

1. Greater variation of the venous anatomy. Specifically, the presence of accessory or collateral veins can confound the placement of the initial puncture. The clotted fistula may be draining via the collateral veins which may confuse the operator. It is crucial to get access into the main draining vein to successfully declot it.
2. The stenosis can be much tighter and impossible to cross.
3. Venous wall can be much thinner than the synthetic graft and is much more difficult to feel and cannulate.
4. Higher risk of rupture, especially in recently created AVF that has clotted off.

Tips and Troubleshooting

Some of the common problems and complications that you may meet while performing a declotting procedure are covered in Table 11.2.

Table 11.2 Common problems and complications

Problem	Trouble shooting
Venous embolism	In the presence of high thrombus load, significant pulmonary embolism can occur. This could result in respiratory compromise especially in patients who have known poor respiratory reserve. Furthermore, in patients with known right to left cardiac shunt, such as atrial septal defects, declotting is contraindicated due to the risk of paradoxical embolism causing cerebrovascular accident
High thrombus burden expected	Use thrombectomy device for clot removal to decrease risk of significant pulmonary embolism
Clots within the pseudoaneurysm	Clearing of clots from large pseudoaneurysms can be challenging as they typically contain chronic thrombi which are hard, adherent and difficult to remove. If the thrombus load is high, use an thrombectomy device such as the Angiojet (Fig. 11.11a–j) or Arrow-Trerotola device (Fig. 11.12a–d). Chronic thrombus that cannot be cleared are sometimes left alone if adequate flow can re-established. For small aneurysms, press down on the aneurysm while pulling the Forgarty balloon across it. Several passes are often necessary to clear out the clots completely
Arterial embolism (See Fig. 11.13)	One of the most feared complications of declotting. Possible treatment strategies are:
	1. Balloon catheter embolectomy
	(a) Pass guidewire and inflate the Fogarty balloon beyond the level of embolus
	(b) Pull back the clot into the AV access
	2. Catheter thromboaspiration
	(a) Pass the guidewire beyond the embolus and insert a 7Fr catheter up to the level of the embolus
	(b) Attach a 50 ml syringe to the catheter and apply strong aspiration pressure to remove the clot
	3. Back bleeding
	(a) Only works if there is sufficient collaterals in the arterial supply of the upper limb
	(b) Occlude the artery proximal to the AV anastomosis using a blood pressure cuff or angioplasty balloon
	(c) Ask the patient to repeated clench and unclench the fists to increase flow to the hand and retrograde flow towards the AV access
	(d) The retrograde flow will push the emboli into the AV access and the outflow veins
	4. Surgical embolectomy
Residual thrombus on final check angiogram	"Polishing" is done by using the Forgarty balloon. Insert the Forgarty balloon catheter to the site of the residual thrombus. Inflate the balloon and push it forward to dislodge the thrombus. Deflate the balloon, pull back the balloon and repeat the steps till the residual thrombus is cleared

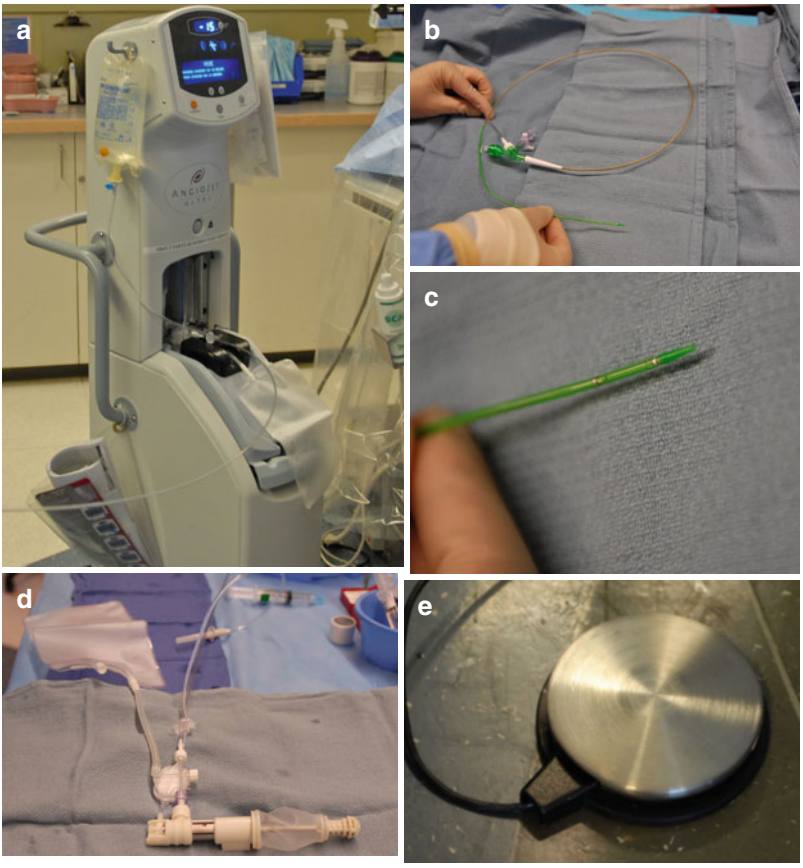

Fig. 11.11 (**a**) The angiojet thrombectomy system consists of three components: the machine (as shown above), disposable angiojet catheter and disposable pump set. The machine can generate high pressure saline jets and suction at an alternating rate of 60 times per minutes. (**b**) The catheter has an over-the wire-catheter tip design. It contains 2 lumen: one for the inflow of high velocity saline jets and one for the passage of guide wire and evacuation of thrombotic debris. (**c**) The angiojet catheter has side holes (marked by radio-opaque markers) near its tip. High velocity saline jets exit through the proximal side holes while suction occur at the distal side holes to aspirate the thrombus into the catheter where it is fragmented by the high pressure saline jets and removed from the body. (**d**) A disposable pump set connects the angiojet catheter to the angiojet machine. It has a collection bag for thrombotic debris and a spike connector to saline bag. (**e**) The operation of the angiojet thrombectomy system is control by a foot pedal. (**f**) After connecting all three components of the system, the angiojet catheter is primed by submerging the catheter in saline and activating the machine to purge air out of the system. (**g**) This patient presented with a thrombosed AVG. A stent was previously placed at the graft vein junction to maintain patency of the graft. A large thrombus was seen just distal to the stent. Decision was made to use the angiojet thrombectomy system to remove the thrombus. (**h**) The angiojet catheter was passed into the sheath via a guide wire to the location of interest. (**i**) Radio-opaque markers are present on the angiojet catheter to mark the location of the catheter. Advance the angiojet catheter to the distal end of the thrombus. Start the machine and pull back the catheter through the thrombus. On average, 3 to 5 passes are needed to clear the thrombus. (**j**) Thrombotic debris mixed with normal saline are collected within the bag at the end of procedure

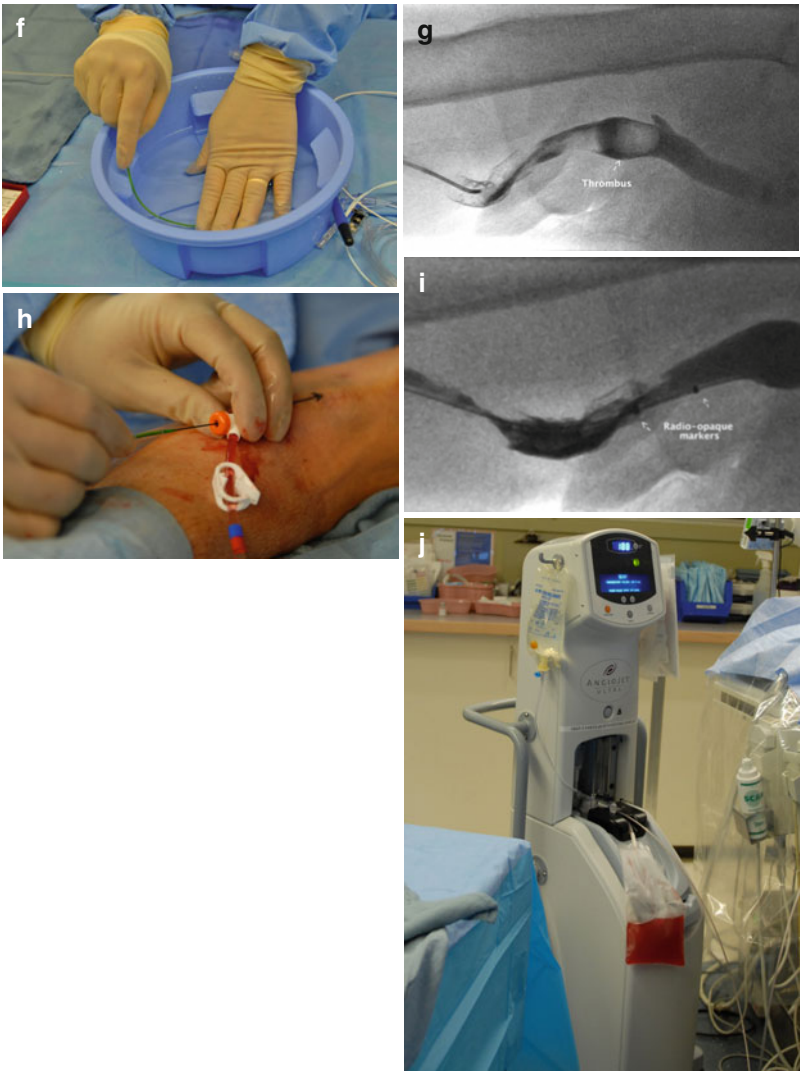

Fig. 11.11 (continued)

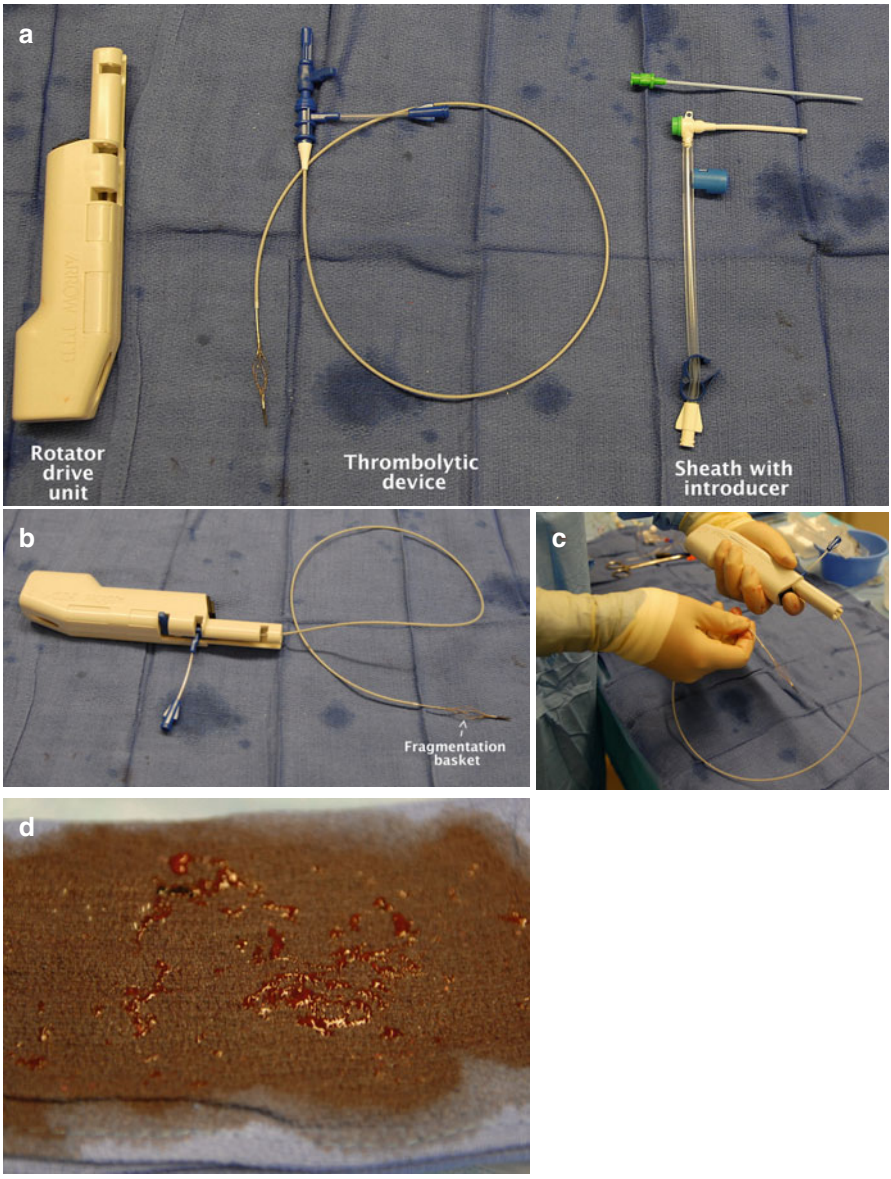

Fig. 11.12 (**a**) The Arrow-Trerotola Thrombectomy device comes in three components: The rotator drive unit, thrombolytic device and the introducer sheath. (**b**) The thrombolytic device has a unique 9 mm self expanding fragmentation basket that will conform to the wall of the vessels. The 5 Fr. standard basket thrombolytic device is shown here. The device also comes in a 7 Fr. over-the-wire configuration. The setup is completed by fitting the thrombolytic device to the rotor drive unit. (**c**) Once activated, the disposable hand-held rotator drive unit will spin the basket at a rate of 3,000 rpm to macerate the thrombus. (**d**) Macerated clots were aspirated from the side-arm of the sheath after the device was pulled though the thrombus

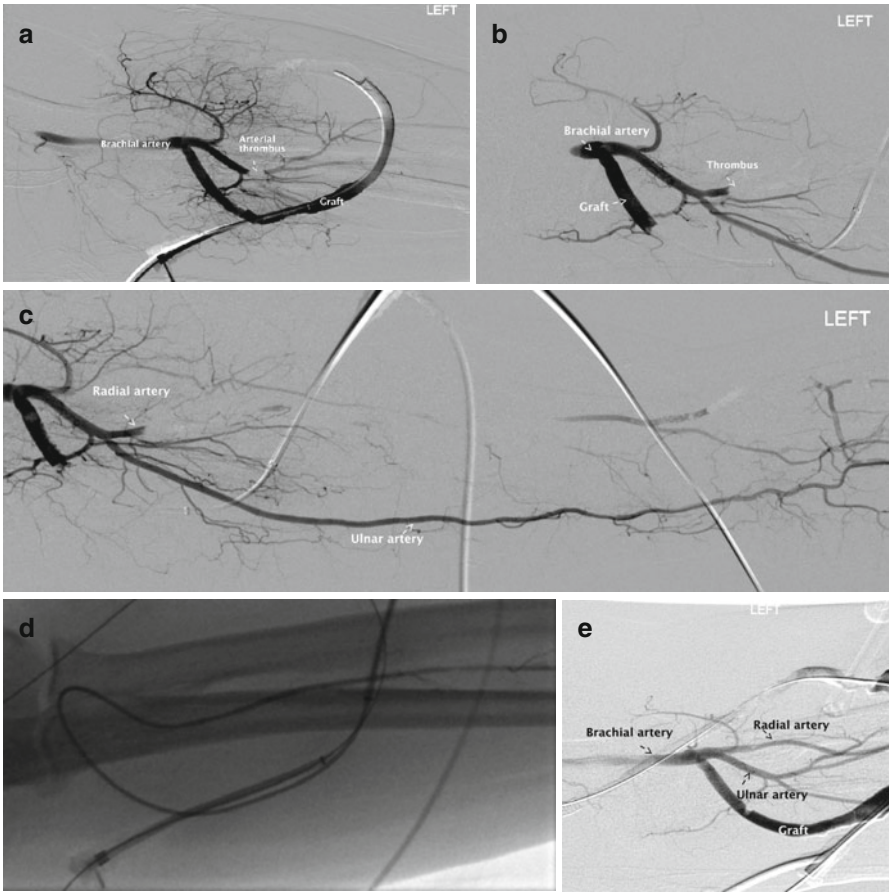

Fig. 11.13 (**a**) Post de-clotting graftogram is performed by doing a retrograde graftogram while occluding the graft using a Forgarty balloon. It showed an arterial thrombus at the bifurcation of the brachial artery with absence of flow in both the radial and ulnar artery. (**b**) A repeat retrograde graftogram showed migration of the thrombus into the radial artery. Note the reestablishment of flow in the ulnar artery and the absence of flow in the radial artery. (**c**) Absence of contrast within the radial artery. (**d**) A Forgarty balloon was used to pull the thrombus back into the AVG. Re-establishment of flow within the radial artery is seen. (**e**): Reestablishment of flow down the radial artery

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Endovascular Stent Placement

12

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Introduction

The use of stents, specifically covered stents or stent grafts, in the treatment of dialysis vascular access dysfunction has been increasing over the past decade [1, 2]. Several retrospective studies have investigated the role of stent versus angioplasty in the management of dialysis access interventions and concerns are raised over the frequency and severity of in-stent restenosis [3, 4]. Nevertheless, due to the lack of robust level 1 evidence, placement of stents in the AV access circuit has remained controversial. According to the KDOQI guidelines, published in 2006 [5], stent placement should be considered in the following situations:

1. Central vein stenosis where there is acute elastic recoil of the vein (>50 %) after angioplasty or recurrence of stenosis within a 3-month period.
2. Angioplasty-induced vascular rupture, patients with surgically inaccessible lesion or contraindication to surgery.

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The increase in the utilization of stent grafts is partly driven by the lack of durability of angioplasty alone in maintaining access patency and the brisk intimal hyperplasia associated with the bare metal stents. Moreover, since the publication of the KDOQI guidelines, two randomized controlled trials have demonstrated the potential benefits of stent graft in the treatment of cephalic arch stenosis and AVG associated venous anastomotic stenosis. In the study published by Shemesh et al. [6], stent grafts as compared to the bare metal stents, were found to be superior in maintaing venous patency in the treatment of recurrent cephalic arch stenosis. Furthermore, in the treatment of AVG associated venous anastomotic stenosis, Haskal et al. [7] demonstrated the beneficial effect of the stent grafts compared to angioplasty alone in maintaining access patency.

Careful planning and great care should be used when deploying stent grafts. Not only are stent grafts more expensive, they carry the risk of migration, infection, and can compromise future access options. As such, their use should be limited to salvage situations, approved indications, and clinical scenarios described in the aforementioned level 1 trial.

Equipment

1. 0.035 in. guidewire
2. 9 Fr introducer sheath
3. Sterile syringes
4. Contrast material
5. Saline solution
6. Appropriate diagnostic catheter and accessories
7. Appropriate sized angioplasty balloon

Steps for Stent Deployment

1. Ensure that the stenotic segment can be completely effaced by an angioplasty balloon before stent placement. A lesion that cannot be effaced with an angioplasty balloon should not be stented.
2. Sizing
   (a) *Diameter*

   Appropriate sizing is critical for stent deployment. Measure the diameter of the adjacent normal vein segment where the stent will be deployed. The stent should be oversized by approximately 10 % from the measured diameter. For stent graft, it should not be oversized by more than 1 mm as it can cause infolding of the graft material. As self-expanding stents cannot be expanded beyond their maximal diameter, an undersized stent will not anchor well and run the risk of migration.

(b) *Length*

The length of the stent should overextend the lesion by approximately 1 cm. If the stent is to be placed near the bifurcating junction of a vessel, it should not extend beyond the bifurcation point.

(c) Sheath.

A larger sheath is usually required for stent deployment. Remember to upsize the sheath to the appropriate size as recommended by the stent manufacturer.

3. Considerable variation of the stent delivery system exits between stent manufacturers and it is advisable to read the instruction for use provided by the stent manufacturer (Figs. 12.1a–g and 12.2a–e). The common feature in most of the delivery system is that the stent is crimped onto the shaft of the catheter by a covering layer. The stent is deployed when this layer is retracted. The tip of the delivery system is radio-opaque to facilitate navigation under fluoroscopy. Radio-opaque markers may be present to mark the two ends of the compressed stent within the delivery system. An additional radio-opaque marker may also be present on the covering layer. This marker acts as a visual guide during retraction of the covering layer.
4. Prime the delivery system with normal saline.
5. The stent and the shaft of the delivery system should be aligned in a straight line to allow precise placement of the stent.
6. Insert the delivery device over the guidewire to the site of stenosis
7. Center the stenotic or target segment between the 2 markers under fluoroscopy.
8. The delivery of the stent is based on the "fix and pull" system. Once the markers are in position, fix its position by holding on to the handle of the delivery system with one hand. Pull the covering layer with the other hand towards the handle of the delivery system to uncover the stent.
9. Retract the covering gently and slowly. The distal end of the stent will begin to open up like a flower. After retracting approximately 15 mm of the covering layer, wait for the distal end of the stent to fully expand before continuing retraction.
10. After the covering layer has been completely removed and stent is fully deployed, wait for the stent to fully expand before removing the delivery system.
11. Dilate the stent graft with an angioplasty balloon that is equal to the size of the stent graft that is placed.

Trouble Shooting

1. Stent embolism

Vein diameter progressively increase as they drain centrally, hence, there is a possibility that the stent may emboli to the heart and lungs during deployment.

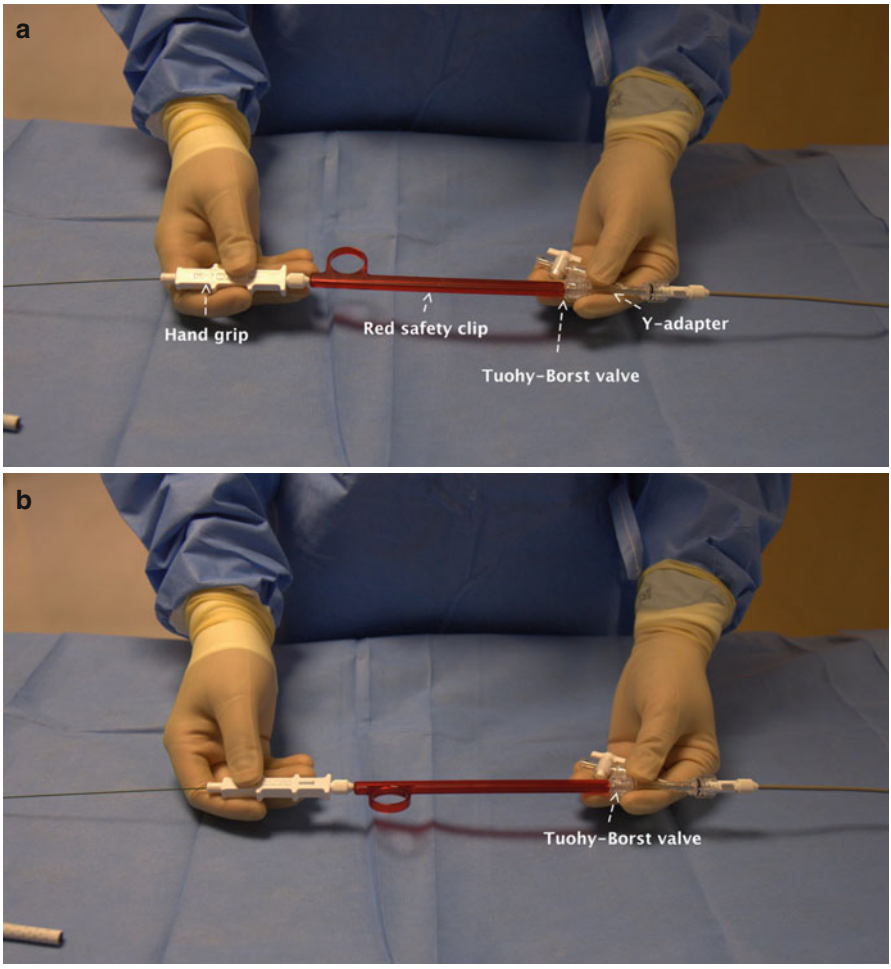
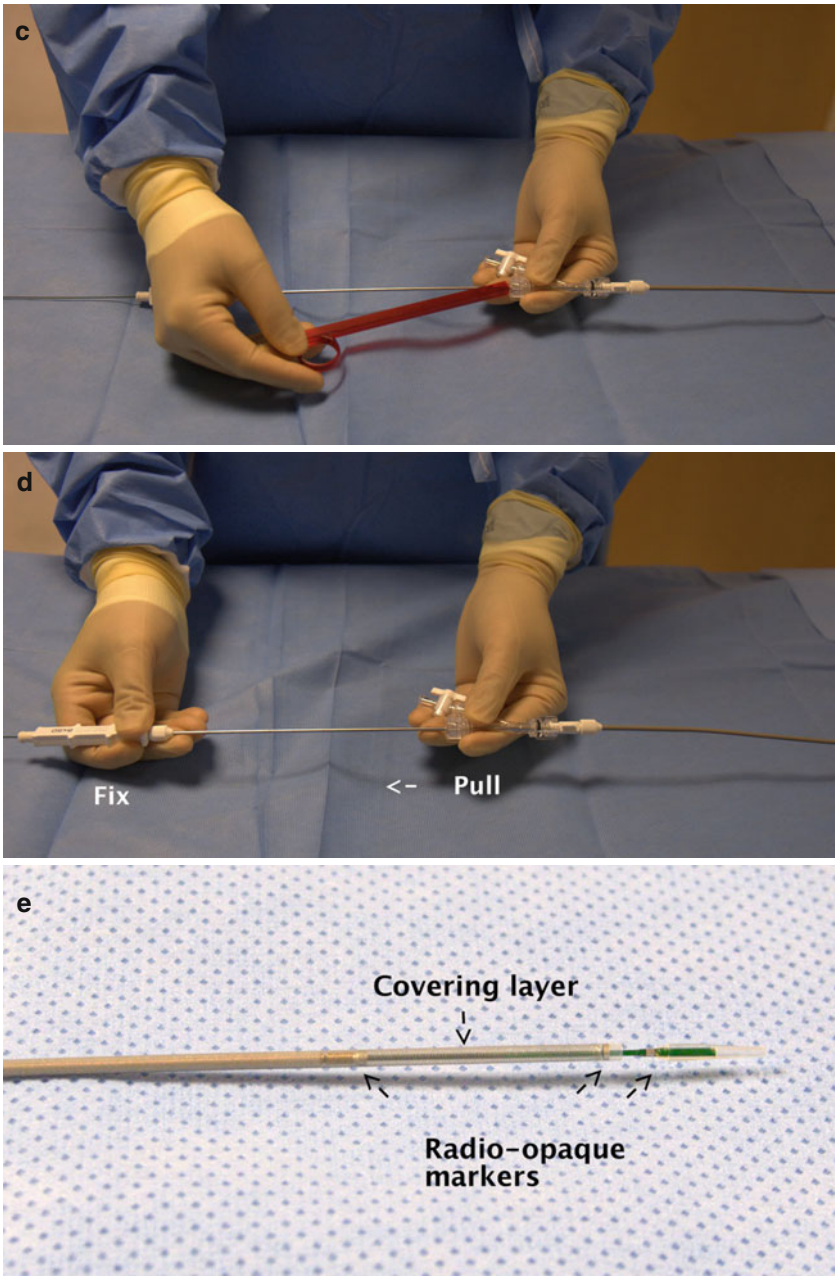


Fig. 12.1 (**a**) The delivery system for a covered stent is as shown above. (**b**) Once the stent is positioned over the site of stenosis, open the Tuohy-Borst valve to release the red safety clip. (**c**) Remove the red safety clip. (**d**) Fix the hand grip of the delivery system while pulling the Y connector towards it. (**e**) As the Y connector moves towards the hand grip, the covering layer over the stent is retracted to release the stent. Radio-opaque makers are present on the covering layer and shaft of the catheter to serve as a visual guide during the process. (**f**) Pull the Y connector towards the hand grip while keeping the entire system aligned in a straight line to allow precise placement of the stent. (**g**) The stent is fully deployed when the Y connector reaches the hand grip



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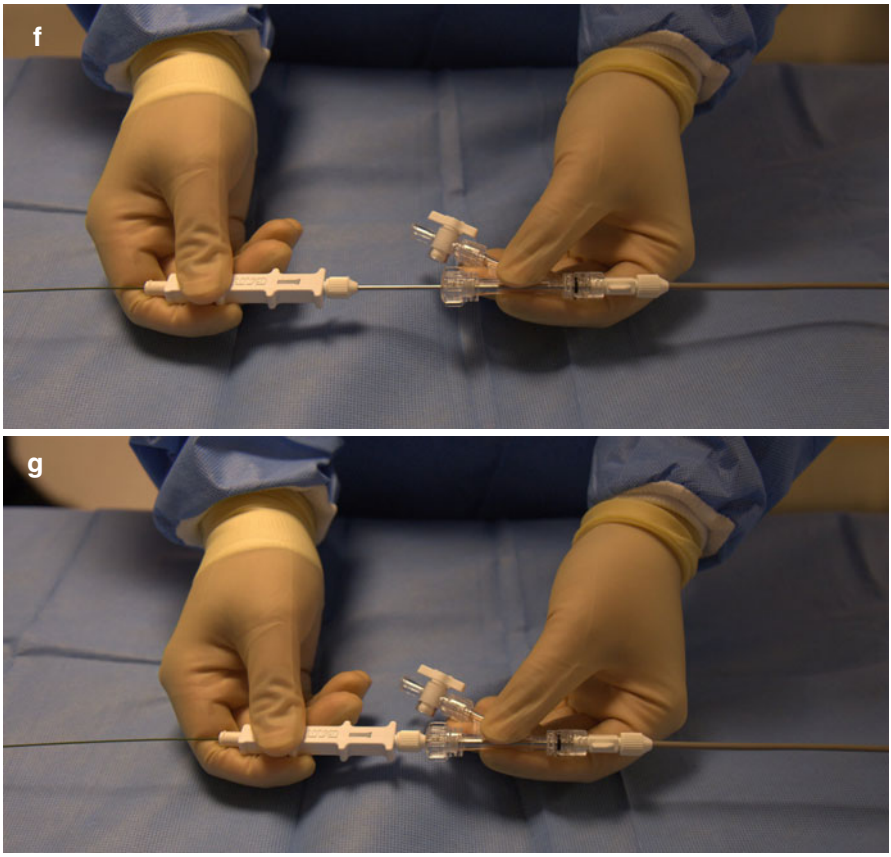

Fig. 12.1 (continued)

Therefore, it is important to have the guide wire tip in the inferior vena cava before stent deployment. In the event of stent embolism, the stent will end up in the inferior vena cava rather than the heart where it may trigger off life-threatening arrhythmias.

Depending on the location of the migrated stent, one can chose to remove it or place a larger stent within the migrated stent to "fix" it in place. If the stent gets lodged within the central veins, it would be advisable to remove it. To remove the stent, place a large sheath in the femoral vein, at least 1–2 Fr larger than the stent that you are trying to retrieve. Grab one end of the stent with a tulip snare or a biopsy forceps and pull it into the sheath. Remove the sheath together with the stent.

2. Malpositioning of stent

It is important to be precise during stent placement as salvage or repositioning can be a tedious process. Due to the direction of blood flow, the tenancy is for the

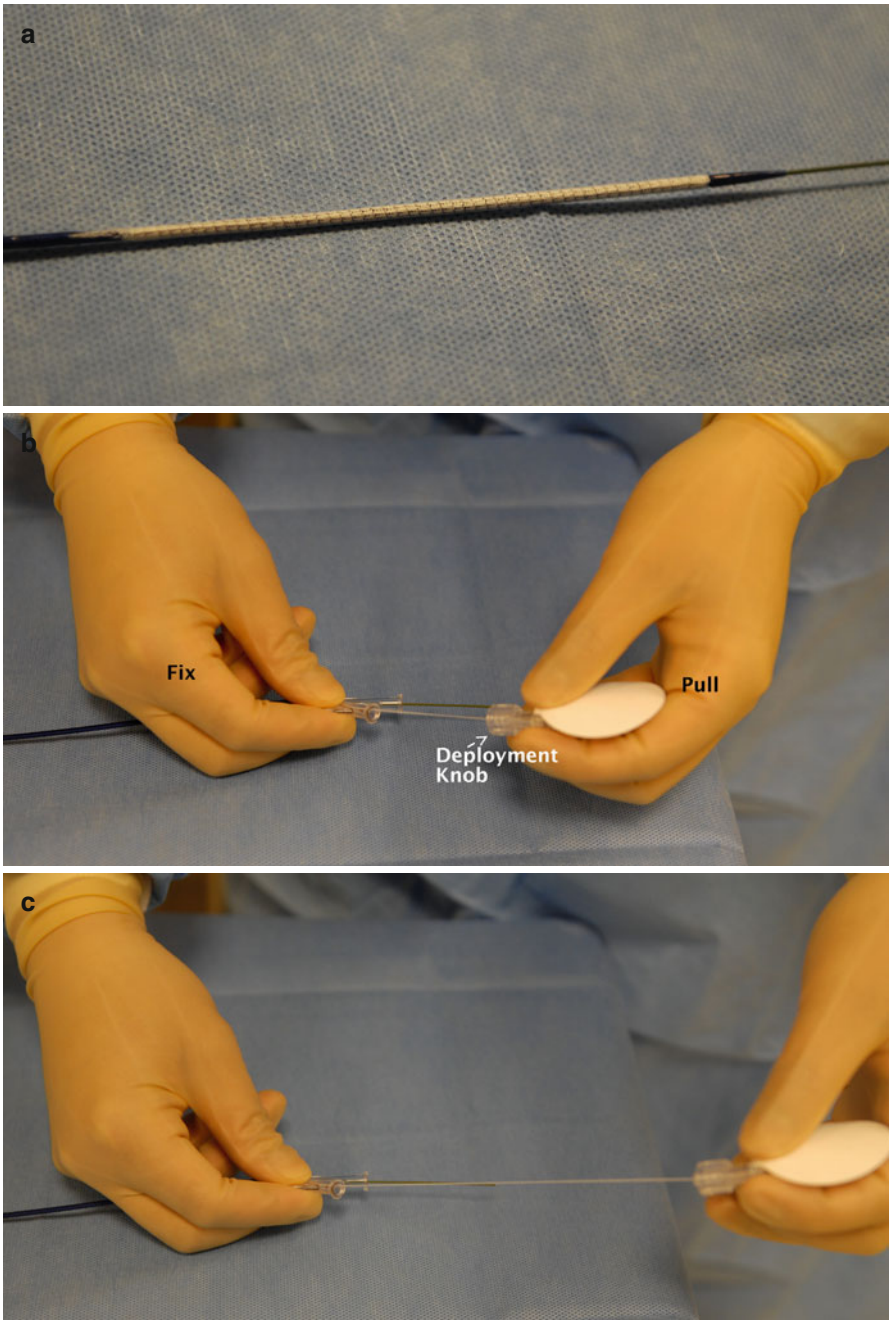

Fig. 12.2 (**a**) The stent is tightly crimped onto the shaft of the delivery catheter by a covering layer. Radio-opaque markers are present to mark the tip of the catheter and the position of the stent on the catheter. (**b**) The delivery system for the Viabahn stent consists of a Y shape hub assembly. Once the stent is positioned over the site of stenosis, unscrew the deployment knob. A release string is attached to the knob. Fix down the Y shape hub and pull the knob away from the hub. (**c**) Keep the Y shape hub fixed with one hand while pulling the deployment knob away from the hub assembly. (**d**) The deployment of the stent will occur from the tip of the delivery catheter towards the hub. (**e**) The entire stent is released when the string is fully unwound

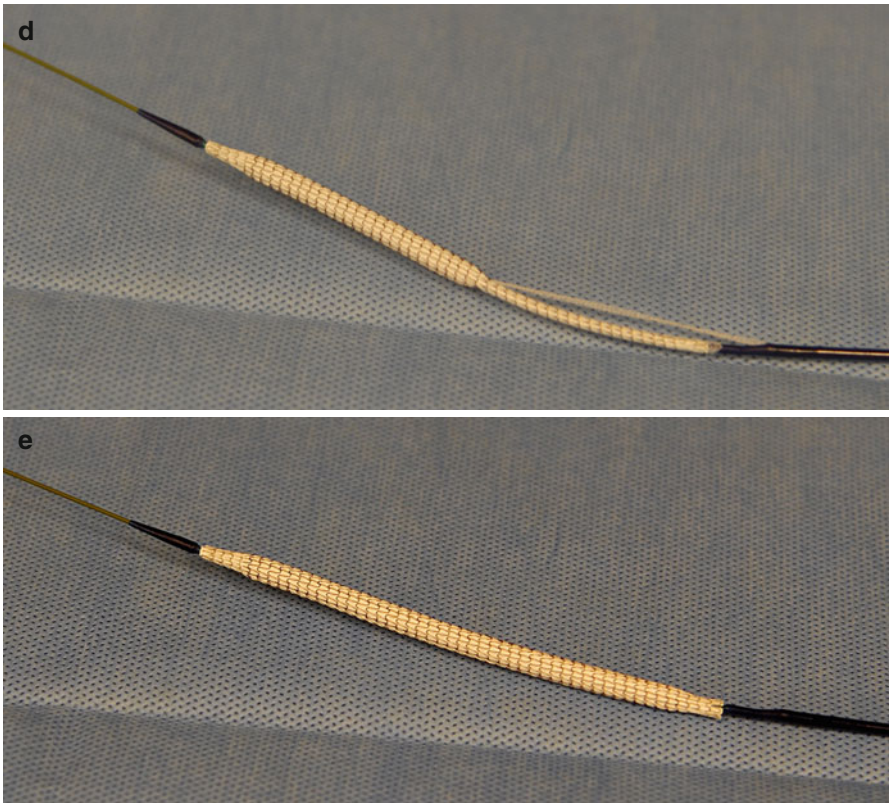

Fig. 12.2 (continued)

stent to be malpositioned distal to the lesion. If the distance between the malpositioned stent and the lesion is short, two strategies can be used:

(a) Inflate an angioplasty balloon (same size or 1 mm larger than the stent) within the stent to capture the stent. Pull the angioplasty balloon together with the stent towards the lesion and deflate the balloon to reposition the stent. This may not work if the self-expanding stent has fully expanded and is much larger than the proximal lesion.
(b) Place a longer stent to cover both the lesion and the malpositioned stent.

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Minimally Invasive Banding Procedure

13

Chieh Suai Tan, Stephan Wicky van Doyer, and Steven Wu

Introduction

The creation of a hemodialysis access is a non-physiological process that joins the high flow arterial circuit to the low-flow, low-resistance venous pathway. The systemic vascular resistance decreases immediately post anastomosis and the cardiac output increases to accommodate the shunting effect of the arteriovenous (AV) access. This creates the potential for a spectrum of problems, including high-output cardiac failure and vascular access-associated distal hypoperfusion ischemic syndrome (DHIS) or steal syndrome. High-output cardiac failure occurs when the cardiac function is unable to meet up with the demands created by the shunting effects of the AV access while DHIS results when the AV access diverts an excessive amount of blood away from the distal artery, resulting in tissue hypoperfusion.

Banding of the AV access is a procedure that is used to reduce the blood flow to the access by creating a high resistance band to restrict the flow of blood into

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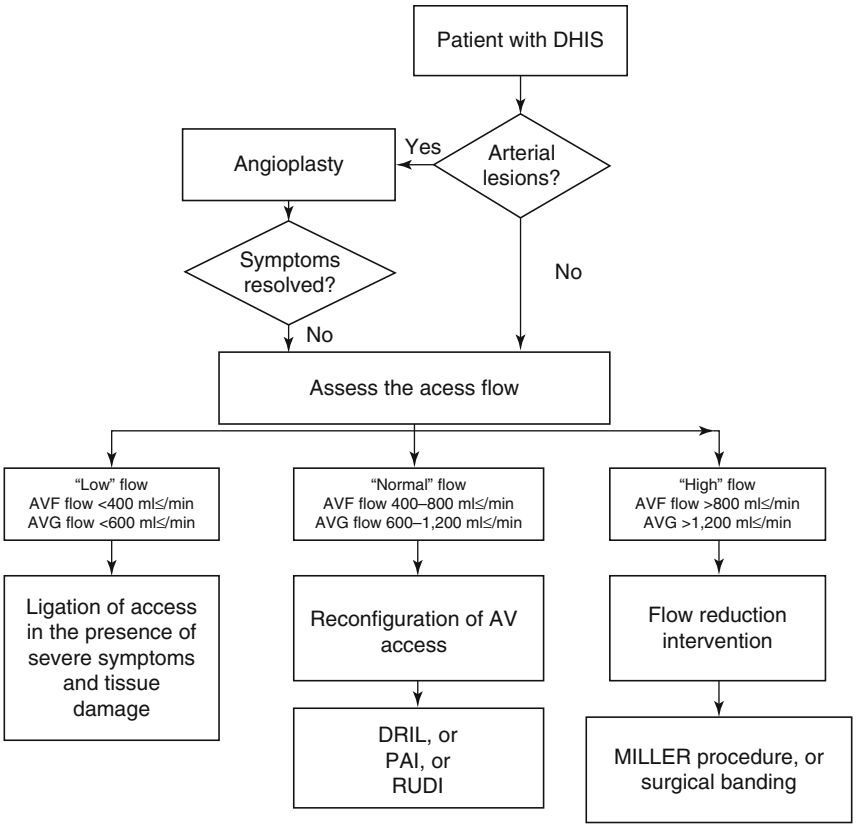


Fig. 13.1 Approach to patients with Distal Hypoperfusion Ischemic Syndrome (DHIS). *DRIL* Distal Revascularization and Interval Ligation, *PAI* proximalization of the arterial inflow, *RUDI* revision using distal inflow, *DRIL* PAI and RUDI are surgical procedures

the AV access. Specifically, the MILLER (Minimally Invasive Limited Ligation Endoluminal-Assisted Revision) banding procedure is a technique that can be used to reduce blood flow to the access with the aid of fluoroscopy and endovascular equipments. The indications for MILLER banding procedure are

1. Vascular access-associated distal hypoperfusion ischemic (DHIS) or steal syndrome. Before performing the MILLER procedure, it is crucial to exclude any arterial disease that may be causing the distal hypoperfusion or steal syndrome. The baseline blood flow rate of the access should also be measured. Banding is most suitable for AV access that has high flow. Banding a low or normal flow access that is causing steal syndrome will decrease the AV access flow rate further, resulting in access thrombosis or AV access flow rate that is too low for dialysis treatment. Such AV access should be ligated or revised. The algorithm for patients with DHIS is as shown in Fig. 13.1.
2. Vascular access causing high output cardiac failure

Equipments for MILLER Procedure

1. Lidocaine
2. 18G intravenous catheter
3. 6 Fr vascular sheath
4. 0.035 in. guidewire
5. Angioplasty balloon
6. Surgical blade
7. 2/0 Prolene suture
8. 3/0 Vicryl suture
9. Hemostat
10. Catheter-based thermodilution system to measure flow

Steps for MILLER Procedure

1. Clean and drape the patient. Cannulate the AV access in the retrograde direction with a 18G intravenous catheter at a reasonable distance from the AV anastomosis. Image the outflow and central veins to exclude the presence of any stenosis. Any significant stenosis within the outflow and central veins should be treated with balloon angioplasty before the MILLER banding procedure.
2. Image the inflow of the AV access by doing a "reflux" angiogram (Fig. 13.2a). This is done by injecting the contrast while compressing the outflow of the AV access.
3. Insert a 0.035-in. guidewire over the 18G intravenous catheter and exchange it for a 6 Fr vascular sheath. Make a flow measurement of the vascular access using the catheter-based thermodilution system.
4. Selection of the banding site. Palpate the vein adjacent to the arterial anastomosis site to find an area in which the banding site would be as close to the anastomosis as possible (1–3 cm) and superficial enough for dissection. Ultrasound may be used to determine the depth of the vein and the presence of adjacent vascular structure (Fig. 13.2b).
5. Do an angiogram to confirm the location of the arterial anastomosis and the banding site. Measure the diameter of the inflow artery and the vein at the banding site (Fig. 13.2c).
6. Make two 1 cm lateral incisions parallel to the vein at the banding site. Using a hemostat, create a tunnel under the vein between the two lateral incision sites by blunt dissection. Pull two strands of 2/0 Prolene through the tunnel that was created (Fig. 13.3a–e).
7. Create a second tunnel just below the skin but above the vein between the two lateral incisions. Pull the suture across the tunnel so that it is now looped circumferentially around the vein (Fig. 13.4a, b).

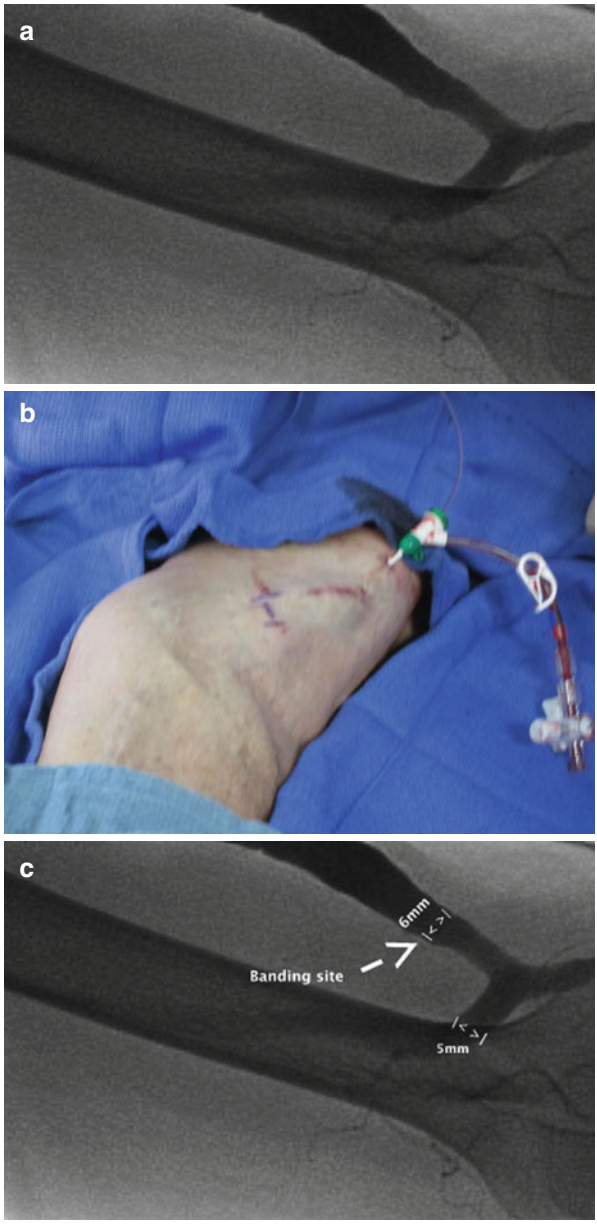


Fig. 13.2 (**a**) This patient has a high flow left brachiocephalic fistula. A reflux angiogram was done to visualize the inflow of the fistula. (**b**) After insertion of the vascular sheath, palpate and mark out the banding site. (**c**) Confirm the location of the banding site and measure the diameter of the inflow artery and the vein at the banding site

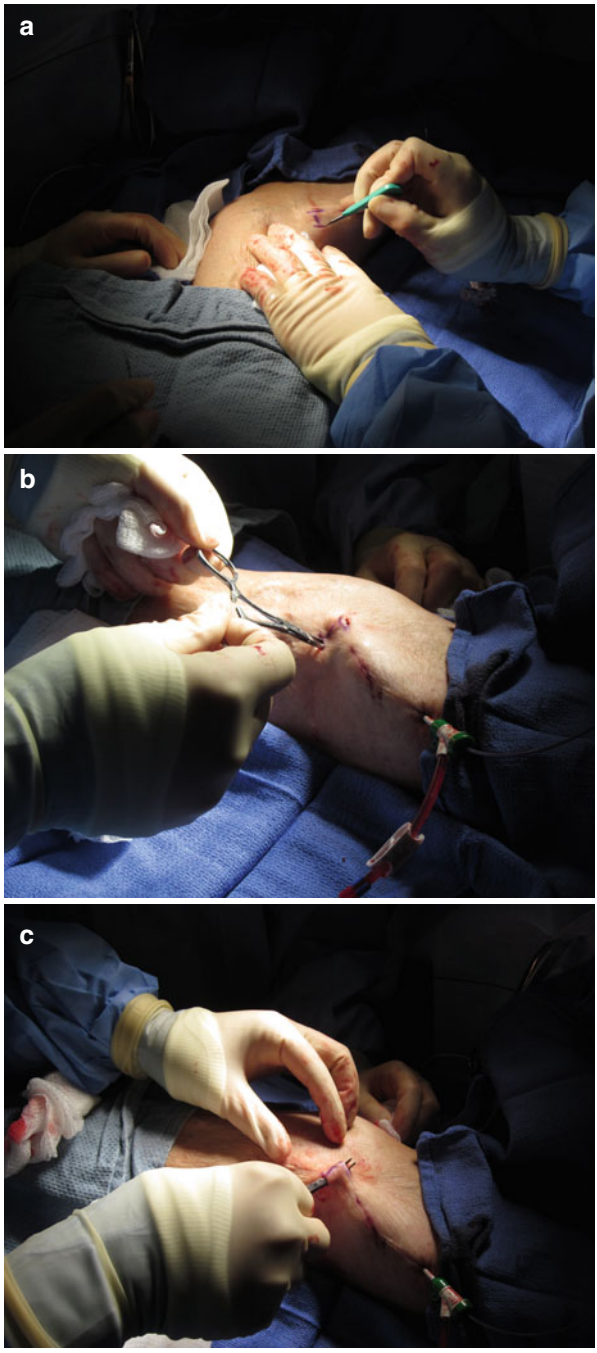
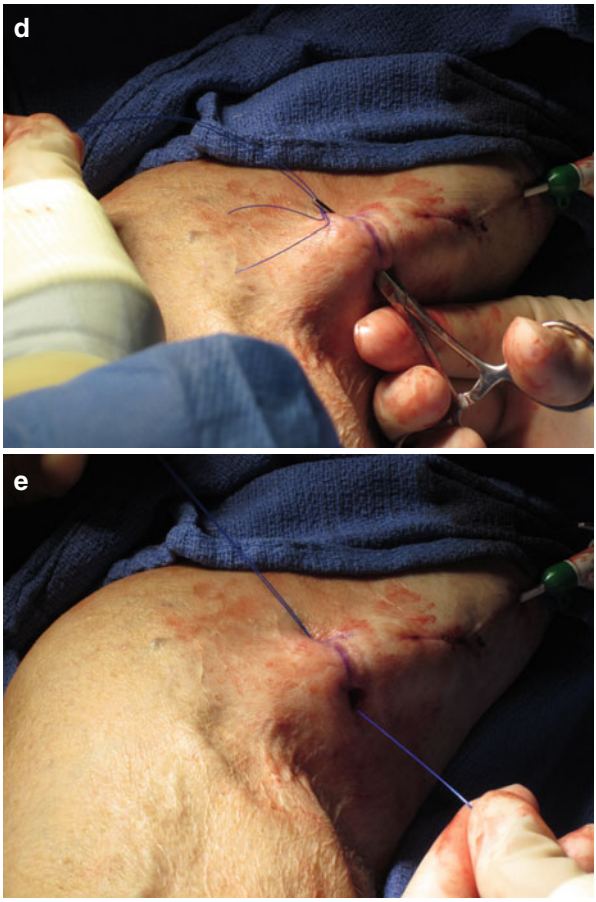


Fig. 13.3 (**a**) After administrating local anesthesia, make two incisions parallel to the vein at the banding site. (**b**) Enlarge the incision sites by blunt dissection. (**c**) Through the process of blunt dissection, create a tunnel beneath the vein between the two lateral incision sites. (**d**) Grab the ends of the prolene suture with the hemostat. (**e**) Pull the sutures into the tunnel beneath the vein

Fig. 13.3 (continued)



8. Pass the guidewire into the inflow artery. Inflate an angioplasty balloon over the banding site and tie the Prolene sutures over the inflated angioplasty balloon. The size of the angioplasty balloon to be used is dependent on the diameter of the inflow artery. In general, the size of the balloon used should be equal or smaller than the size of the artery. The typical balloon sizes are between 4 and 6 mm (Fig. 13.5a–c).
9. Once the ligature is secured, deflate the balloon and do an angiogram of the AV access to document the results. Make a flow measurement of the vascular access using the catheter-based thermodilution system to document the reduction in flow within the vascular access (Fig. 13.6a, b).
10. Palpate the AV access to ensure that flow is adequate for dialysis. In patients where banding is done for steal syndrome, check if the symptoms are better.
11. Close up the incision site with absorbable suture and remove the vascular sheath (Fig. 13.7a–e).

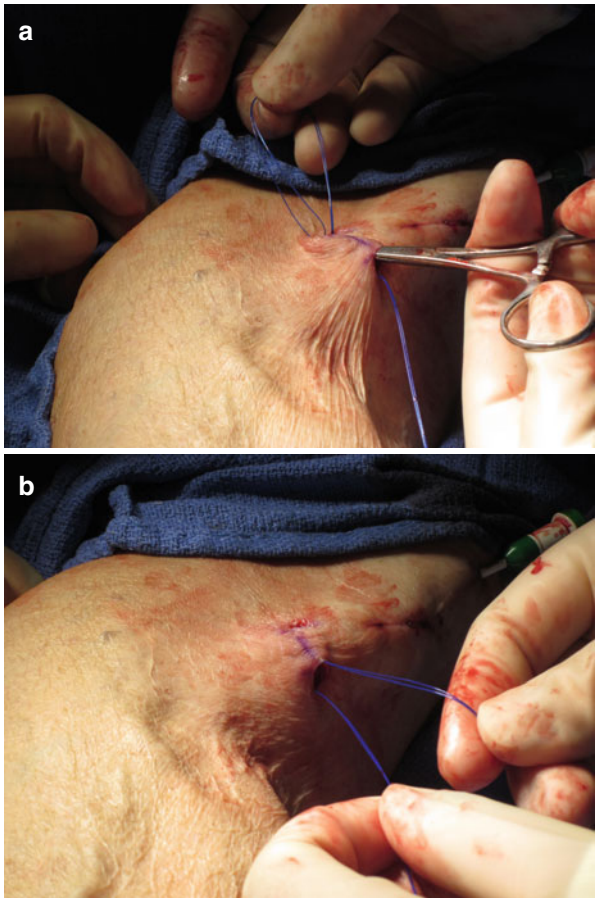


Fig. 13.4 (**a**) Create a second tunnel just below the skin but above the vein between the lateral incisions. (**b**) Pull the sutures across the superficial tunnel. The sutures are now looped circumferentially around the vein

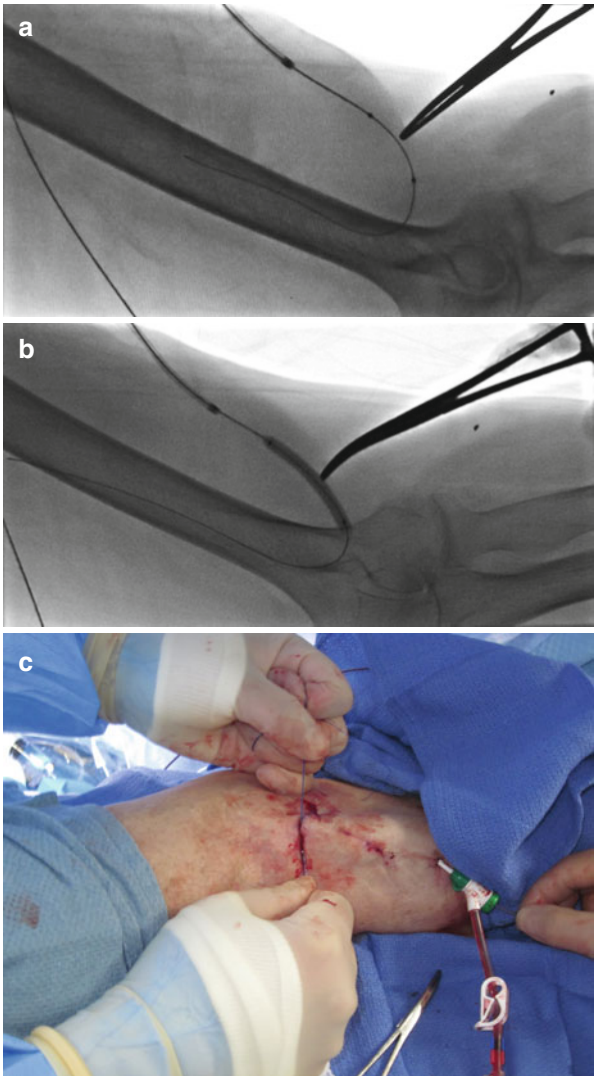


Fig. 13.5 (**a**) Position the angioplasty balloon over the banding site. (**b**) Inflate the angioplasty balloon over the banding site. (**c**) Tie the prolene sutures over the inflated angioplasty balloon. Hold the angioplasty balloon catheter while tying the suture

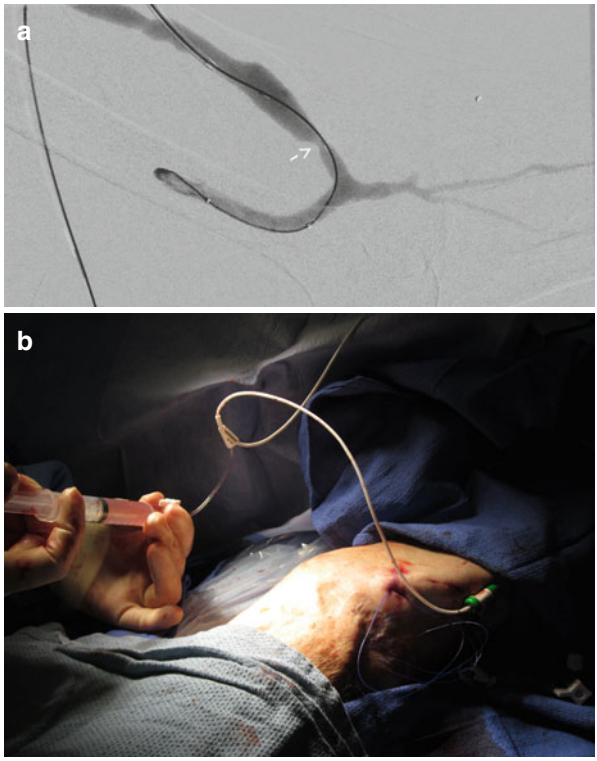


Fig. 13.6 (**a**) Post banding fistulogram showed the stenosis created by the prolene suture. (**b**) Blood flow rate of the fistula is measured using a thermodilution catheter after banding

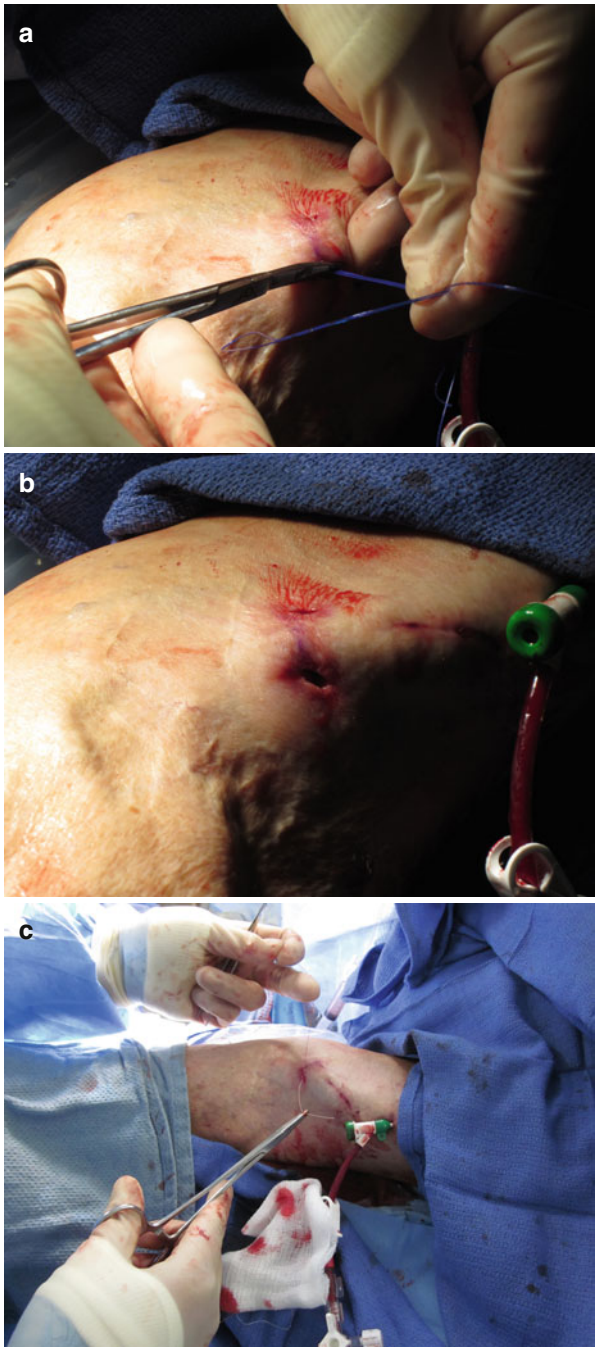
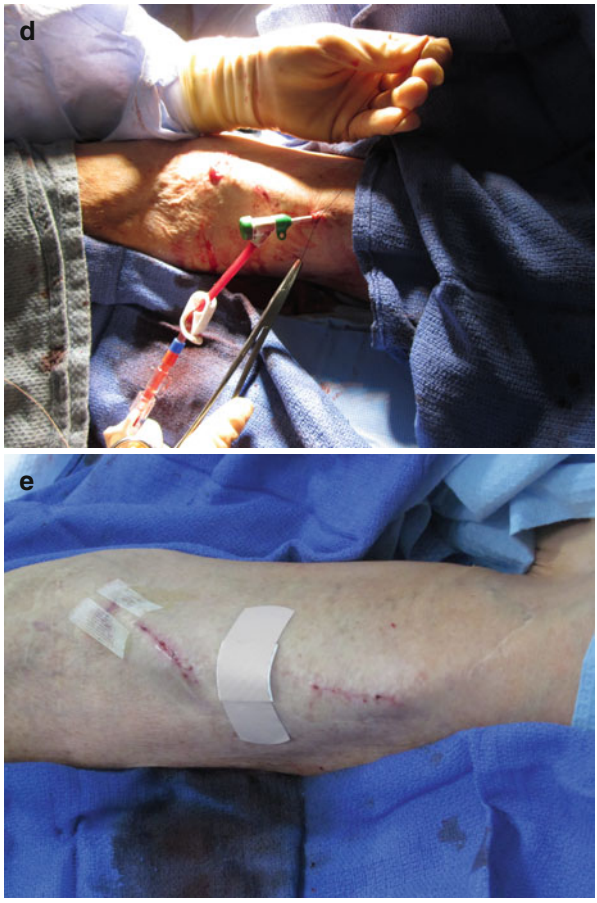


Fig. 13.7 (**a**) Cut the prolene suture and bury the ends within the subcutaneous tissue. (**b**) Appearance of the incision site after the procedure. (**c**) Close the incision sites with non absorbable sutures. (**d**) Remove the vascular sheath after placing a purse string suture around it. (**e**) Final appearance of the fistula after the banding procedure

Fig. 13.7 (continued)



Tips and Troubleshooting

1. Patient selection
   Patients with aneurysmal juxa-anastomotic junction may not be suitable for the banding as the area of blunt dissection to free the vein would be extensive. Surgical revision of the inflow may be a better option in such patients.
2. Banding site management
   The angioplasty balloon should be inflated at least to the rated burst pressure before tying the sutures around the banding site. Excessive forces should not be used when tightening the suture as the balloon might be indented by the sutures, resulting in over correction of banding procedure.
3. Poor flow within the AV access after banding.
   If the flow within the AV access is too low to be used for dialysis after banding (over correction), inflate a balloon with a diameter that is 1 mm larger than the one that is used to stretch the band.
4. Persistent symptoms despite banding
   If the flow is still elevated post banding, a repeat procedure with a second ligature may be attempted. A balloon with a diameter 1 mm less than that of the balloon used for the first banding procedure should be used for the second attempt. If the flow after banding is low but the patient is still having persistent syndrome, ligation of the fistula should be considered.

Peripheral Arterial Disease in Hemodialysis Access

14

Kanwar Singh, Matthew E. Anderson, Anil Kumar Pillai, and Sanjeeva P. Kalva

Introduction

Peripheral artery disease (PAD) is a major health concern and its incidence increases with age. End stage renal disease is a major risk factor for developing PAD and is associated with a remarkably high incidence of cardiovascular morbidity and mortality [1]. In patients with end stage renal disease (ESRD), the estimated prevalence of PAD ranges between 17 and 48 % [2, 3]. Data on the prevalence of clinically significant upper extremity PAD are scarce, however, a 10–20 fold lower incidence may be appreciated compared to that affecting the lower extremity [4].

Hemodialysis is the major renal replacement technique used in the United States. Per the 2009 statistics published by the National Kidney and Urological disease information clearinghouse, 94 % of patients on dialysis in the United States are on hemodialysis [4]. The hemodialysis accesses are of three types, arteriovenous fistulas (AVF), arteriovenous grafts (AVG) and hemodialysis catheters. AVF is considered the gold standard for access based on its superior patency and low complication rate [5].

Per the Dialysis outcome and practice pattern study (DOPPS) practice monitor (accessed May 2014), 60 % of the hemodialysis in the US occurs via a native arteriovenous fistula, where as 20 % use synthetic arteriovenous grafts [5]. Irrespective of the type of vascular access, a robust inflow to maintain the circuit and also perfuse the upper extremity is essential for access patency and limb perfusion. Even in the best-case scenario of having an AVF, there is a 30 % abandonment rate

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after 1 year [6]. The most common cause of failure for AVF is perianastomotic stenosis compromising the arterial inflow [7]. The other major problem with compromised arterial inflow is dialysis access associated steal syndrome (DASS), which occurs in 3.7–5 % of dialysis patients [8]. Thus, the focus of the current chapter is on arterial inflow disease affecting patients on hemodialysis.

Normal and Variant Anatomy

The upper extremities derive their blood supply form the aorta via the subclavian arteries. On the right side the subclavian artery arises from the brachiocephalic artery where as the left subclavian artery originates directly off of the aortic arch. The subclavian artery continues as the axillary after crossing the lateral

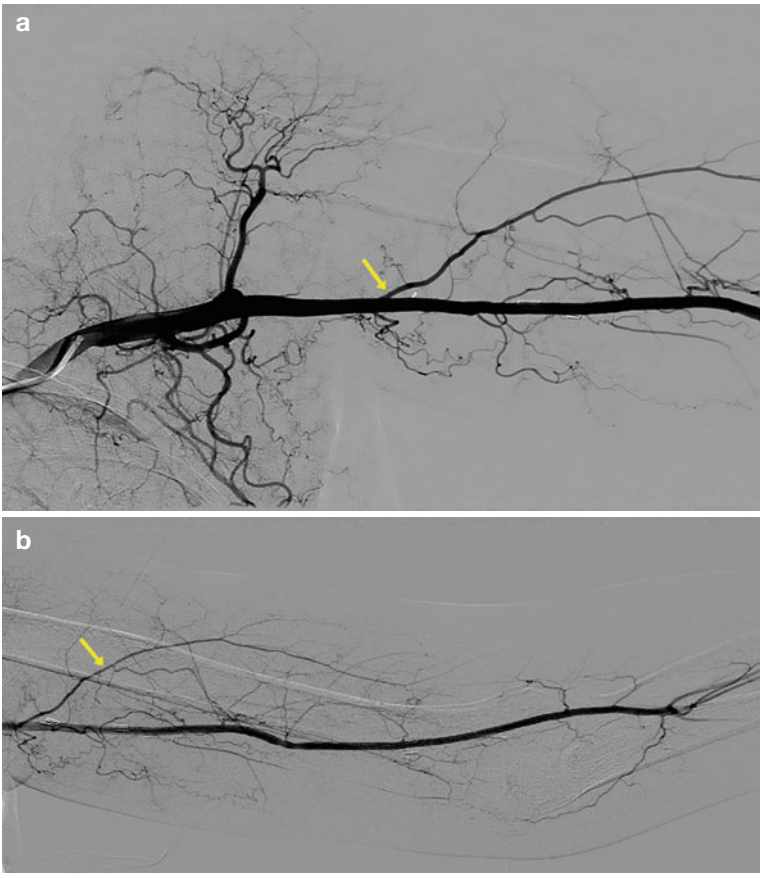

Fig. 14.1 (**a**) Digital subtraction angiogram of the left upper extremity demonstrates the origin of the deep brachial artery (*arrow*). (**b**) Digital subtraction angiogram of the left upper extremity delineates the course of the deep brachial artery (*arrow*)

margin of the first rib. The axillary artery supplies branches to the shoulder girdle and lateral chest wall and subsequently continues as the brachial artery beyond the inferior lateral margins of the teres minor muscle. The brachial artery gives rise to the deep brachial artery and additional branches around the elbow (Fig. 14.1a, b).

In the cubital fossa, the brachial artery divides into the radial and ulnar arteries. The radial recurrent artery and the anterior and posterior ulnar recurrent arteries arise immediately beyond the origin of their respective arteries to anastomose with the branches of the brachial and deep brachial arteries around the elbow. The radial artery courses along the radial aspect of the forearm to the wrist, traverses the anatomical snuff box, and gives rise to the deep palmar arch. The ulnar artery courses along the ulnar aspect of the forearm and continues as the superficial palmar arch. The common interosseous artery arises from the ulnar artery and gives rise to the anterior and posterior interosseous arteries. The terminal branches of these arteries anastomose with branches of the radial and ulnar arteries to form the dorsal and volar carpal arches. The two carpal and two palmar arches form a rich collateral pathway between the radial and ulnar arteries.

A high origin of the radial artery from the axillary artery (2.7–5 %) or the upper brachial artery (5.9–12.1 %) is an important anatomical [9] (Fig. 14.2a, b). A high origin

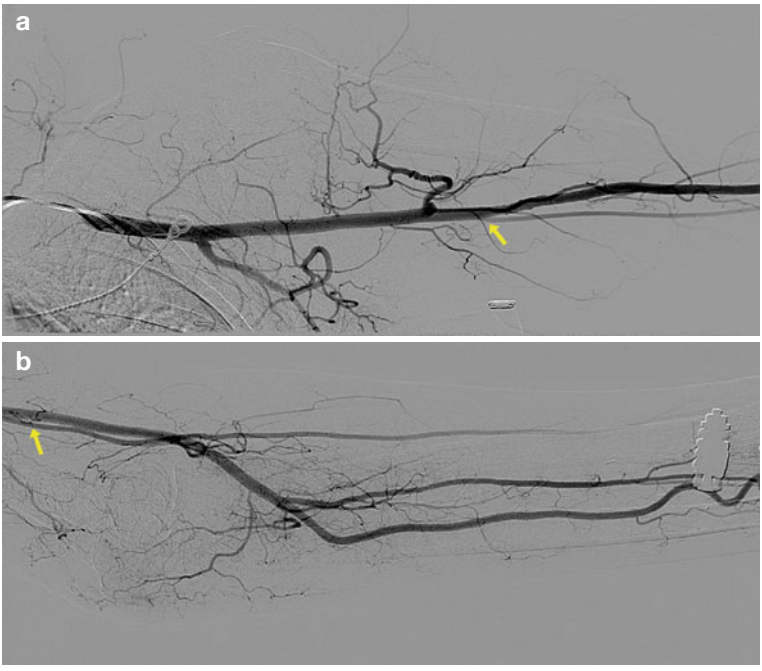

Fig. 14.2 (**a**) Digital subtraction angiogram of the left upper extremity demonstrates high origin of the radial artery (*arrow*). (**b**) Digital subtraction angiogram of the left upper extremity demonstrating the course of the radial artery with high origin in the forearm (*arrow*)

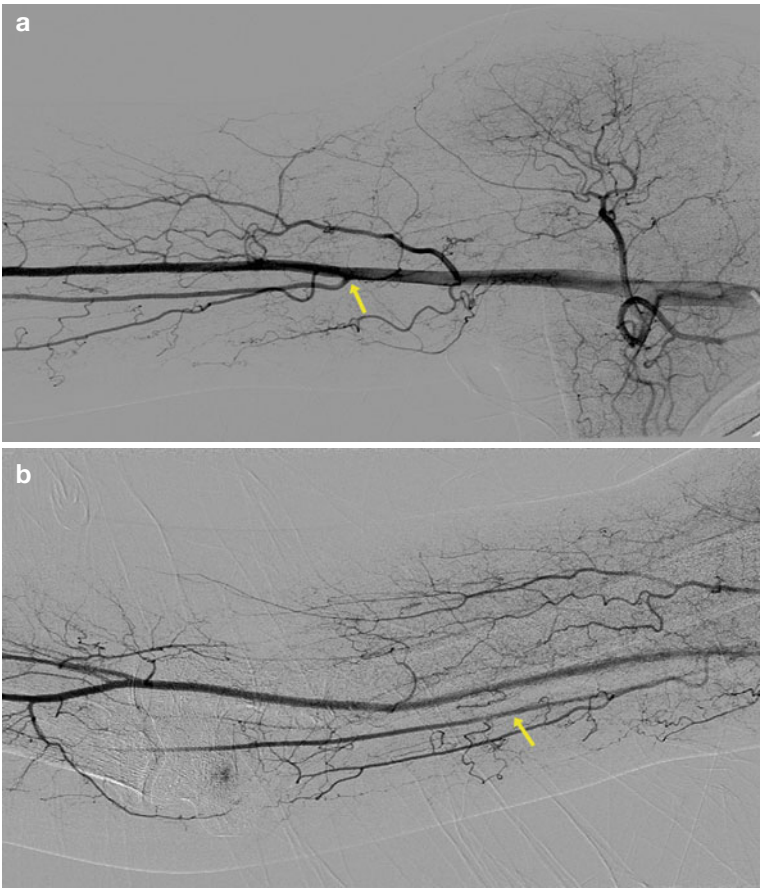

Fig. 14.3 (**a**) Digital subtraction angiogram of the right upper extremity demonstrating high origin of the ulnar artery (*arrow*). (**b**) Digital subtraction angiogram of the right upper extremity demonstrating high origin of the ulnar artery (*arrow*) as it courses into the forearm. Note the origin of the radial and interosseous arteries in the cubital fossa

of the ulnar artery is much less common (0.17–2.0 %) [9] (Fig. 14.3a, b). Duplication of the brachial artery and hypoplasia or aplasias of the radial/ulnar arteries are rare variants. A persistent median artery results from lack of regression of the embryonic median branch arising from the common interosseous artery and is found in 2–4 % of the population [10].

Pathophysiology

Creation of an arteriovenous (AV) shunt causes a significant local and systemic change to the blood flow. There is bypassing of the resistance vessels in the distal extremity and creation of a parallel fixed low resistance return pathway to the heart. As the volume flow within the fistula increases there is diminished perfusion of the

tissues distal to the fistula. To compensate for this loss of tissue perfusion, there is arterial vasodilatation. Mean arterial blood flow in the brachial artery at rest is around 50 ml/min, whereas the mean blood flow in the radial artery at rest is 25 ml/min [11]. To achieve dialysis compatible flow (which averages 500 ml/min) the blood flow in the artery must increase 10–20 fold. Poiseuille's Law states that the volume of a homogenous fluid passing per unit time (flow) through a capillary tube is directly proportional to the pressure difference between its ends and to the fourth power of its internal radius and inversely proportional to its length and the viscosity of the fluid. Thus if the blood flow is steady and the viscosity and pressure gradient down the artery are constant, then the brachial artery needs to dilate approximately 80 % to achieve a tenfold increase in flow [11].

In reality this is not the case, the pressure gradient changes pre and post creation of the AV fistula. A "steal phenomenon" occurs due to the change in pressure gradient. The term "steal" refers to the phenomenon that occurs when there is a connection between two vascular beds. The difference in resistance causes arterial blood to be diverted from the higher resistance vascular circuit to the lower resistance vascular circuit. In the case of dialysis vascular access, the two vascular beds are the extremity distal to the AV access and the AV access itself. This results in retrograde flow in the artery distal to the anastomosis [12] (Fig. 14.4a, b). Blood flow assessment reports in the AVF with steal phenomenon have shown that the blood flow in the AVF actually exceeds that of the feeding artery by 15–20 % due to retrograde contribution [13, 14]. The steal phenomenon is a physiological response to resistance differences and occurs in the majority of patients with AV access. By itself, steal phenomenon, does not lead to hand ischemia or dialysis access dysfunction.

Substantial arterial dilatation is still required to achieve good dialysis flow. There is evidence that this arterial vasodilatation is mediated by nitric oxide release from the endothelial cells in response to wall shear stress. In experimental studies of fistula maturation there is evidence of fragmentation of the arterial internal elastic lamina in order to facilitate vasodilatation. The vasodilatation is mediated by metalloproteases, which are activated by nitric oxide [11, 15]. The arterial diameter continues to increase as long as the sheer stress persists, which may take up to 1 year.

Any condition that prevents arterial remodeling leads to poor flow through the shunt. For example, poor collateralization distal to the AV access site can result in tissue ischemia, which is further accentuated by the steal phenomenon.

Risk Factors

Recognizing the risk factors at the time of access planning is critical for successful creation of a durable AV access. Major predisposing risk factors which will limit the inflow include female sex (OR 2.77), age > 60 years (OR 1.03), diabetes (OR 6.04) peripheral artery disease (OR 2.70) and the use of brachial artery as the inflow (OR 8.42) [16]. These conditions could be focal or diffuse. Focal stenosis in the inflow circuit can occur anywhere in the aorta, subclavian (Fig. 14.5a, b), axillary, brachial (Fig. 14.6a, b) and radial arteries (Fig. 14.7a, b) or at the arterial anastomosis. Diffuse vessel wall calcification leads to limited ability of the artery to dilate.

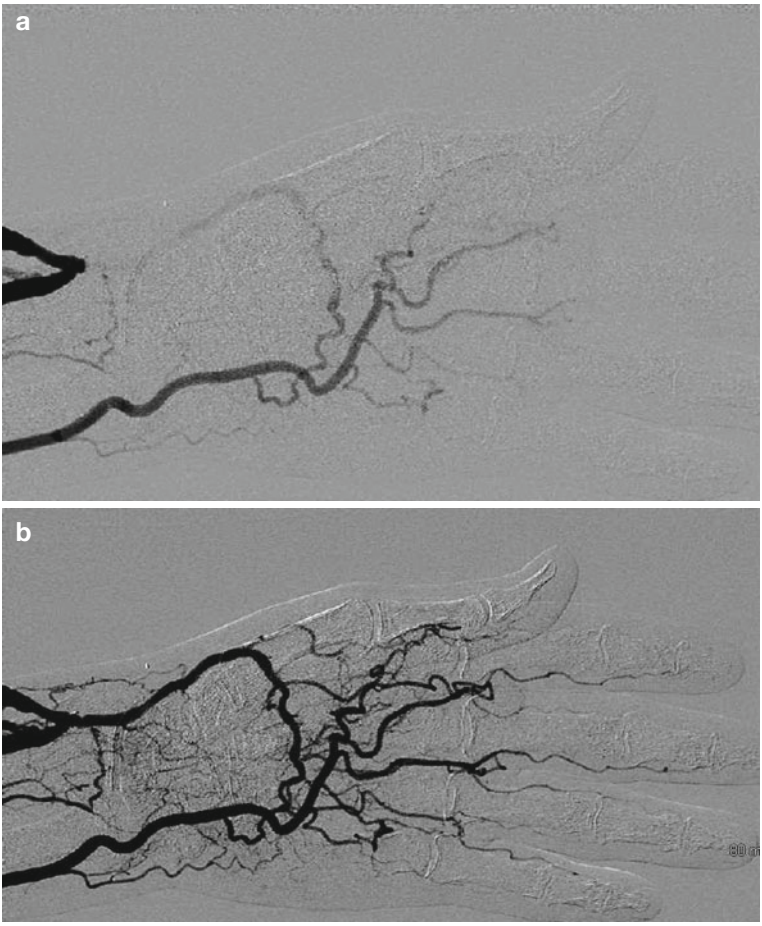

Fig. 14.4 (**a**) Digital subtraction angiogram of the right upper extremity demonstrating flow into a dominant ulnar artery downstream from an upper extremity dialysis access. (**b**) Digital subtraction angiogram of the right upper extremity in a more delayed frame demonstrating retrograde flow into the radial artery distal to the anastomosis, consistent with steal phenomenon.

Signs and Symptoms

Clinical presentations vary based on the site of stenosis. In general, AV access dysfunction/non-maturation occurs due to juxta anastomotic disease (JXA). More proximal arterial inflow disease presents with dialysis access associated steal syndrome (DASS) and/or ischemic monomelic neuropathy (IMN).

JXA presents with early fistula failure (within 3 months) or access dysfunction. This specific type of stenosis has a typical appearance; the lesion occurs in the segment of the vein that is immediately adjacent the anastomosis (Fig. 14.8).

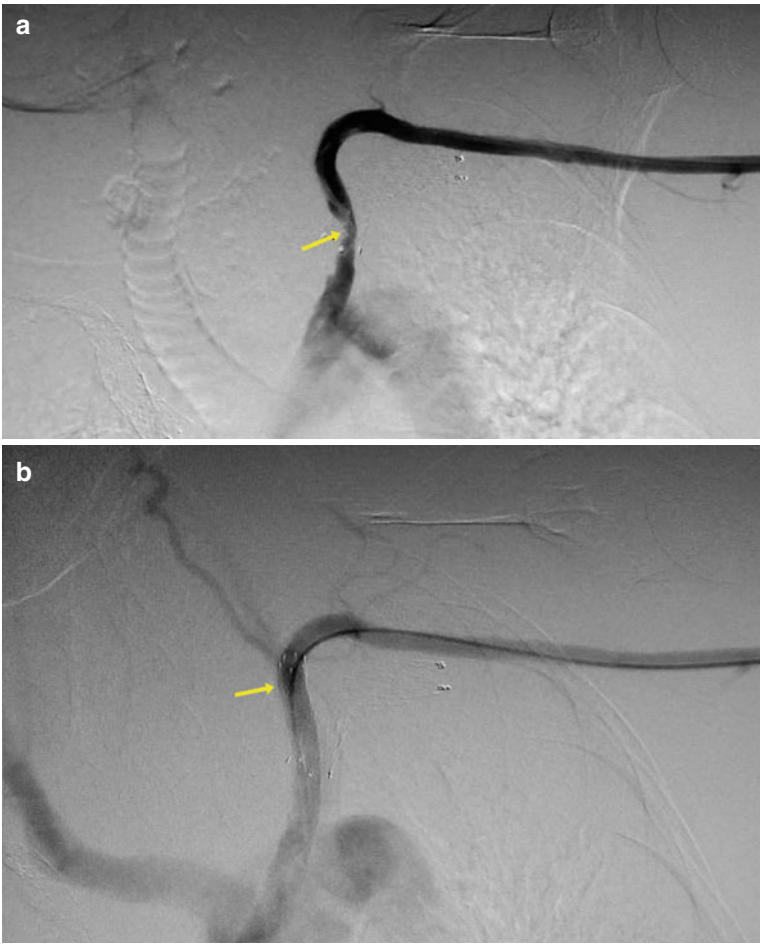

Fig. 14.5 (**a**) Digital subtraction angiogram of the subclavian artery demonstrates focal stenosis (*arrow*). The vertebral artery is not opacified. (**b**) Digital subtraction angiogram of the subclavian artery after stent (*arrow*) placement. There is resolution of the subclavian stenosis and flow in the vertebral artery

The etiology of this phenomenon is unclear. It is thought to be due to trauma during surgical manipulation resulting in ischemic injury to the vasa venosum supplying the vein [17]. Clinical examination will reveal a very accentuated pulse at the arterial anastomosis with a water-hammer character. As one moves up the vein from the anastomosis the pulse goes away abruptly at the site of stenosis. Above this level, the pulse is very weak and the vein is poorly developed [18].

DASS results from arterial insufficiency distal to the AV access site (Fig. 14.9a, b). The incidence of hand ischemia after placement of a hemodialysis shunt is 5 %

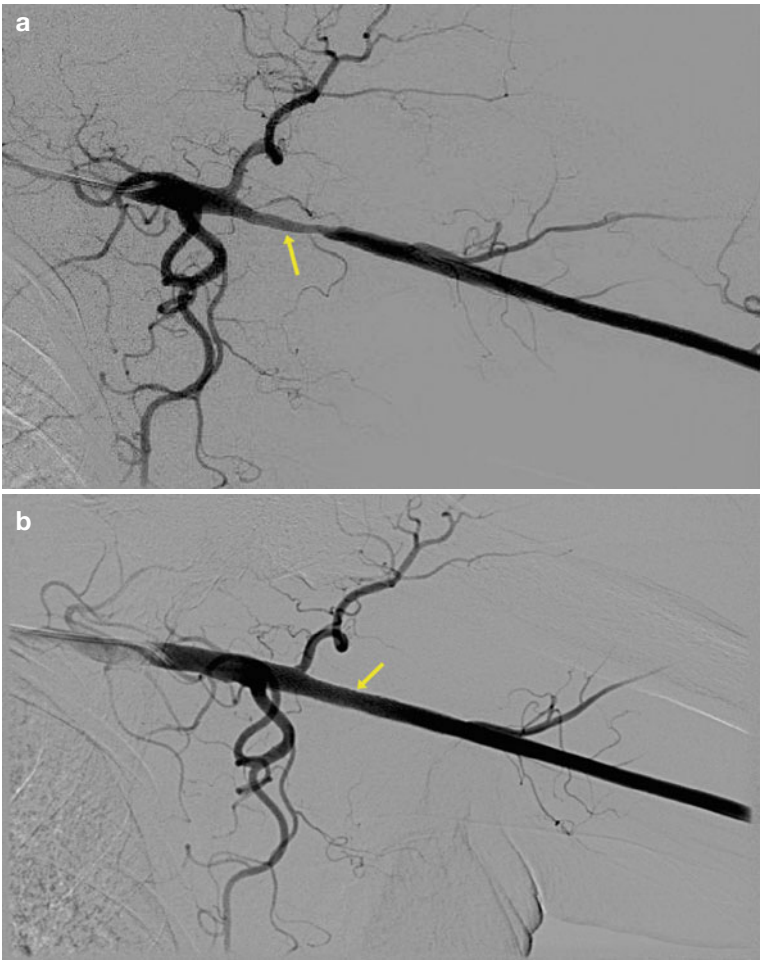

Fig. 14.6 (**a**) Digital subtraction angiogram demonstrates focal stenosis (*arrow*) in the brachial artery. (**b**) Digital subtraction angiogram demonstrates resolution of stenosis after angioplasty and stent (*arrow*) placement

[19]. Clinical features of DASS have been classified into four classes akin to the Rutherford classification for lower limb ischemia [20, 21]. These are as follows:

Stage I: No clinical symptoms, discrete signs of mild ischemia are present. Hand may be cold compared to the opposite side. Numbness, paresthesia, absent or diminished pulses may be noted. Management is conservative.

Stage II: Divided into two categories based on whether the symptoms are tolerable (IIa) or not tolerable (IIb). The pain is not present at rest and is brought on only during dialysis or exercise. Stage IIb usually requires invasive therapy.

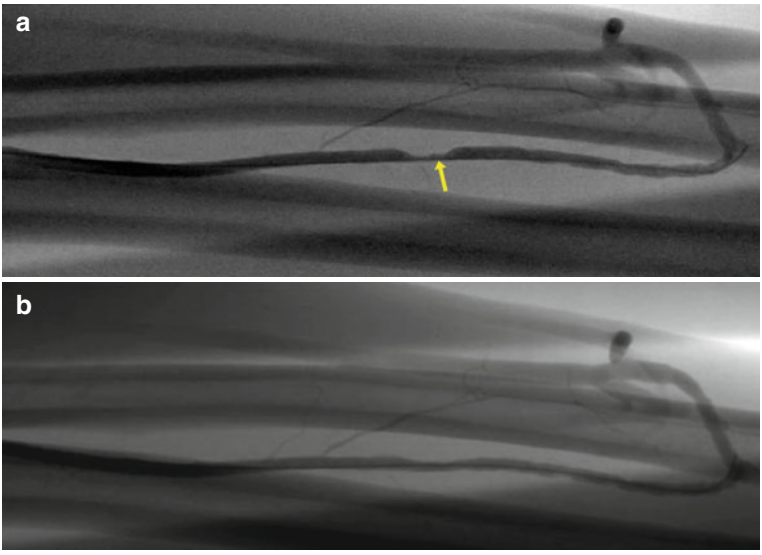

Fig. 14.7 (**a**) Digital angiogram demonstrates a left upper extremity radio-cephalic fistula with severe stenosis (*arrow*) of the radial artery. (**b**) Digital angiogram demonstrates resolution of radial artery stenosis following successful angioplasty with a 3 mm balloon

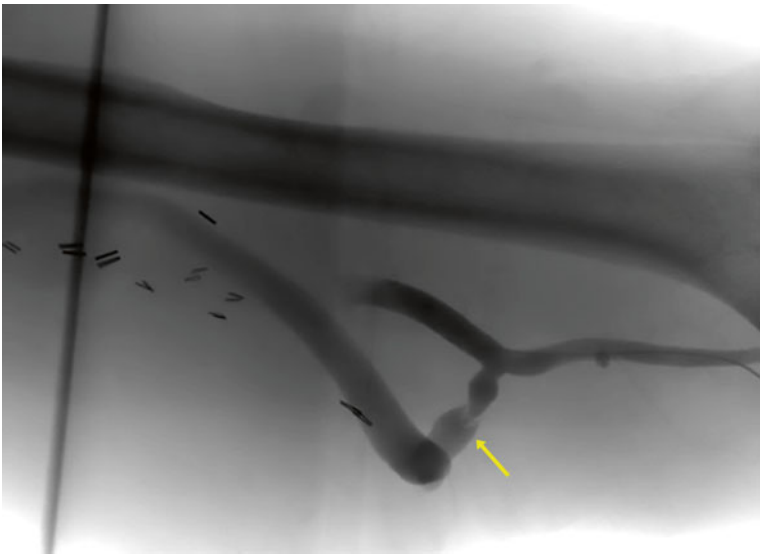

Fig. 14.8 Digital angiogram demonstrates a brachial artery to basilica vein fistula with venous stenosis (*arrow*) approximately 1 cm distal to the arterial anastomosis

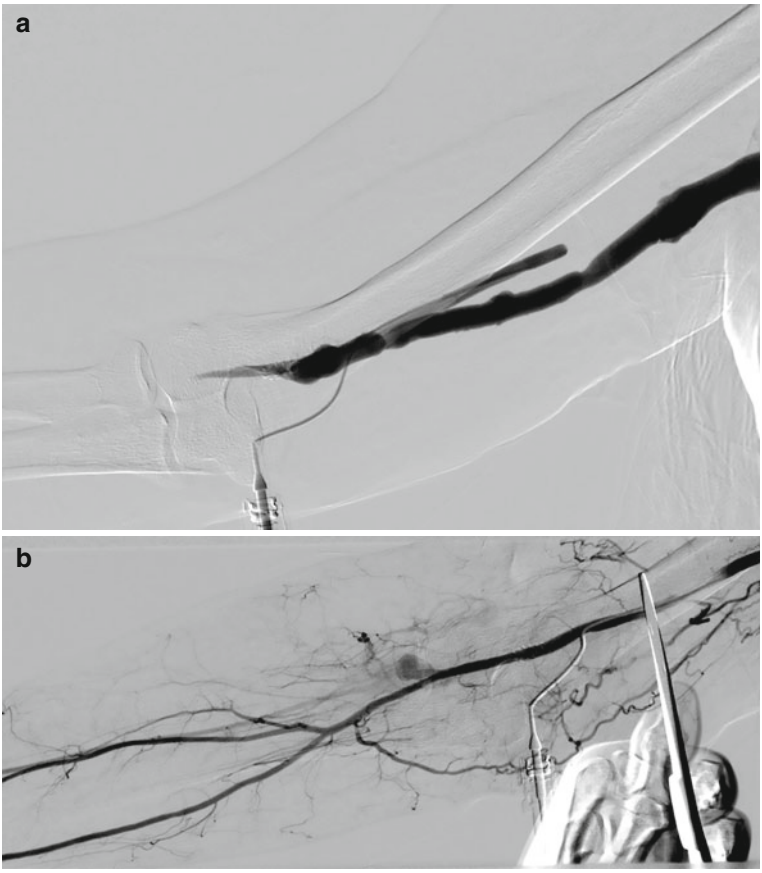

Fig. 14.9 (**a**) Digital subtraction angiogram demonstrates a right upper extremity brachiobasilic fistula with decreased flow downstream to the fistula in a patient with clinical symptoms of ischemia consistent with steal syndrome. (**b**) Digital subtraction arteriogram in the same patient demonstrates increased downstream arterial flow after manual compression of the venous outflow of the fistula

Stage III: Pain at rest and/or loss of motor functions; urgent invasive therapy is recommended.

Stage IV: Presence of tissue loss. This stage is further classified into reversible (IVa) and irreversible (IVb). Both require urgent intervention. In the former any intervention to improve blood flow should be undertaken. In the latter, significant loss of function may require more invasive measures such as amputation.

Ischemic monomelic neuropathy is caused by focal ischemic axonal nerve injury involving the sensory and motor branches in the distal portions of the affected limb, usually occurring in diabetic hemodialysis patients. Signs of DASS may be entirely absent [22]. Typically IMN involves the three nerves of the upper limb and occurs immediately after creation of the access. Management is mainly symptomatic.

Diagnosis

An arterial stenosis is defined as 50 % or greater decrease in lumen diameter as compared with an adjacent normal appearing artery [23]. Inflow stenosis can occur anywhere from the ascending aorta to the AV anastomosis [24]. In the setting of an AVF, stenosis that develops up to 4 cm from the anastomosis is termed a JXA [25]. Imaging studies that are commonly used to evaluate AV access inflow vessels include Doppler ultrasound, CT/MR angiography and conventional angiography.

Doppler ultrasound is performed using 5–7.5 mHz linear array probes. Transverse and longitudinal B-mode and color flow images are obtained along the arterial inflow from the subclavian artery, the arterial anastomosis, and into the JXA segment (Fig. 14.10a, b). The artery is thick walled, less compressible, deeply situated and has long straight segments with similar diameter. Waveforms are recorded from a small sampling volume placed in the central flow stream at attempted angles of 60° relative to the vessel walls. Based on the velocity of flow and vessel diameter, the flow is calculated electronically. Unfortunately, there is no general agreement on the objective diagnostic criteria for hemodynamically significant access stenosis. A proposed criterion for diagnosis of arterial stenosis include [26]:

- Arterial luminal narrowing of ≥50 % on the B-mode scan
- >2-fold increase in peak systolic velocity at the site of stenosis compared to normal appearing proximal arterial segment
- plus one of the following additional criterion:
  - Flow reduction by 20 % during dialysis
  - Flow <600 ml/min during dialysis
  - Residual luminal diameter of <2 mm on B-mode scan

Brachial artery resistive indices have shown to correlate with graft dysfunction [27]. In DASS, the blood flow distal to the arterial anastomosis may be reversed or bidirectional [28]. Digital blood pressure evaluation using both blood pressure (DBP) and digit brachial index (DBI: ratio of the DBP to contralateral brachial blood pressure) has been used to evaluate patients with DASS. Normal DBI varies between 0.8 and 1.1. A DBI below 0.4 and a DBP of less than 60 mmHg is considered indicative of DASS [29]. The accuracy of a DBP of below 60 mmHg for determining hand ischemia was 92 % (sensitivity 100 %, specificity 87 %) compared with 94 % for DBI of less than 0.4 (sensitivity 92 %, specificity 96 %) [12].

The role of CTA/MRA in the diagnosis of arterial inflow has been studied and proven to be superior to doppler ultrasound [30]. However, due to the expense associated with these tests and the fear of nephrogenic systemic sclerosis with MRA, these tests are utilized only in problem solving situations.

Angiographic evaluation is the gold standard for arterial inflow evaluation. Angiographic evaluation should be performed for the entire arterial inflow from the aortic arch to the outflow veins. The key is to distinguish physiological steal and an obstructing lesion, such as stenosis or occlusion, in the feeding artery causing the

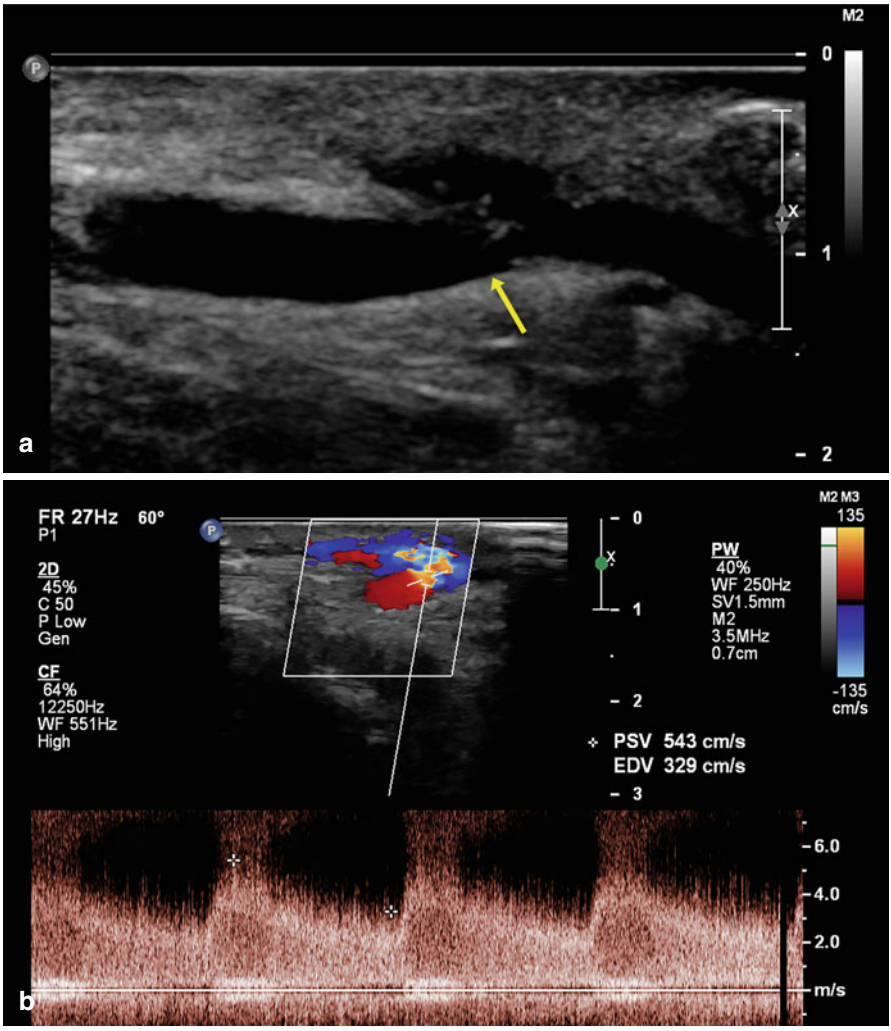

Fig. 14.10 (**a**) Grayscale ultrasound demonstrates juxta-anastomotic stenosis (*arrow*) of the radial artery. (**b**) Color Doppler ultrasound at the same location demonstrates increased velocity at the site of stenosis consistent with hemodynamically significant stenosis of the radial artery

ischemia. An angiogram of the arterial tree distal to the anastomosis should be performed both with the access open and occluded. The status of the distal circulation can then be evaluated.

Management

Preoperative evaluation is critical in avoiding access failures and complications. Arterial system evaluation should begin with bilateral blood pressure measurement. A difference of greater than 20 mm is suggestive of subclavian stenosis

[31]. Further, all peripheral pulses should be present and strong. A modified Allen's test should be performed as a screening test for evaluating the competency of the palmar arch. Ultrasound imaging of the proposed arterial inflow should be performed. The optimal diameter of the artery should be more than 1.6 mm [32] with a peak systolic velocity >50 cm/s. A resistive index ≥0.7 is also proposed [33].

In patients who are at high risk for developing DASS, it is prudent to evaluate further with DBI and DBP measurements. There is no established numerical threshold value for DBI and DBP for development of DASS.

The incidence of arterial stenosis in an AV access is about 5–13 % [34]. Traditionally, JXA has been treated by surgical revision using a jump graft or by creating a proximal neoanastomosis. JXA stenosis has a high recurrence rate after balloon angioplasty. The primary patency rates vary between 41 and 55 % at 1 year [35, 36]. Recently there has been interest in drug eluting balloons for treating JXA stenosis. A recent report using a paclitaxel coated balloon used after the standard balloon angioplasty for JXA showed a primary patency of 81 % at 1 year [37]. Standard balloon sizes for the arterial anastomosis are 4–5 mm whereas the venous side of the JXA is treated with 6–7 mm balloons. Role of placing a stent in the juxta anastomosis region is controversial.

The management of DASS is based on the clinical classification. Once the patient has stage IIb symptoms, endovascular/surgical therapy should be considered. Management further depends on the location of the access. Access at the wrist, with retrograde flow in the radial artery and hand ischemia can be remedied by ligating or endovascular coil embolization of the radial artery beyond the anastomosis. Management of access at the brachial artery requires more work up. A Doppler ultrasound to determine the flow will dictate the management options. A low to normal flow where the flow in a fistula is less than 800 ml/min or less than 1,000 ml/min in a graft should be surgically corrected by using a technique referred to as proximalization of the arterial inflow (PAI) [38, 39]. During PAI, a bypass is created from a proximal artery (axillary artery) to the proximal portion of the fistula. This procedure is considered superior to the distal revascularization with interval ligation (DRIL) procedure for low-normal flow DASS. The primary patency of the bypass graft at 2 years ranges between 45 and 70 % [40]. More proximal arterial disease affecting the subclavian or right brachiocephalic arteries are best diagnosed on CTA/MRA and treated with either endovascular stenting or surgical bypass.

In patients with high flow DASS, another surgical procedure, revision using distal inflow (RUDI), is the procedure of choice. An additional procedure to reduce the flow includes banding. Banding can be done surgically without pressure measurement (blind banding), with pressure measurement (precision banding), or endovascular-surgical combined.

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Non-tunneled Hemodialysis Catheter

15

Chieh Suai Tan, Anil Agarwal, and Steven Wu

Introduction

While tunneled dialysis catheters are preferred over non-tunneled dialysis catheters, the use of non tunneled dialysis catheter is indicated when

1. Duration of catheter use is expected to be short, e.g. 1 week
2. Presence of bacteremia or sepsis where placement of a tunneled dialysis catheter is contraindicated
3. Deranged coagulation parameters where placement of a tunneled dialysis catheter is considered high risk for bleeding

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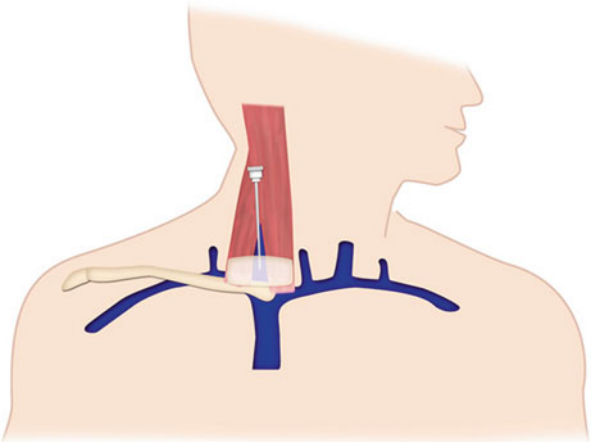


Fig. 15.1 Site of puncture for right internal jugular approach. Identify the 2 heads of the sternocleidomastoid muscle and place the ultrasound probe just above the level of the clavicle. Identify the internal jugular vein on the ultrasound screen and adjust the probe such that the vein is in the center of the screen. The needle is then inserted at the midpoint on the superior border of the ultrasound probe

Sites of Insertion

Similar to tunneled dialysis catheter insertion, the preferred site of insertion is the right internal jugular (IJ) vein. The alternate insertion sites, in descending order of preference, are the left IJ, follow by the right and left femoral veins. Due to the high incidence of stenosis associated with placement of subclavian catheters, such approach should be avoided unless in dire straits where there are no other alternatives. Femoral catheters are associated with a higher incidence of infection, especially in individuals with higher body mass index [1, 2].

For the IJ approach, the puncture site is generally higher (superior) than that commonly used during the placement of a tunneled dialysis catheter (Fig. 15.1). Such an approach has the advantage of providing adequate space for placement of a tunneled dialysis catheter at a later stage. In general, a new puncture site is preferred during tunneled dialysis catheter insertion as conversion of a non-tunneled catheter to a tunneled catheter carries the risk of entry-site contamination and "kinking" of the catheter due to the difference in the angle of approach.

Equipment

Prepare the following items on a sterile trolley:

1. A 21 Gauge mico-puncture access needle
2. A 0.018 in. micro-wire and a 0.035 in. hydrophilic wire
3. A 5 French micro-puncture sheath
4. A set of 8, 10 and 12 French dilators
5. A non tunneled dialysis catheter
6. 1 % Lignocaine (Lidocaine)
7. Normal Saline
8. Syringes: Two 10 cc syringes and one 20 cc syringe
9. A number 11 surgical blade

10. One 2/0 non absorbable suture
11. A Needle holder
12. A hemostat
13. ACD solution

Steps for Right IJ Non Tunneled Catheter Insertion

1. The following steps require use of micropuncture set, ultrasound guidance and fluoroscopy. For bedside insertion, usually only ultrasound guidance is available and is considered adequate except in difficult cases. Not all non-tunneled catheter insertion kits include the micro-puncture kit which needs to be acquired separately. Review the indications for non tunneled dialysis catheter insertion and plan the site of placement.
2. Scan the bilateral IJ veins to assess their patency and finalize the site of placement. If the vein appears small or collapsed, place the patient in the Trendelenburg position to distend the vein. If the vein appears large with multiple collateral veins in the neck, central vein stenosis may be present. If the vein is noncompressible, a thrombus may be present.
3. Clean and drape the insertion site alongwith a large area of neck and chest (Fig. 15.2a).

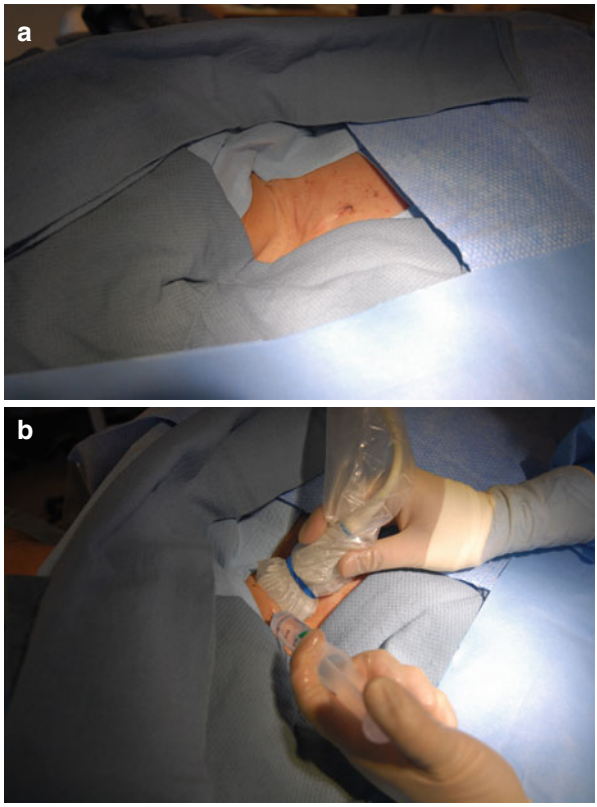
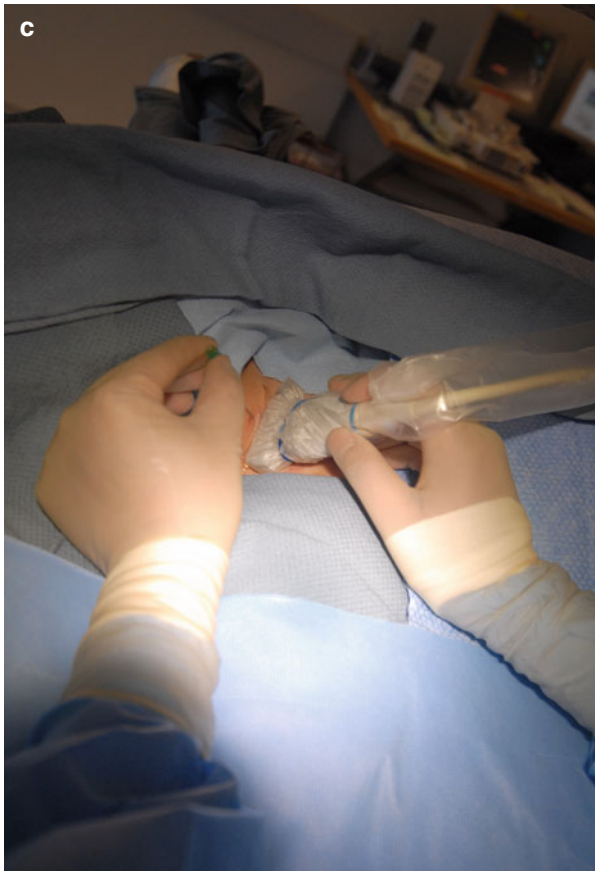


Fig. 15.2 (**a**) Clean and drape the operative site. (**b**) Infiltrate the insertion site with lidocaine. (**c**) Puncture the vein with a micro-puncture needle under ultrasound guidance

Fig. 15.2 (continued)



4. Place the ultrasound probe within the sterile sleeve and place it below the apex of the anatomical triangle that is formed between the two heads of the sternocleidomastiod muscle and the clavicle. Position it perpendicular to the IJ vein to obtain a transverse view of the vein. Infiltrate the skin over the insertion site with 1 % lidocaine (Fig. 15.2b).
5. Insert the 21 gauge micropuncture access needle from the superior aspect of the probe into the vein under real time ultrasound guidance. Avoid puncturing through the muscle as this would result in discomfort whenever the patient turns his head (Fig. 15.2c).
6. After successful cannulation, insert the 0.018 in. microwire into the vein under fluoroscopy. Make a small incision along the micro-puncture wire to enlarge the venotomy site. Exchange the needle for the 5 Fr micro-puncture sheath over the 0.018 in. microwire (Fig. 15.3a–c).
7. Exchange the 0.018 microwire for a 0.035 in. wire and advance the tip into the inferior vena cava (IVC) under fluoroscopy if available. This can be achieved by asking the patient to hold his breath after deep inspiration. Occasionally, a 5-French Kumpe catheter is needed to steer the tip of the wire into the IVC.

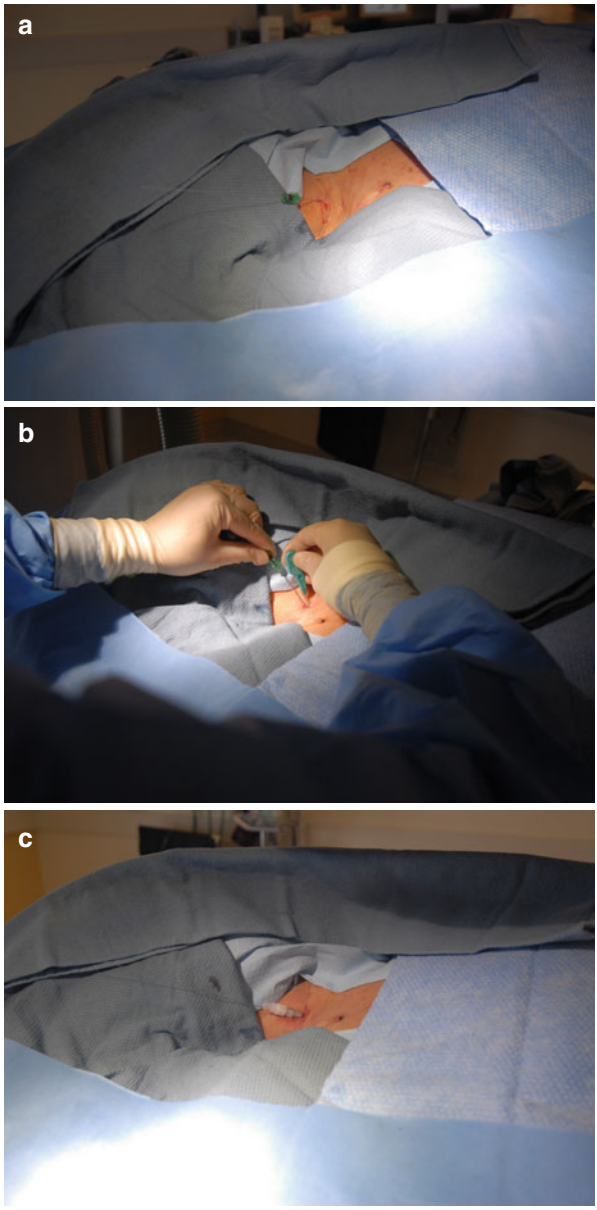


Fig. 15.3 (**a**) Insert the mirco-wire into the needle. (**b**) Make a small incision in the skin before exchanging the needle for a micro-puncture sheath. (**c**) Insert the micro-puncture sheath over the wire

(The micro-puncture kit is not universally utilized for insertion of non tunneled catheters and a direct puncture with 18-gauge needle is often utilized followed by advancement of 0.035″ guidewire).

8. Remove the micro-puncture sheath and serially dilate the venotomy tract using 8,10 and 12-French dilators (Fig. 15.4a). The tip of the 8-French dilator is positioned proximal to the right atrium at full inspiration and the external portion of the dilator is marked at the venotomy site. The full length of the dilator

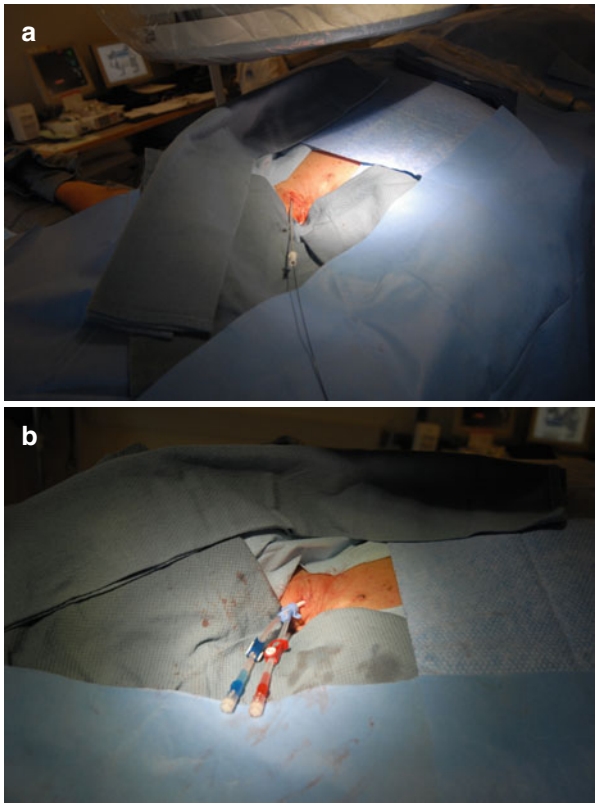


Fig. 15.4 (**a**) Remove the micro puncture sheath and dilate the venotomy tract with dilators. (**b**) Placement of catheter

is approximately 20 cm. The distance between the marking at the venotomy site and the tip of the dilator is equal to the intravascular distance from the venotomy site to the right atrium. This measurement is used to determine the length of the non tunneled catheter to be placed. In general, for the right IJ, the length of the catheter used is between 15 and 20 cm. For the left IJ placement, the length of the catheter used is between 20 and 24 cm.

9. After final dilatation with the 12-French dilator, insert the non-tunneled dialysis catheter over the guide wire.
10. The catheter tip is positioned proximal to the right atrium under fluoroscopy, which is approximately 5 cm inferior to the bifurcation of the trachea.
11. Remove the guide wire and test the flow of the catheter using a 20 mL syringe. The syringe should fill up rapidly within 3 s without much resistance and there should not be any resistance during flushing. The tip position may be rotated to allow best possible flow.
12. Once the flow of the catheter has been optimized, flush the catheter with normal saline and lock with catheter with anticoagulant to prevent thrombus formation within the catheter.

13. Suture the wings of the catheter to the skin with non absorbable sutures and cover the wound and catheter with sterile breathable dressings.
14. The dressing should be changed whenever it is moist or wet. Water impermeable dressings should be used during shower to keep the wound dry (Fig. 15.4b).

Complications of Non Tunneled Catheter Insertion

Acute Complications

The acute complications for non tunneled dialysis catheter insertion are similar to those seen with tunneled dialysis catheter insertion. Briefly, these include:

1. Arterial puncture
2. Pneumothorax and hemothorax
3. Air embolism
4. Arrhythmia

The approach and treatment strategies for the complications are described in Chap. 11.

Subacute Complications

1. Infection
   Non tunneled dialysis catheters should not be left in-situ for more than 1 week as they have a higher risk of infection compared to tunneled dialysis catheters. In the event of infection, the patient should be treated with broad spectrum antibiotics and the non tunneled dialysis catheter should be removed.
2. Poor flow
   Do not attempt thrombolysis with tPA if the non tunneled dialysis catheter develops poor flow. The appropriate treatment is to adjust it under fluoroscopy or place a new catheter over a guide wire.

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Tunneled Hemodialysis Catheter

16

Chieh Suai Tan, Steven Wu, and Kenneth D. Abreo

Insertion of Tunneled Dialysis Catheter

Introduction

Insertion of a central venous catheter for hemodialysis is an interventional procedure in which many principles of endovascular techniques are applied. It involves obtaining vascular access under real time ultrasound guidance, wire manipulations and sheath placements.

Sites of Insertion

The preferred site of insertion is the right internal jugular (IJ) vein as it is the shortest and most direct route to the right atrium. The alternative insertion sites, in descending order of preference, are the left IJ, followed by the right external jugular (EJ), left EJ, right femoral and left femoral vein. Subclavian veins should not be used for catheter placement as they are associated with an unacceptably high incidence of stenosis, which would compromise future upper limb AV access placement. The

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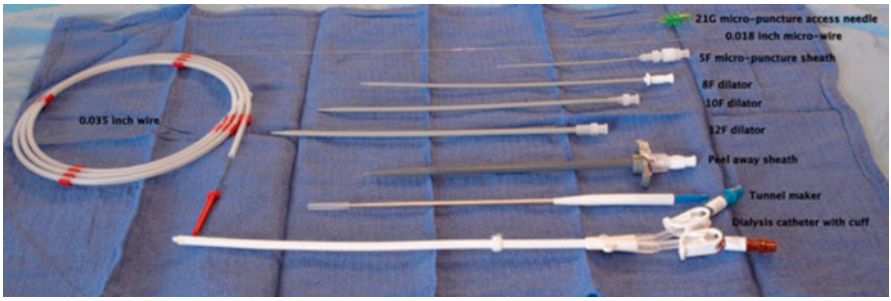

Fig. 16.1 Tools for insertion of tunneled dialysis catheter

femoral catheter should not be placed on the same side of the transplanted kidney as it can lead to venous obstruction or thrombosis of the transplanted kidney.

Equipment

Prepare the following items on a sterile trolley (Fig. 16.1):

1. 21 Gauge mico-puncture access needle
2. 0.018 in. micro-wire and 0.035 in. hydrophilic wire
3. A 5 French micro-puncture sheath
4. A set of 8, 10 and 12 French dilators
5. 14–16 F dilator with a peal-away sheath
6. A tunnel maker
7. Cuffed dialysis catheter
8. 1 % Lidocaine solution for injection
9. Normal Saline
10. Syringes
11. A number 11 surgical blade
12. One 2/0 non-absorbable suture
13. One 2/0 absorbable suture
14. Needle holder
15. Hemostat

Steps for a Right Sided IJ Tunneled Catheter Insertion

1. Review the indications for tunneled dialysis catheter insertion and locate the site of placement.
2. Prepare equipment as described.
3. Scan both IJ veins to assess their patency (Fig. 16.2a–d). Place the ultrasound probe just above the clavicle and perpendicular to the IJ vein to obtain a transverse view of the vein and mark the site of placement.

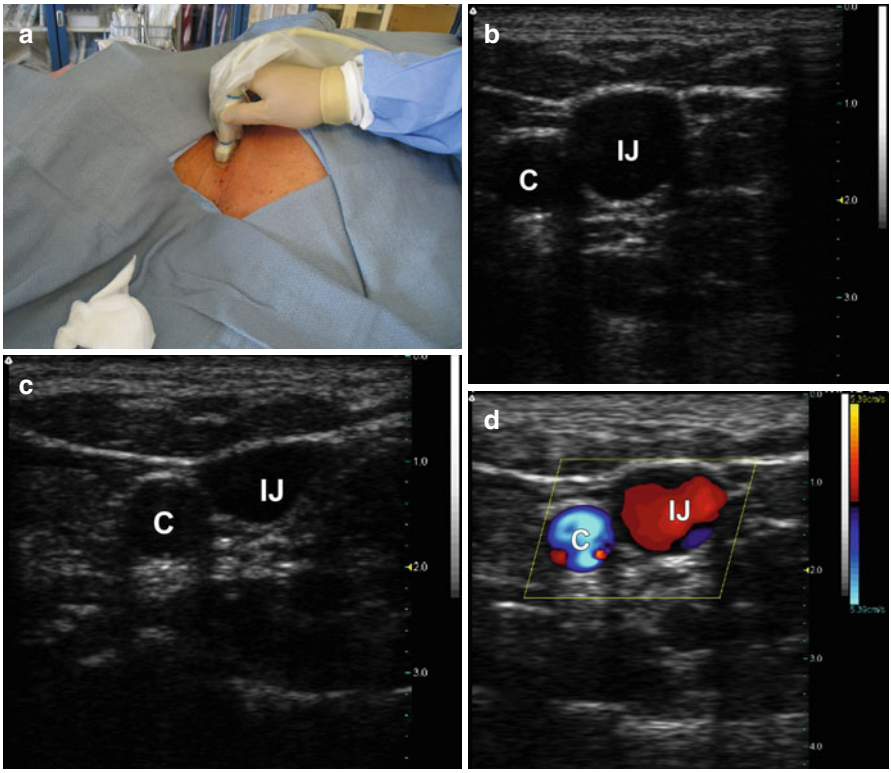

Fig. 16.2 (**a**) Place the ultrasound probe just above the clavicle, between the 2 heads of the sternocleidomastoid muscle. (**b**) The Internal jugular (*IJ*) vein lies lateral to the carotid artery. (**c**) The Internal jugular vein is easily compressible with the ultrasound probe. (**d**) Occasionally, color doppler may be used to confirm flow within the vessels. *C* carotid artery, *IJ* internal jugular vein

4. Clean and drape the patient.
5. Infiltrate the insertion site with 1 % lidocaine.
6. Make a small venotomy incision at the desired insertion site and dilate the incision with an artery forcep.
7. Place the ultrasound probe within the sterile sleeve and place it next to the skin incision. Insert the 21 gauge micropuncture access needle from the lateral aspect of the probe through the venotomy incision into the vein under real time ultrasound guidance (Fig. 16.3a–c). Flow of blood from the needle hub indicates successful cannulation.
8. After successful cannulation, insert the 0.018 in. microwire through the micropuncture needle into the vein. Confirm the position with fluoroscopy (Fig. 16.4a).
9. Exchange the needle for the 5 Fr micro-puncture sheath over the 0.018 in. microwire.
10. Remove the 0.018 microwire together with the inner dilator from the micropuncture sheath and insert a 0.035 in. wire into the sheath (Fig. 16.4b).

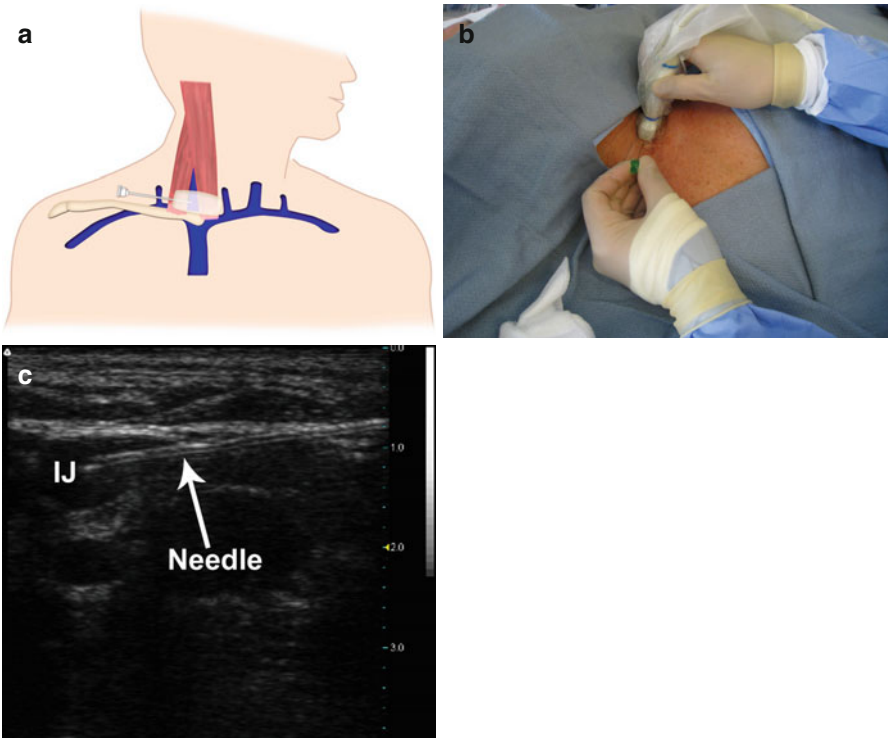

Fig. 16.3 (**a**) Insert the needle at the midpoint on the lateral aspect of the probe under real time ultrasound imaging. (**b**) Advance the needle under ultrasound guidance. The needle should be moving parallel to the superior border of the ultrasound probe to stay within the ultrasound plane. (**c**) The needle should be visualized to enter the internal jugular (*IJ*) vein on real time ultrasound imaging

11. Advance the tip into the inferior vena cava (IVC) under fluoroscopy. This can be achieved by asking the patient to hold his/her breath after deep inspiration (Fig. 16.4c).
12. Occasionally, a 5-French Kumpe catheter is needed to steer the tip of the 0.035 in. guide wire into the IVC. Place the Kumpe catheter over the wire, withdraw the tip of the wire into the catheter, change the direction of the Kumpe catheter tip and re-insert the wire into the IVC (Fig. 16.4d).
13. Remove the micro-puncture sheath and serially dilate the venotomy tract using the 8, 10 and 12-Fr dilators. During the process, position the tip of the 10-Fr dilator at the proximal right atrium and make a marking on the external portion of the dilator at the venotomy site. The 12-Fr dilator is left in-situ while preparing the catheter for insertion (Fig. 16.5a).
14. The dilators are 20 cm in length and the distance from the marking on the 10-Fr dilator to the tip represents the intravascular distance from the venotomy site to the proximal right atrium (Fig. 16.5b).
15. Catheter lengths are measured from the cuff to the tip. For the right and left IJ approaches, the lengths of the catheter used are 19 and 23 cm respec-

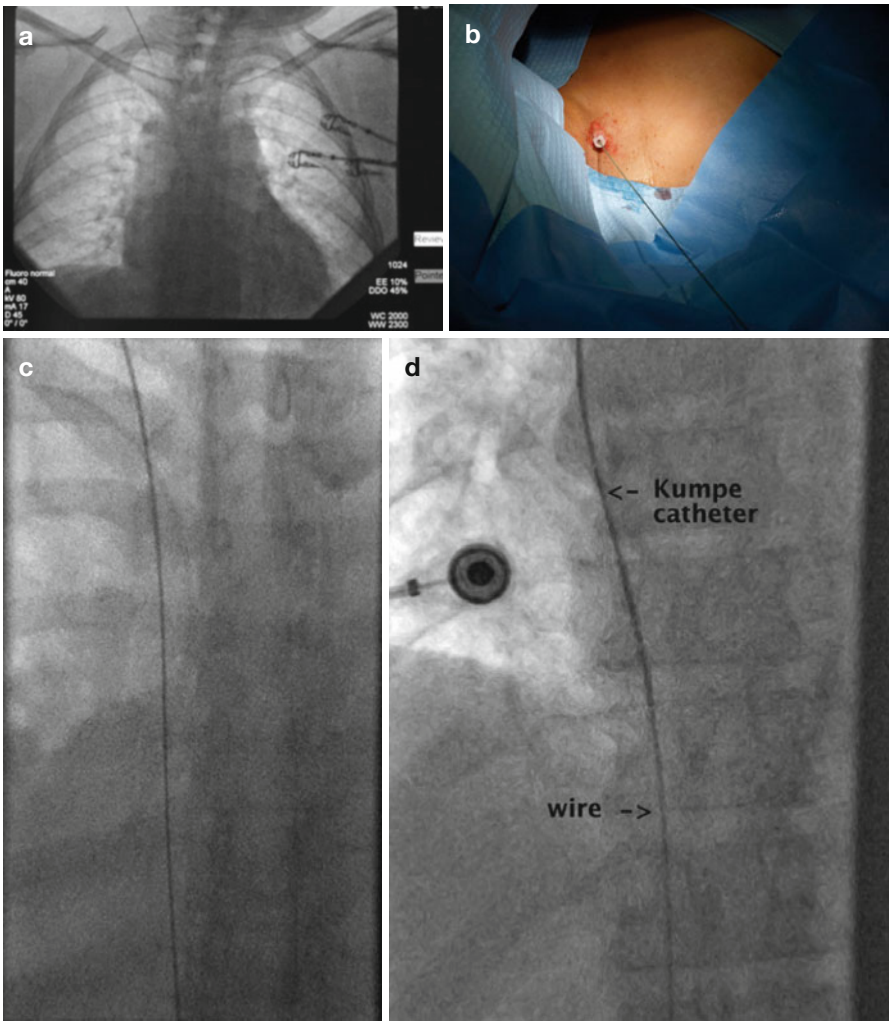

Fig. 16.4 (**a**) Insert the microwire under fluoroscopy. (**b**) Exchange for a 0.035 in. wire. (**c**) Ensure that the tip of the wire is in the IVC. (**d**) Use of Kumpe catheter

tively. A 28 cm catheter is usually used for the femoral approach. The intravascular segment of the catheter is estimated using the marking on the 10-Fr dilator. The position of the exit site is determined by holding the catheter against the chest wall. Mark the position of the desired exit site. The cuff of the catheter should be approximately 2 cm from the exit site (Fig. 16.5c).

16. After infiltrating the skin with lidocaine, make a small incision at the desired exit site (Fig. 16.6a).
17. To create a subcutaneous tunnel, use the tunnel maker. Mount the catheter to the end of the tunnel maker (Fig. 16.6b).

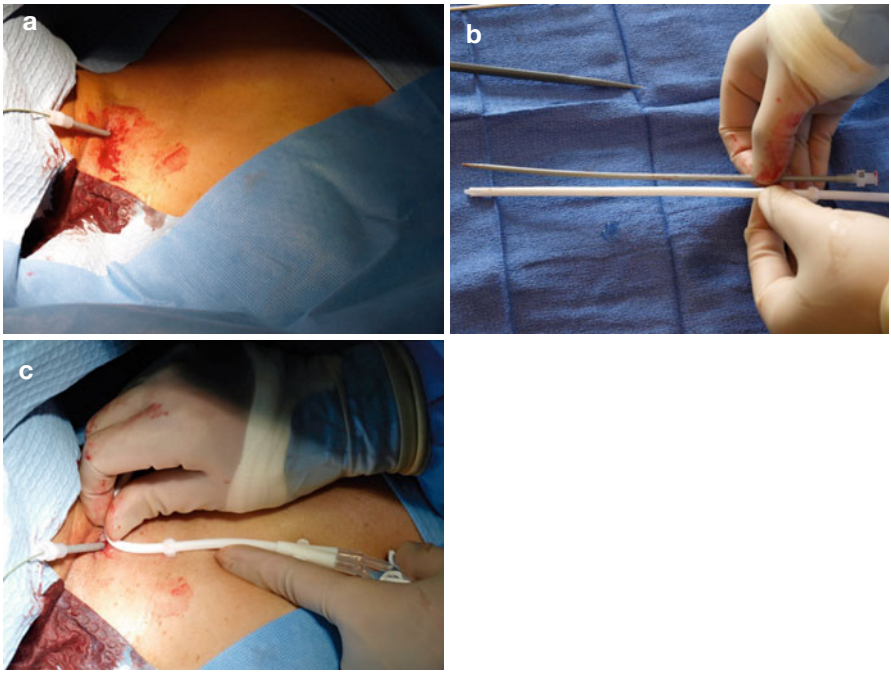

Fig. 16.5 (**a**) Leave the 12 Fr dilator in situ after dilatation. (**b**) Use the10 Fr dilator to estimate the length of the intravascular portion of the catheter. (**c**) Mark the position of the exit site

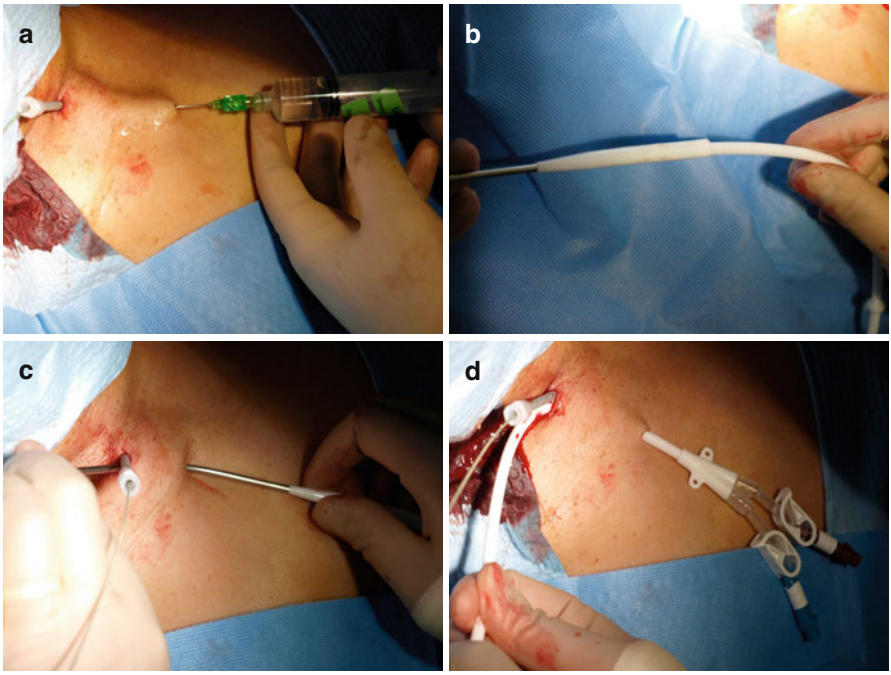

Fig. 16.6 (**a**) Infiltrate the skin with lignocaine. (**b**) Mount the catheter to the end of the tunnel maker. (**c**) Create s subcutaneous tunnel using the tunnel maker. (**d**) The catheter is pulled through the tunnel

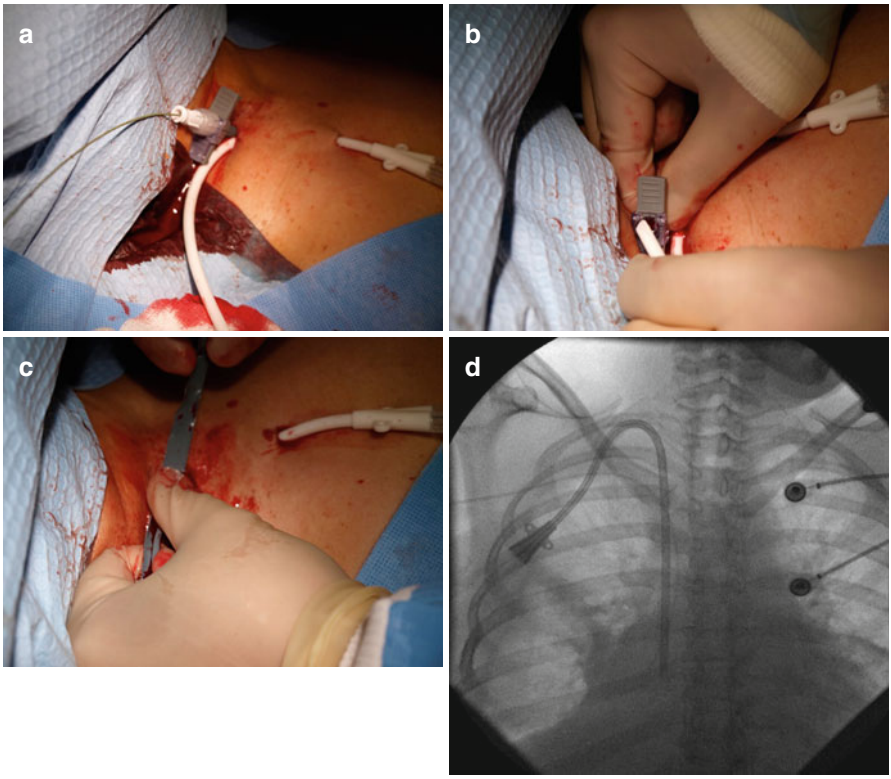

Fig. 16.7 (**a**) Insert the peel away sheath. (**b**) Insert the catheter into the peel away sheath. (**c**) Push the catheter into the vein via the peel away sheath. (**d**) Check the final position of the catheter

18. Create the tunnel using the tunnel maker and pull the catheter with it towards the venotomy site (Fig. 16.6c).
19. The catheter is pulled through the tunnel to the venotomy site (Fig. 16.6d).
20. Remove the 12-French dilator and insert a peel-away sheath/dilator set and place it into the superior vena cava under fluoroscopy. Remove the 0.035 in. wire and inner dilator from the peel away sheath and insert the catheter into the peel away sheath (Fig. 16.7a).
21. Insert the catheter tip into the peel away sheath (Fig. 16.7b).
22. Using a series of "push" (pushing in the catheter with the thumb) and "pull" (pulling apart the peel away sheath), push the entire length of the catheter into the vein (Fig. 16.7c).
23. Position the tip of the catheter at the right mid-atrium under fluoroscopy, which is approximately 5 cm inferior to the level of the tracheal bifurcation (Fig. 16.7d). Test the flow of the catheter using a 20 ml syringe. The syringe should fill up rapidly within 3 s without much resistance and there should not be any resistance during flushing. The tip position may be adjusted to allow best possible flow.
24. Once the flow of the catheter has been optimized, flush the catheter with normal saline and lock the catheter with an anticoagulant to prevent thrombus forma-

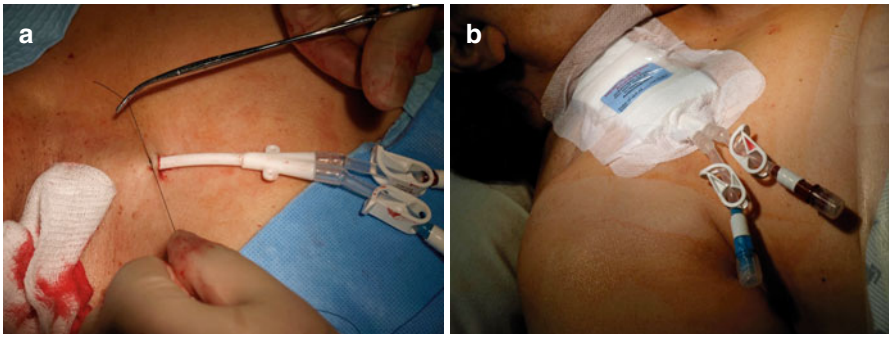

Fig. 16.8 (**a**) Close the exit site with a purse string suture. (**b**) Protect the wound with sterile dressings

tion within the catheter. Either heparin (1,000–5,000 units/ml) or 4 % acid citrate dextrose (ACD) solution can be used. The exact amount needed is usually indicated on the hub of the catheter. The risk of heparin induced thrombocytopenia can be avoided by using ACD as a locking agent instead of heparin.

25. The venotomy site is closed using absorbable interrupted sutures and a non absorbable purse string suture is applied at the exit site to secure hemostasis (Fig. 16.8a). The catheter is secured to the chest by suturing the wings of the catheter to the skin with non- absorbable sutures.
26. The surgical sites should be covered with sterile breathable dressings to protect the wound. Patients should be given clear instructions on how to care for their catheters after tunneled catheter placement. In particular, the dressings should be changed whenever it is moist or wet. Water impermeable dressings should be used during showers to keep the wound dry (Fig. 16.8b).
27. Heparin free dialysis should be ordered if the catheter is being used immediately after placement.
28. All non absorbable sutures can be removed 14 days after insertion. Before suture removal, confirm that the catheter is anchored to the subcutaneous tissue via the catheter cuff by giving it a gentle tug.

Acute Complications of Tunneled Dialysis Catheter Insertion

Regardless of how "minor" or "simple" the procedure is perceived to be, never underestimate the complications that may arise during the procedure. Obeying the "rules" of endovascular intervention and developing good habits during training can go a long way to decrease procedure related complications. The following are some of the complications that one may encounter during dialysis catheter placement, and the precautions and steps to treat them if they occur.

Arterial Puncture

Prevention is always easier than treatment.

1. Always access the vein under real time ultrasound guidance and be cognizant of the depth and ultrasound plane.
2. Always use the micro puncture set to access the vein initially as cannulation created using the micro puncture needle is small and bleeding can be stopped readily by compression.
3. Always verify the position of the micro puncture wire by fluoroscopy.

In the event of an arterial puncture, treatment is dependent on which stage of the procedure the complication is discovered.

1. If the complication is discovered before dilatation of the venotomy tract, the wires and micro-puncture sheath can be safely removed and direct compression applied to arrest the bleeding.
2. If the complication is discovered after dilatation of the venotomy tract, leave the dilator in-situ to tamponade the vessel and call for help. The arterial puncture can be closed either by open surgical repair or using an arterial closure device.

Pneumothorax

In the event of a pneumothorax, chest tube insertion is often necessary to evacuate the air leak

Hemothorax

In the event of a hemothorax, surgical intervention is often necessary to stop the bleeding and evacuate the blood.

Air Embolism

Preventive measures include:

1. Identify high risk patients. Patients who are dehydrated are at increased risk of air embolism during line insertion. Their veins may be collapsed or show variation in size with the respiratory cycle on ultrasound. Give fluid boluses and perform the insertion with the patient in the Trendelenburg position to minimize the risk of air embolism.
2. Always occlude the hub of the needle and close the hemostatic valve of the peel away sheath during the procedure. As an added precaution, pinch the peal away sheath between your fingers after you have removed the inner dilator.

3. Instruct the patient to hold his/her breath during puncture of the IJ vein and insert the wire though the needle rapidly after successful puncture to avoid this complication.
4. The patient should be instructed to hold his/her breath during exchanges over the wire.

If there is significant air embolism

1. Immediately place the patient in the left lateral decubitus and Trendelenburg position. If cardiopulmonary resuscitation is needed, place the patient in a supine and head down position.
2. Administer 100 % oxygen and do endotracheal intubation if necessary.
3. Attempt removal of air from the circulation by aspirating from the central venous catheter.
4. Fluid resuscitate the patient and consider hyperbaric oxygen treatment.

Cardiac Arrhythmia

To prevent the wire from triggering arrhythmias during the procedure, always pass the guide wire tip into the IVC during the procedure.

Vessel Injury During Dilatation of the Venotomy Tract

The guide wire might kink or buckle during dilatation of the venotomy tract. Always pull back the wire slightly before pushing the dilators into the vessels.

Subacute Complications of Tunneled Dialysis Catheter

Suboptimal Flow

1. If the tunneled catheter has poor flow within a week of placement, it is often due to suboptimal positioning of the catheter tip, migration of catheter tip or kinking of catheter.
   (a) Check the position of the catheter tip on a chest x ray, in particular, look for any kinks in the catheter (Fig. 16.9a–c)
   (b) Withdraw the catheter if the tip of the catheter is distal to the mid atrium. If the tip of the catheter is proximal to the mid atrium, advancing the catheter carries the risk of contaminating the subcutaneous tunnel tract and infection. In the latter situation, exchanging the catheter over a guide wire is preferred.
2. If the catheter tip is in the correct position, a trial of a thrombolytic agent may be attempted.
   (a) The procedure should be carried out in a sterile manner. Clean and drape the patient.

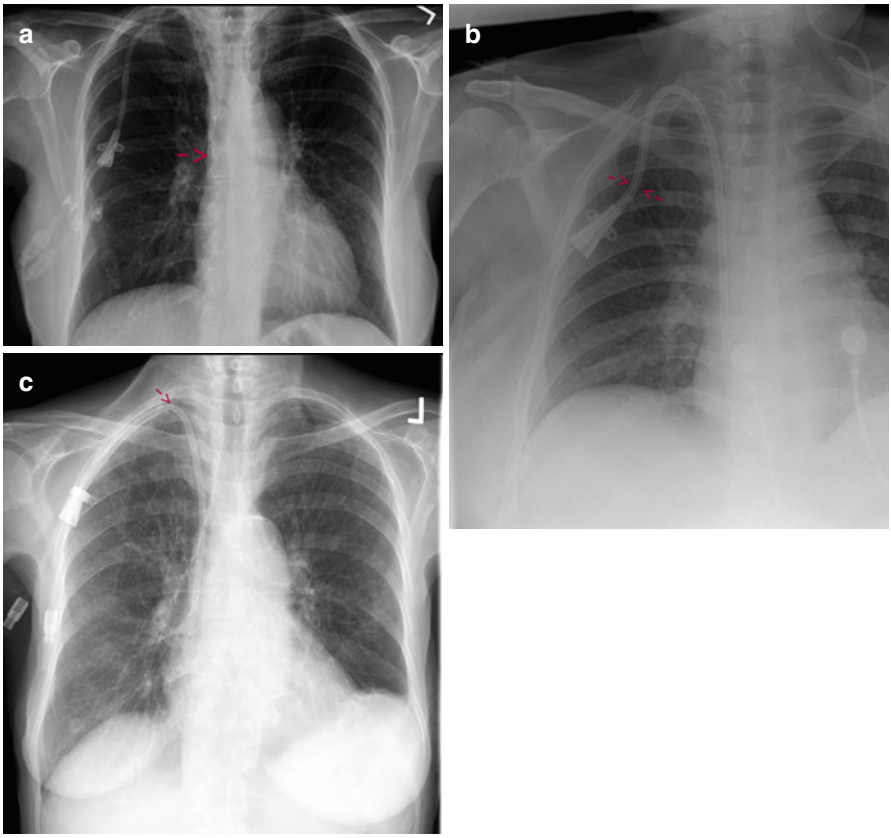

Fig. 16.9 (**a**) Catheter is too short. *Arrow* shows that the of catheter is in the superior vena Cava. (**b**) Tip of catheter is in an optimal position but the *arrow* shows that catheter is "kinked" by the purse string suture at the exit site. (**c**) *Arrow* shows that the catheter is "kinked" at the venotomy site

(b) Remove the caps of the catheter ports and aspirate 5 ml of blood from each lumen to remove the locking agent.
(c) Instill 2 ml of TPA (1 mg/ml) into each lumen and allow it to dwell for half an hour.
(d) Aspirate both catheter ports and discard the initial 5 ml of blood.
(e) Test catheter flow with a 20 ml syringe. If the flow remains suboptimal, schedule for catheter exchange over a guide wire.

3. If the catheter developes poor flow more than a month after placement, it is probably secondary to obstruction from fibrin sheath formation around the tip of the catheter. A trial of tPA may be attempted. If unsuccessful, exchanging the tunneled catheter over a guide wire with or without disruption of the fibrin sheath is the treatment of choice.
   (a) Check the position of the catheter tip on chest x ray.
   (b) Aspirate both catheter ports and discard the initial 5 ml of blood which contains the locking agent

(c) Insert a 0.035 in. angled stiff guide wire through the venous port of the catheter into the inferior vena cava (Fig. 16.10a).
(d) Free the preexisting catheter cuff by blunt dissection and withdraw the catheter gently by approximately 3 cm. Gently inject 10–15 ml of contrast material into the arterial port to visualize the fibrin sheath (Fig. 16.10b).
(e) Remove the preexisting catheter and insert the 12–14 mm angioplasty balloon catheter over the wire via the subcutaneous tunnel tract, and inflate the balloon in the SVC to disrupt the fibrin sheath (Fig. 16.10c).
(f) Exchange a new-tunneled dialysis catheter over the guide wire and place the tip within the proximal SVC. Inject 10–15 ml of contrast via the arterial port to check for residual fibrin sheath (Fig. 16.10d). If fibrin sheath is still present, repeat the angioplasty. If there is no residual fibrin sheath, advance the catheter tip to the desired position in the mid atrium.

Catheter Related Bacteremia

The approach to catheter related bacteremia (CRB) is as shown in Fig. 16.11.

1. All patients with suspected dialysis catheter related systemic bacteremia should be treated with broad spectrum antibiotics until the blood culture results are known. Empiric antibiotics should include coverage for both gram positive cocci and gram negative rods, as gram negative rods account for a significant proportion of CRB after ~~the~~ staphylococcus species. A loading dose of intravenous (IV) vancomycin 20 mg/kg followed by IV 500 mg during the last 30 min of each subsequent dialysis session plus IV gentamicin 1 mg/kg or ceftazidime 1 g after each dialysis session is recommended by the Infectious Diseases Society of America. Antibiotic lock may also be used in conjunction with systemic antibiotics but there are concerns of developing antibiotic resistant organisms.
   (a) If the patient is hemodynamically stable with no signs of systemic infection, the catheter can continue to be used while blood culture results are pending.
      (i) If the patient responds well to treatment and blood cultures grow organisms other than S. Aureus, Pseudomonas species or Candida species, a new catheter may be exchanged over a guide wire to replace the preexisting catheter or the pre-existing catheter may be preserved with concurrent antibiotic lock therapy for at least 2 weeks.
      (ii) If the patient becomes hemodynamically unstable, has persistent symptoms, bacteremia persists despite IV antibiotics, blood cultures grow S. Aureus, Pseudomonas or Candida species, or metastatic infection develops, the tunneled catheter should be removed and reinserted after clearance of the bacteremia. A temporary catheter is inserted for dialysis access during this period.
      (iii) The total duration of antibiotics is 10–14 days and the patient can be managed as an outpatient if stable.

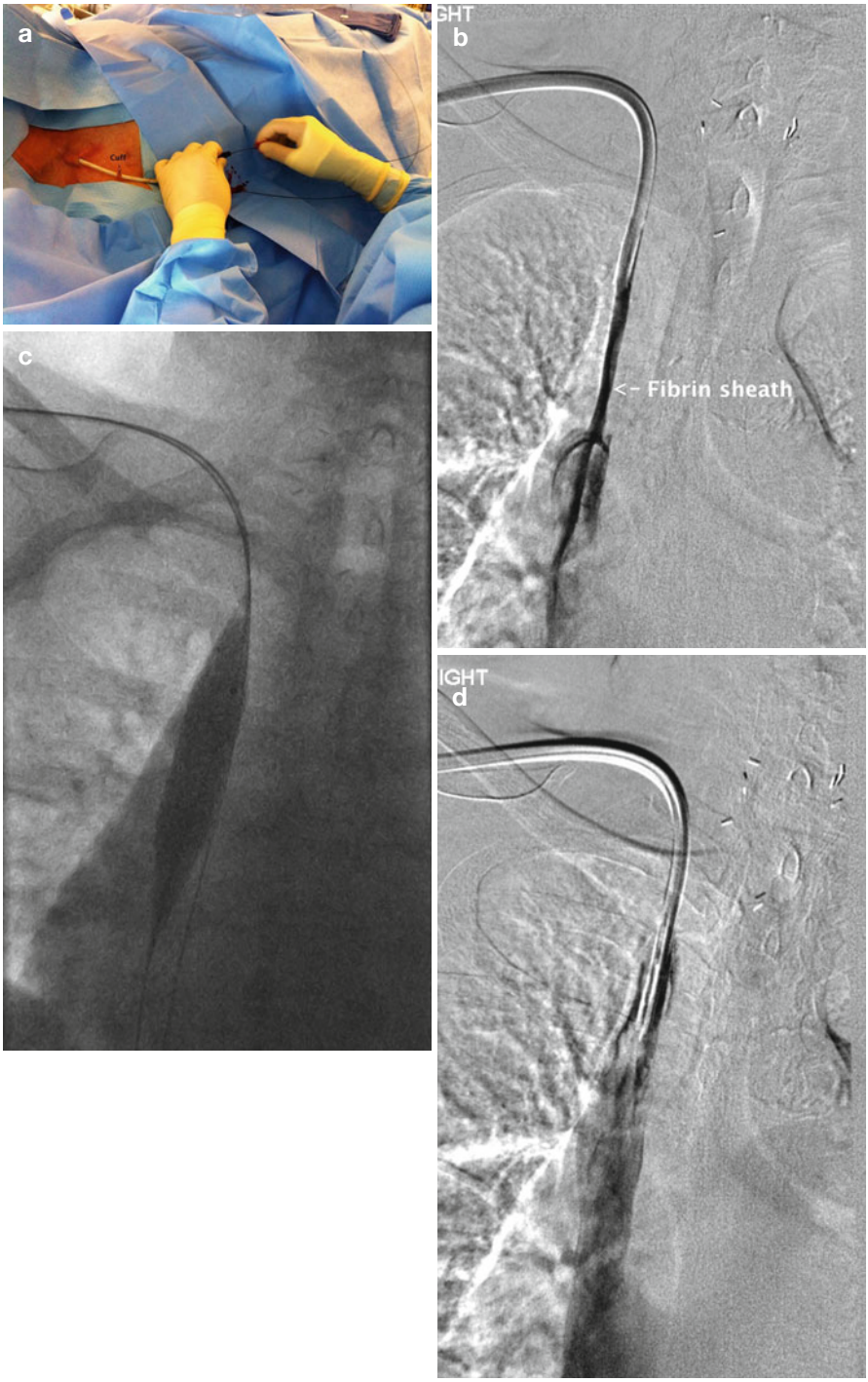

Fig. 16.10 (**a**) Insertion of guidewire into catheter. (**b**) Presence of fibrin sheath is demonstrated. (**c**) Disruption of fibrin sheath with angioplasty balloon. (**d**) Outcomes post angioplasty

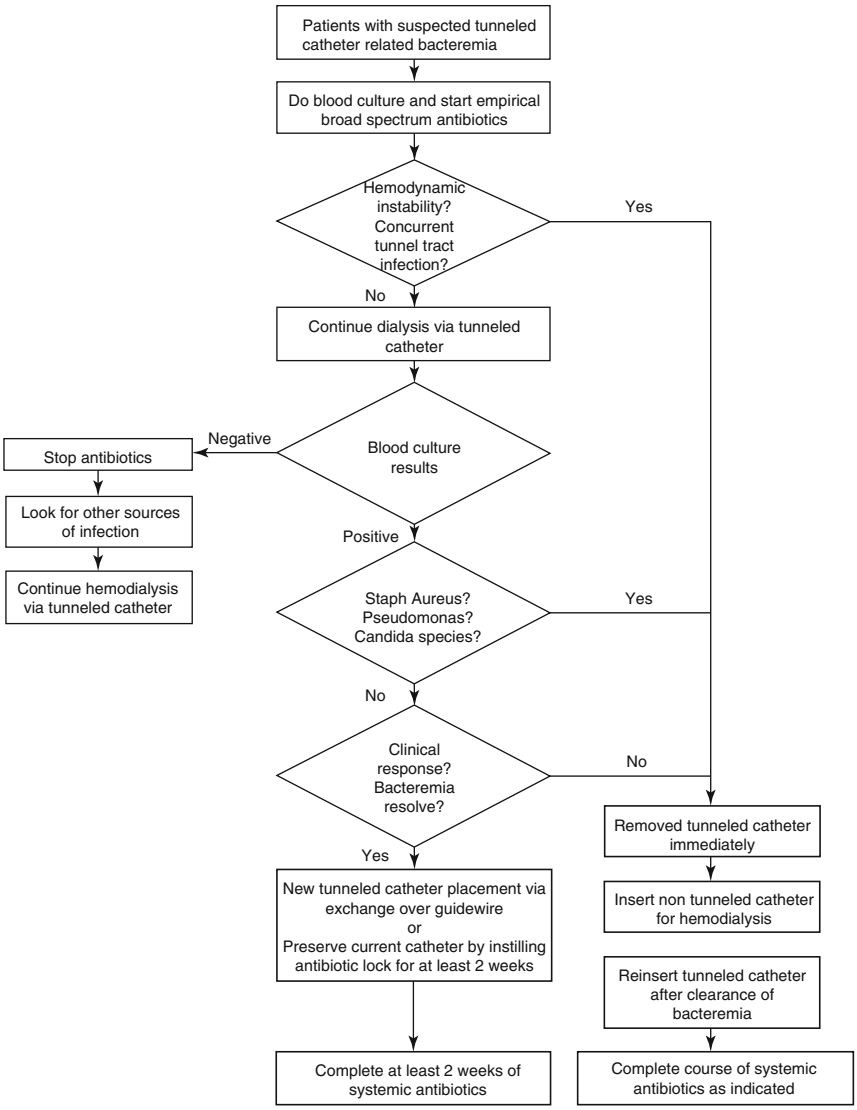

Fig. 16.11 Treatment algorithm for catheter related bacteremia

(b) If the patient is hemodynamically unstable or has a concurrent tunneled tract infection, the tunneled dialysis catheter should be removed immediately and reinserted after clearance of the bacteremia. A temporary dialysis catheter is required for dialysis access during this period.

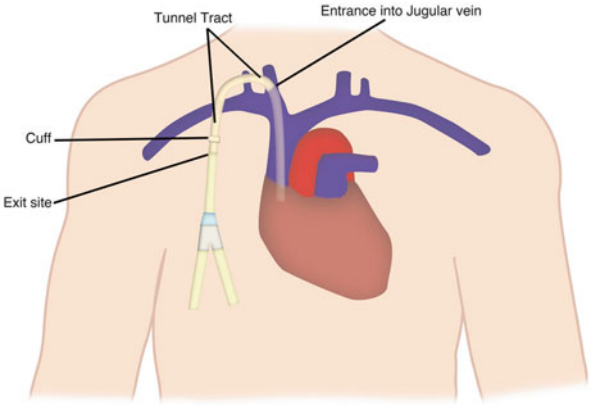

Fig. 16.12 Tunnel tract infection is defined as infection of the subcutaneous tunnel between the cuff and the entrance into the jugular vein. Exit site infection is usually superficial and does not involve the cuff

Tunnel Tract Infection

1. Tunnel tract infection is defined as infection of the portion of the subcutaneous tunnel that extends between the catheter cuff and the venotomy site (Fig. 16.12). Broad spectrum antibiotics are required accompanied by removal of the tunneled dialysis catheter.
2. Temporary dialysis catheter is often required for dialysis access. A new tunneled catheter is placed at a new site after the tunnel tract infection is treated

Exit Site Infection

1. Exit site infection is usually superficial and involves tissues distal to the catheter cuff, however, if it is left untreated, it may progress to become a tunnel tract infection with loss of catheter access.
2. Depending on the severity of the infection, oral or systemic antibiotics may be used.
3. If the infection does not improve or progresses despite antibiotic therapy, exchange of the catheter with creation of new tunnel tract and exit site may be attempted.

Removal of Tunneled Dialysis Catheter

Introduction

Although tunneled catheters have lower infection rates compared to non-tunneled dialysis catheters, they should be removed once the patient's vascular access is ready for cannulation. Prolonged catheter usage is associated with the development of central vein stenosis, hence an effort should be made to minimize duration of catheter use.

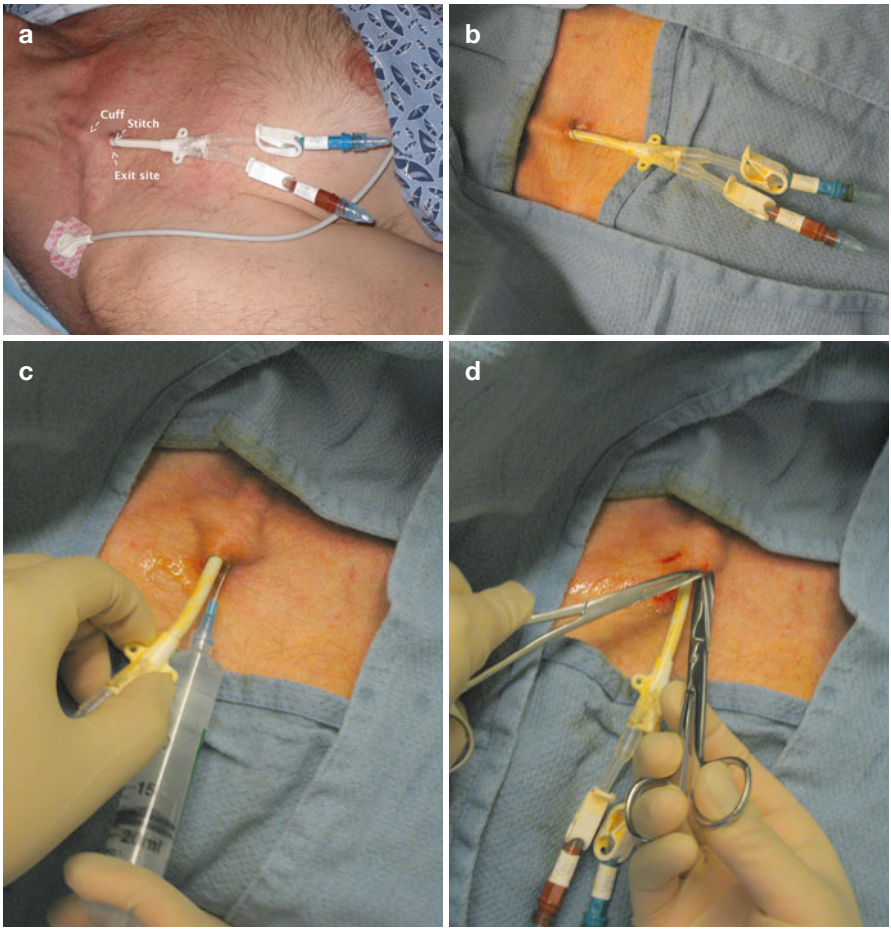

Fig. 16.13 (**a**) Physical examination of the patient. (**b**) Clean and drape the patient. (**c**) Anesthetize the exit site and cuff. (**d**) Remove any stitches that are present

Removal of a tunneled dialysis catheter is generally a simple and straightforward procedure that can be performed in an outpatient office. Difficulties may be met if the cuff is located more than 2 cm from the exit site or when the cuff is "stuck down" by profound fibrosis, usually from prolonged catheter use.

Steps for Catheter Removal

1. Examine the patient. The cuff should be palpable approximately 2 cm from the exit site (Fig. 16.13a). The purse string stitch may be present if the catheter was placed recently.
2. Clean and drape the patient (Fig. 16.13b). Patient should be in the Trendlenberg position for tunneled catheter removal.

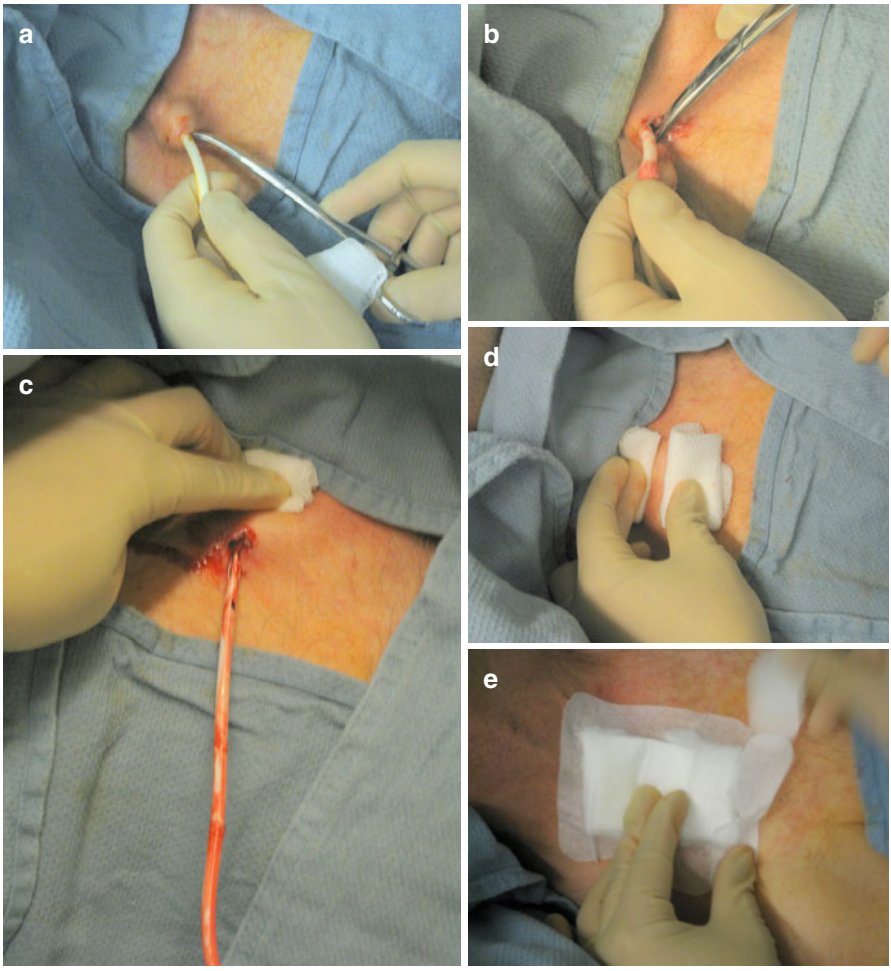

Fig. 16.14 (**a**) Blunt dissection around the cuff using an artery forcep. (**b**) Gentle traction to free the cuff. (**c**) Removal of the catheter. (**d**) Secure hemostasis by direct compression. (**e**) Wound dressing

3. Inject lidocaine at the exit site and around the cuff (Fig. 16.13c). The hydrostatic pressure generated by the injection around the cuff will help to separate it from the surrounding tissue.
4. Remove any stitches that are present (Fig. 16.13d).
5. Using a combination of gentle traction and blunt dissection with a hemostat, separate the cuff from the surrounding tissue (Fig. 16.14a–b).
6. The cuff is the only part of the catheter that is tethered to the body. Once it is free, the catheter can be easily removed (Fig. 16.14c). Compress the internal jugular vein while removing the catheter.
7. Compress the internal jugular vein at the root of the neck after removal for 3–5 min (Fig. 16.14d).

8. Observe for any bleeding complications after removal.
9. No stitches are usually required. Cover the wound with dressing (Fig. 16.14e).

Potential Problems and Troubleshooting

Table 16.1 Potential problems and troubleshooting

Problem	Troubleshooting
Cuff is placed too far from the exit site. Unable to reach cuff with hemostat	Make a small incision over the cuff and do blunt dissection through the incision to free up the cuff
Cuff became separated from the catheter and was left behind in the subcutaneous tunnel after removal of the catheter	Palpate for the cuff in the subcutaneous tunnel. Make a small incision over the cuff. Using a hemostat and a forceps, remove the cuff using blunt dissection techniques

Part IV

Hemodialysis Access Management: Surgical Interventions

Surgical Placement of Hemodialysis Vascular Accesses

17

Shouwen Wang and James F. Markmann

Introduction

The goal of surgical creation of an arteriovenous vascular access is to produce a conduit that can be easily cannulated repeatedly for hemodialysis therapy. Because of their reduced complication rates and improved efficiency, arteriovenous fistulas (AVF) and arteriovenous grafts (AVG) are preferred vascular accesses for hemodialysis over catheters [1].

Given their reduced complication rates and longevity over AVGs, AVFs should be considered first line therapy in all patients needing hemodialysis vascular accesses (Table 17.1) [1]. However, the choice between AVF and AVG for a particular patient may be influenced by many factors. The availability of suitable vasculature is a crucial factor to consider. Other factors to consider are: the patient's general health and life expectancy, whether the patient is on dialysis or close to needing dialysis, obesity, and others [2]. Creating a usable AVF may require weeks or even months of time, and sometimes endovascular interventions or secondary surgery may be required to promote its maturation. An AVG can be cannulated soon after placement, thus may potentially minimize catheter-depend duration if a patient is already on hemodialysis or eliminate the need for a catheter if a patient needs to be started on dialysis non-urgently. However, an AVG generally requires more maintenance interventions and does not last as long as an AVF.

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Table 17.1 Comparison of AVF and AVG

	AVF	AVG
Indications	Usually should be considered first and preferred for most patients	When AVF not practical, or may be preferred in some patients
Configuration	One anastomosis: artery to adjacent vein or transposed vein	Two anastomoses: artery to graft and graft to vein
Blood vessel requirements	Usually artery ≥2 mm and vein ≥2.5 mm in diameters	Require larger vessels for anastomoses
Surgical technical difficulty	Moderate	Higher than AVF
Time required before usable	Weeks to months, may need interventions to facilitate maturation	Days to 2–3 weeks
Timing of placement	May be created in advance of needing dialysis. Need time to mature, lower maintenance requirements	Before needing dialysis. Need short time before usable, but higher complications and maintenance requirements
Early postoperative complications	Low	Much higher than AVF
Incidence of distal ischemia (steal syndrome)	Low	Several fold higher than AVF
Access flow rate	Variable, remain patent at low flow rate, more likely to develop flow >2 L/min and related complications	Moderate, more likely to clot if flow <600 ml/min
Incidence of thrombosis	Low	High
Incidence of aneurysms	Moderate	Pseudoaneurysms, lower than AVF
Potential infection	Low	Several fold higher than AVF
Longevity	Usually long	<AVF, generally less than a few years
Overall preference	Preferred	<AVF, >catheter

Surgical creation of AVF and AVG can be safely performed in an outpatient setting or same-day surgical suite of a hospital. Although general anesthesia or regional nerve block has often been employed for these surgical procedures, local anesthesia plus conscious sedation generally provides sufficient comfort for patient going through these procedures. One advantage of conscious sedation is that nerve injury can be minimized as the patient can still respond to nerve stimuli during surgery. The following sections describe surgical procedures performed under local anesthesia plus conscious sedation.

While similar surgical skills and techniques can be used for creation of AVF and AVG, there are substantial differences in how these procedures are performed.

Generally, the placement of an AVG is technically more difficult and time-consuming than an AVF creation. For clarity, the creation of AVF and placement of AVG are illustrated separately in the following sections.

Creation of Autogenous Arteriovenous Fistulas

Native vessels are utilized to create AVFs. Although many blood vessels may be used for AVF creation (Table 17.2), the blood vessels in the upper extremity are most often chosen for their convenient locations and higher success rate. The generally accepted criteria for fistula creation are an artery ≥2 mm and a vein ≥2.5 mm in diameters at the anastomosis sites [3]. Additionally, sufficient diameters of the feeding artery and draining veins along their paths are essential. In younger patients or patients with limited vasculature, smaller vessels may be exploited to create an AVF.

Pneumatic tourniquet has been employed to assist AVF creation. It can reduce procedure time, minimize required dissection, reduce vascular trauma by eliminating vascular clamps and potentially improve the outcomes of surgical procedures of

Table 17.2 Configurations of autogenous AV fistulas [3]

Arteries	Veins	Comments
Posterior radial branch	Cephalic	Snuffbox, uncommon
Radial	Cephalic	Most common forearm
Radial	Transposed forearm cephalic	May be considered in obese patients.
Brachial/PRA	Transposed forearm cephalic (loop)	Less common
Radial	Transposed forearm basilic	Less common
Ulnar	Transposed forearm basilic	Less common
Brachial or PRA	Transposed forearm basilic (loop)	Less common
Brachial/PRA	Cephalic	Most common
Brachial	Transposed upper cephalic	Uncommon, when cephalic far away from brachial artery
Brachial/PRA	Upper basilic	Common, needs one- or two- stage transposition
Brachial/PRA	Brachial	Uncommon, need two-stage transposition
Brachial/PRA	Median antebrachial or perforating vein	Bidirectional flow, not a first-line choice
Radial or brachial	Translocated saphenous	Rare
Femoral	Transposed saphenous	Uncommon
Femoral	Transposed femoral	Uncommon
Posterior tibial	Great saphenous	Uncommon

PRA proximal radial artery

hemodialysis access [4]. It may be utilized in over 90 % of the patients for fistula creation based on our experience, but this practice varies widely between surgeons and institutions. The following section describes the creation of a brachiocephalic fistula assisted by pneumatic tourniquet.

Equipment for AVF Creation (Fig. 17.1)

1. Surgical optical loops (2.5×)
2. Supplies for sterilization and draping of extremities, gowns, gloves
3. Normal saline for flushing vessels and incision
4. Syringes (10 and 20 ml), needles (25 gauge), and heparin tip
5. 1 % Lidocaine solution (without epinephrine)
6. Gauze (4″x4″) and Lap sponges
7. Surgical blades (No. 15 for skin; No. 11 for arteriotomy and venotomy)
8. Scissors (Tenotomy scissors for tissue dissection; suture scissors)
9. Forceps (DeBakey for skin; Gerald for blood vessels and finer tissue)
10. Electrocautery unit, grounding pad and monopolar handswitch pencil
11. Vessel clips and clip appliers (small and medium, Ethicon™)
12. Vacuum suction equipment, tubing and tips (Yankauer and Frazier)
13. Retractors (Weitlaner with dull jaw; Senn)
14. Kelly hemostats, right-angle hemostat, and needle holder
15. Vascular loops (round elastic rubber band for holding vessels)
16. Potts scissors

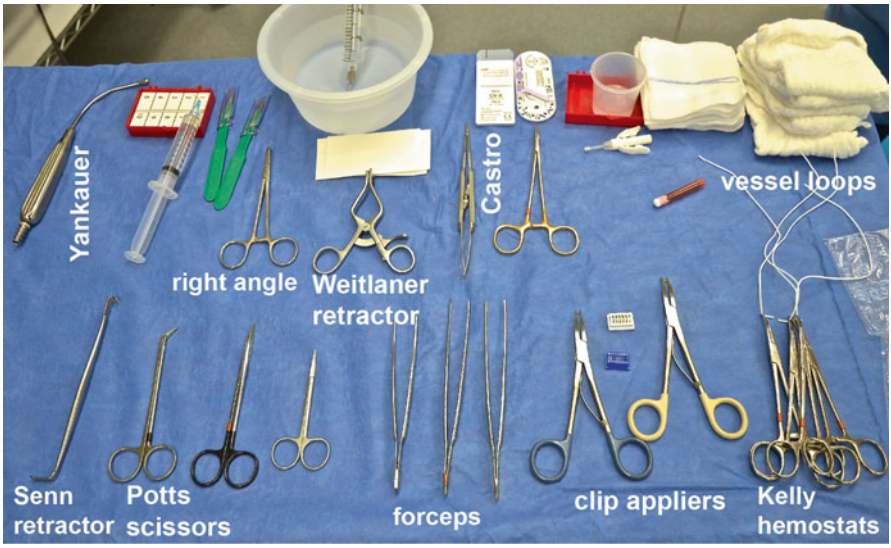

Fig. 17.1 Equipment for AVF creation. Main sterile tools used during AVF surgery

17. Garrett vessel dilators/probes (1, 1.5, 2, 2.5 mm in diameters)
18. Castro needle holder
19. 3-0 sutures for skin (Vicryl ™ – absorbable or Prolene ™ – non-absorbable)
20. Sterile strips
21. Bulldog and Glover Bulldog vessel clamps
22. Pneumatic tourniquet system
23. Esmark elastic bandage
24. Non-absorbable vessel sutures with taper-point needles (CV-8 Gore-Tex™ and 7-0 Prolene ™)

Steps of AVF Creation (Brachiocephalic AVF)

1. Preoperatively, the patient is examined and relevant history is reviewed.
2. Blood vessels on the chosen arm are visualized with ultrasound (Fig. 17.2) and a surgical plan is formulated. Locations of the vessels for anastomosis are marked.
3. The surgical instruments are organized on a sterile table (Fig. 17.1).
4. A pneumatic tourniquet cuff is applied on the upper arm and connected to the control unit system (Fig. 17.3).
5. The arm is prepared and draped to create a sterile surgical field (Fig. 17.4a).
6. Sedation medications (midazolam and fentanyl) are given intravenously. The starting doses of these medications need to be tailored to an individual patient. A dedicated nurse monitors continuous electrocardiogram, pulse oximetry, and intermittent blood pressure.

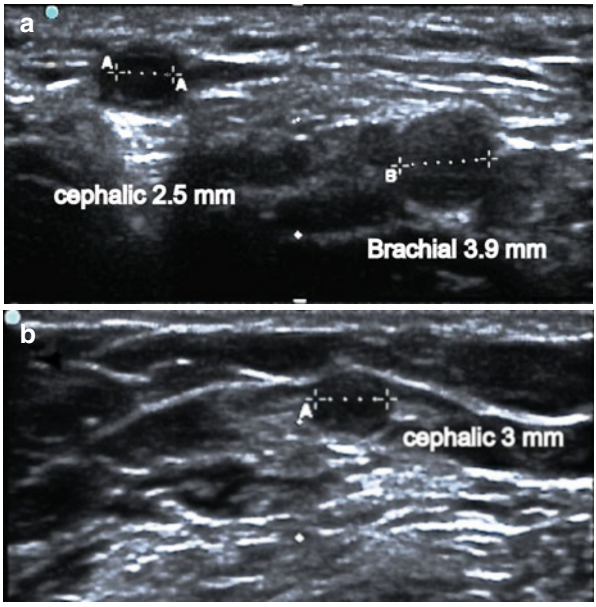

Fig. 17.2 Preoperative evaluation before AVF creation. Preoperative ultrasound images reveal (**a**) cephalic vein (*left*) and adjacent brachial artery (*right*) at the elbow of a right arm with venous tourniquet applied; (**b**) upper arm cephalic vein

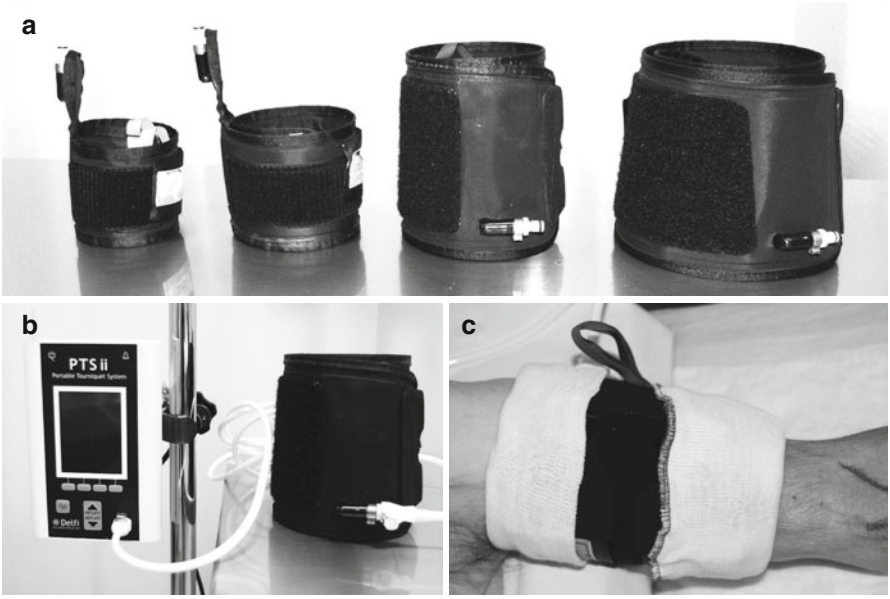

Fig. 17.3 Utilizing an automated pneumatic tourniquet system. The system consists of inflatable cuff, connection tubing and pressure control device. The selection of tourniquet cuff (Panel **a**) is based on the size and shape of a patient's limb and the location of surgical site. Notice the contoured conical shape of the two larger cuffs. The standard cuff width is 14 cm for the upper arm (second right). The cuff is connected to the pressure control device via connection tubing (Panel **b**). The cuff is applied on the upper arm over a double-layered stretchable protective sleeve (stockinet) to prevent injury to the underlying skin (Panel **c**) [4].

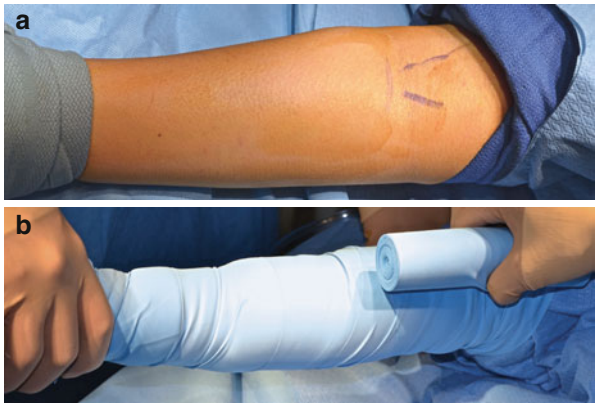

Fig. 17.4 Preparation of the arm for AVF surgery. (**a**) Prepared arm ready for surgery. Notice the markings on the skin to indicate location of cephalic vein and brachial artery based on preoperative ultrasound evaluation. (**b**) The arm is exsanguinated with Esmark elastic bandage and the pneumatic tourniquet is then inflated

7. Local anesthetic (1 % lidocaine) is infiltrated along the incision site and around the vein that will be dissected.
8. The arm is exsanguinated with Esmark bandage and the pneumatic tourniquet cuff is inflated to preset pressure (Fig. 17.4b). Please refer to a recent review for further discussion of tourniquet use [4].

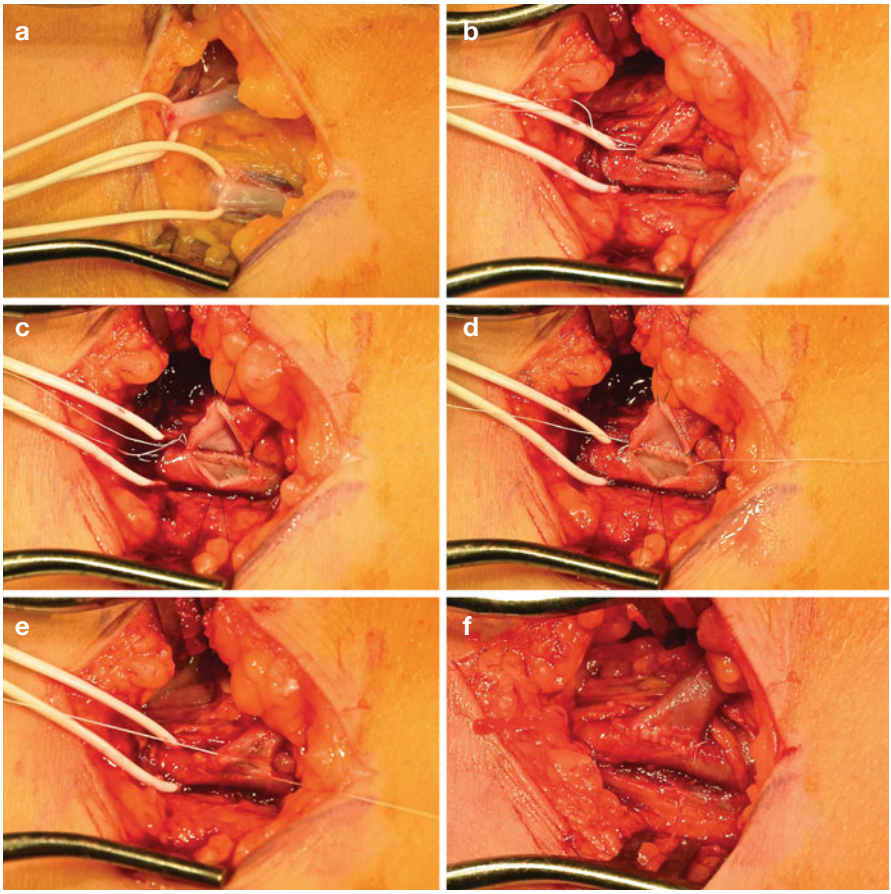

Fig. 17.5 Exposure of vessels and arteriovenous anastomosis. (**a**) The cephalic vein (*upper*) and the brachial artery (*lower*) are isolated. (**b**) The transected cephalic vein is anchored to the toe-corner of the longitudinal arteriotomy on the brachial artery with a CV-8 Gore-Tex™ suture. Care should be taken not to produce torsion on the cephalic vein. (**c**) The heel-corner of the anastomosis is anchored with 7-0 Prolene™ suture. (**d**) The posterior anastomosis is finished with the CV-8 Gore-Tex™ suture in a continuous fashion. (**e**) The CV-8 Gore-Tex™ suture is used to continue suturing the corners of the anastomosis. (**f**) Finished brachial artery to cephalic vein anastomosis with established flow through the anastomosis

9. A longitudinal incision is made over the distal brachial artery near the elbow crease. Blunt and sharp dissections are carried out laterally to free 2–3 cm of the cephalic vein from surrounding tissues. Blunt and sharp dissections are carried out posteriorly through the bicipital aponeurosis. The distal brachial artery is exposed (Fig. 17.5a). Care should be taken to preserve the adjacent nerves and vessels.
10. The distal cephalic vein is clipped or ligated, and the cephalic vein is transected. The cephalic vein is swung toward the brachial artery. There should be no laxity or excessive tension between the end of the cephalic vein and the side

of the brachial artery. The cephalic vein may be gently dilated with saline flush. A 4–6 mm arteriotomy is made on the anterior aspect of the brachial artery using a No. 11 blade followed by Potts scissors (Fig. 17.5b). Care is taken not to damage the posterior wall of the brachial artery.

11. The toe corner of the anastomosis is anchored with a CV-8 Gore-Tex™ or 7-0 Prolene™ suture (Fig. 17.5b). Attention is paid that the cephalic vein is not twisted. Some lateral rotation of the cephalic vein is desirable when it is swung toward the brachial artery in order to avoid twisting [5]. The heel corner of the anastomosis is anchored with a 7-0 Prolene™ suture to assure good alignment between the end of the cephalic vein and arteriotomy (Fig. 17.5c). The anterior aspects of the cephalic vein and brachial artery are pulled open with a 7-0 Prolene™ suture to expose the posterior edges of the cephalic vein and the arteriotomy (Fig. 17.5c). The posterior anastomosis is accomplished with the CV-8 suture in a continuous over-and-over fashion (Fig. 17.5d). The remaining anastomosis is completed using the continuous CV-8 suture. Several passes of the suture are required to turn the corners of the anastomosis (Fig. 17.5e). The suture is tied snugly, avoiding "purse-string effect" on the anastomosis.
12. The pneumatic tourniquet is released. Now blood flow through the fistula is established (Fig. 17.5f). Check the anastomosis for any significant leaks. Mild oozing at the anastomosis often will stop spontaneously. Any significant leakage at the anastomosis may be repaired with interrupted CV-8 suture. Subcutaneous fat may be sutured to the leakage site to facilitate hemostasis. Palpate the fistula for a smooth thrill.
13. Palpate radial pulse if it is palpable preoperatively. Unwrap the hand and check oxygenation on the fingers using an oximeter. Good plethysmography wave and oxygen saturation well above 90 % indicate sufficient hand circulation (Fig. 17.6).
14. Check the incision to assure good hemostasis. The incision is closed with 3-0 Vicryl sutures in layers: subcutaneous and subcuticular (Fig. 17.6d). Sterile strips and dressings are applied, or a skin glue such as Dermabond™ is utilized.

Placement of Prosthetic Arteriovenous Grafts

For some patients, AVG placement may be required (such as in a patient with exhausted superficial veins for AVF) or preferred (such as a patient with a life expectancy <2 years and already on hemodialysis). Because of the increased technical difficulty of anastomosing vessels to synthetic grafts and higher blood flow rate required to maintain AVG patency, larger arteries and veins are needed for the anastomoses with AVG. The generally accepted criteria for graft placement are an artery ≥2 mm (radial or ulnar arteries) and a vein ≥4 mm in diameters at the anastomosis sites [3]. Given the increased incidence of steal syndrome when distal brachial artery is used for access inflow, a larger diameter of brachial artery is preferred (≥4 mm, or ≥3 mm if 4-mm tapered graft is used). The most commonly used hemodialysis grafts are made of synthetic ePTFE (expanded polytetrafluoroethylene). Biological grafts, such as decellularized bovine heterografts, are also commercially available. However, these biological grafts are more expensive than synthetic grafts

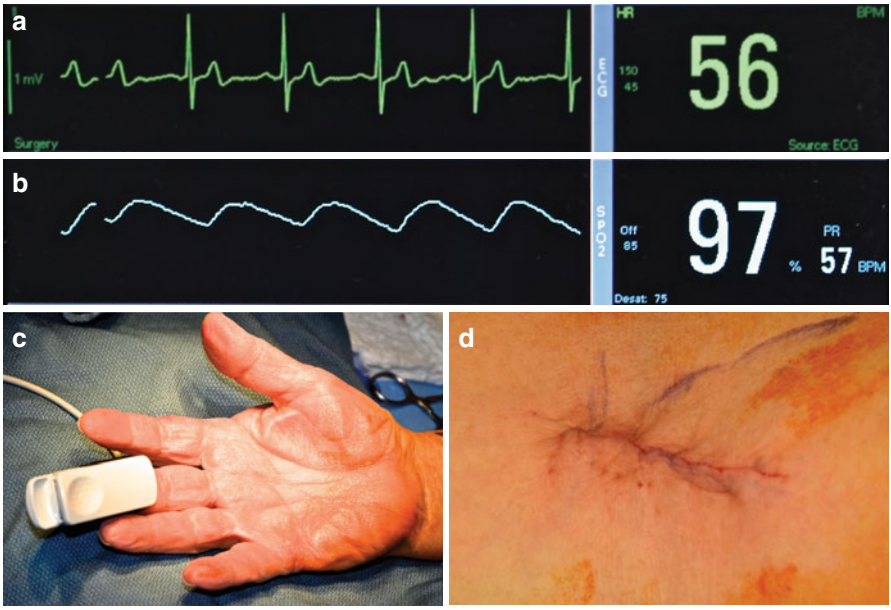

Fig. 17.6 Evaluation of distal circulation and closure of the incision. The distal circulation is evaluated before skin closure. (**a**) Electrocardiographic monitoring. (**b**) Corresponding plethysmography wave and oxygen saturation reading through the probe on a digit of the operated arm (**c**). (**d**) Closed skin incision

Table 17.3 Configurations of prosthetic AV grafts [3]

Arteries	Veins	Comments
Radial	Antecubital (straight)	Less common
Brachial	Antecubital (forearm loop)	Common
Brachial	Axillary, basilic, brachial	Most common
Axillary/Brachial	Axillary, basilic, brachial (upper arm loop)	Less common
Femoral	Femoral (thigh loop)	When arm not suitable
Axillary	Contralateral axillary (chest wall, necklace)	Rare, when extremity access exhausted
Axillary	Ipsilateral axillary (chest loop)	Rare, when extremity access exhausted
Axillary	Ipsilateral internal jugular (chest loop)	Rare, when extremity access exhausted
Axillary	Femoral (body wall)	Rare, when extremity access exhausted

and their superiority for clinical success remains to be established [6]. A graft may be placed at various locations with various configurations (Table 17.3). The following section describes the placement of a 6-mm synthetic AVG in the upper arm in a typical configuration.

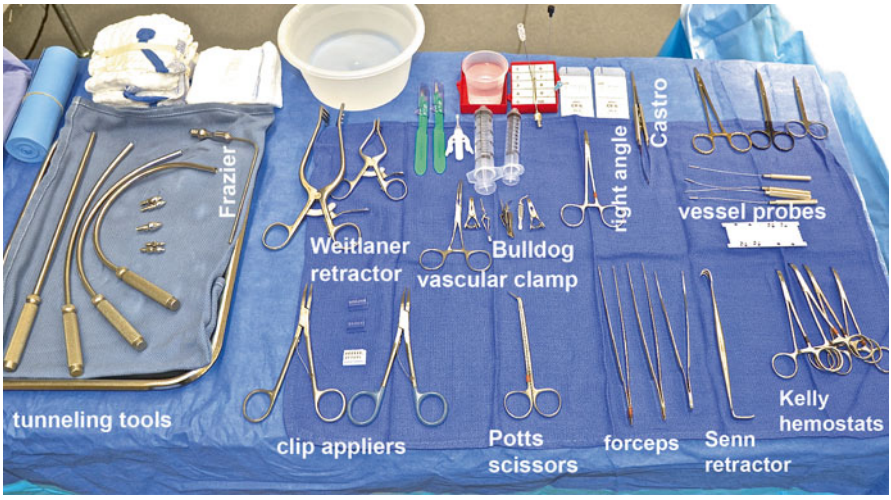

Fig. 17.7 Equipment for AVG placement. Main sterile tools used during AVG surgery

Equipment for AVG Placement (Fig. 17.7)

1. 1–20 of equipment for AVF creation
2. Tunneling tools
3. Graft for hemodialysis (ePTFE – expanded polytetrafluoroethylene)
4. DeBakey vascular clamp
5. Non-absorbable vessel sutures with taper-point needles (CV-6 Gore-Tex™ or 6-0 Prolene ™)

Steps of AVG Placement (Brachiobasilic AVG)

1. Preoperatively, the patient is examined and relevant history is reviewed.
2. Blood vessels on the chosen arm are visualized with ultrasound and surgical plan is formed. Locations of the vessels for anastomosis with the graft are marked (Fig. 17.8).
3. Prophylactic antibiotics (2 g of cefazolin or 1 g of vancomycin) are administered preoperatively.
4. The surgical instruments are organized on a sterile table (Fig. 17.7).
5. The arm is prepared and draped to create a sterile surgical field.
6. Sedation medications (midazolam and fentanyl) are given intravenously tailored to an individual patient. Continuous electrocardiogram, pulse oximetry, and intermittent blood pressure are monitored.
7. Local anesthetic (1 % lidocaine) is infiltrated along the incision sites.
8. An oblique incision is made over the proximal basilic vein using a No. 15 blade. Blunt and sharp dissections are carried out to free 2–3 cm of the proximal

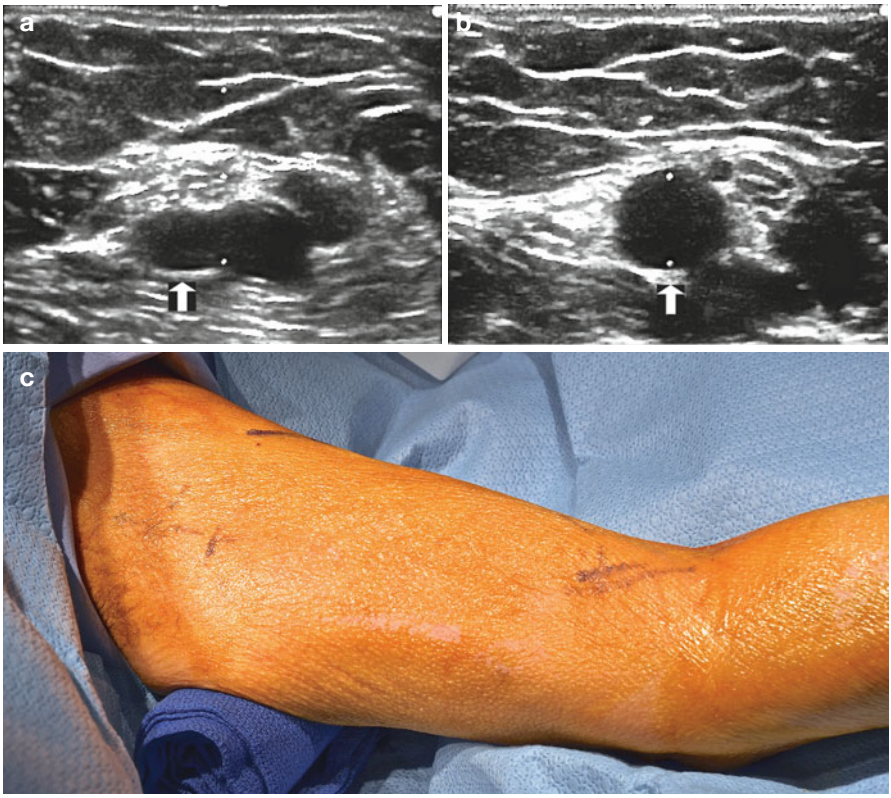

Fig. 17.8 Preparation of the arm for AVG surgery. (**a**) Preoperative ultrasound image of the proximal basilic vein (*arrow*) adjacent to the proximal brachial artery. (**b**) Ultrasound image of the brachial artery (*arrow*) above the elbow crease. (**c**) Prepared arm ready for AVG surgery. Notice the markings on the skin planned based on preoperative ultrasound evaluation

basilic vein from surrounding tissues. A vessel loop is passed around the vein to assist handling. Care should be taken to preserve the adjacent nerves and vessels (Fig. 17.9).

9. A longitudinal incision is made over the distal brachial artery above the elbow crease. Blunt and sharp dissections are carried out to free 2 cm of the distal brachial artery from surrounding tissues (Fig. 17.9).
10. Local anesthetic (0.5 % lidocaine) is infiltrated subcutaneously along the intended graft path using a spinal needle.
11. A tunneling tool with proper curvature and a tip similar to the diameter of the graft is passed subcutaneously from the distal incision to the proximal incision. Attention is made that the tunneling tool is easily palpable from the skin so that the graft will be superficial enough for future cannulation (Fig. 17.10a).
12. The graft is attached to the tunneling tool and pulled through the subcutaneous tunnel (Fig. 17.10b). A graft of 6 mm in diameter or 7 mm in diameter with a 4 mm diameter taper toward the arterial end is typically chosen.

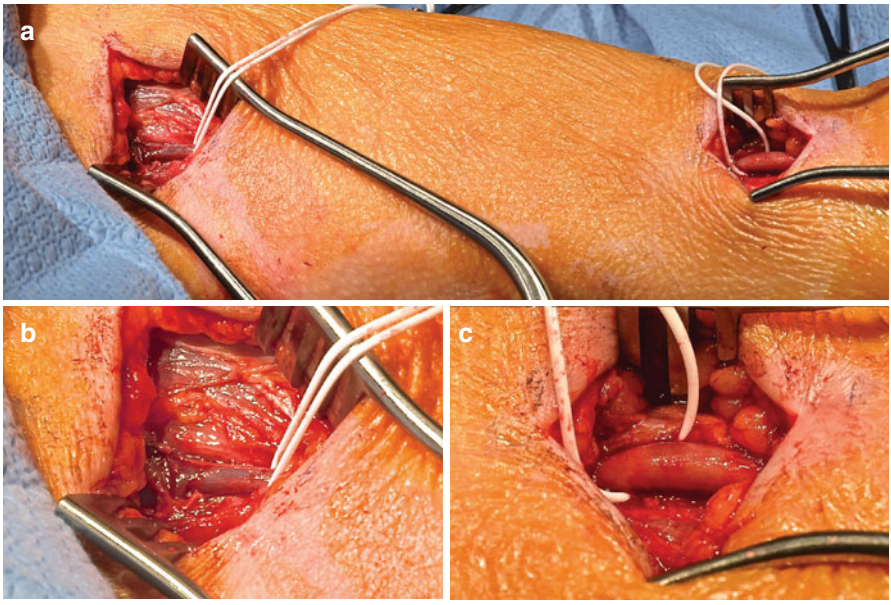

Fig. 17.9 Exposure of the vessels for graft anastomosis. (**a**) Two incisions on the upper arm for exposing the vessels (identified with vessel loops). (**b**) Enlarged view of the exposed proximal basilic vein. (**c**) Enlarged view of the exposed distal brachial artery

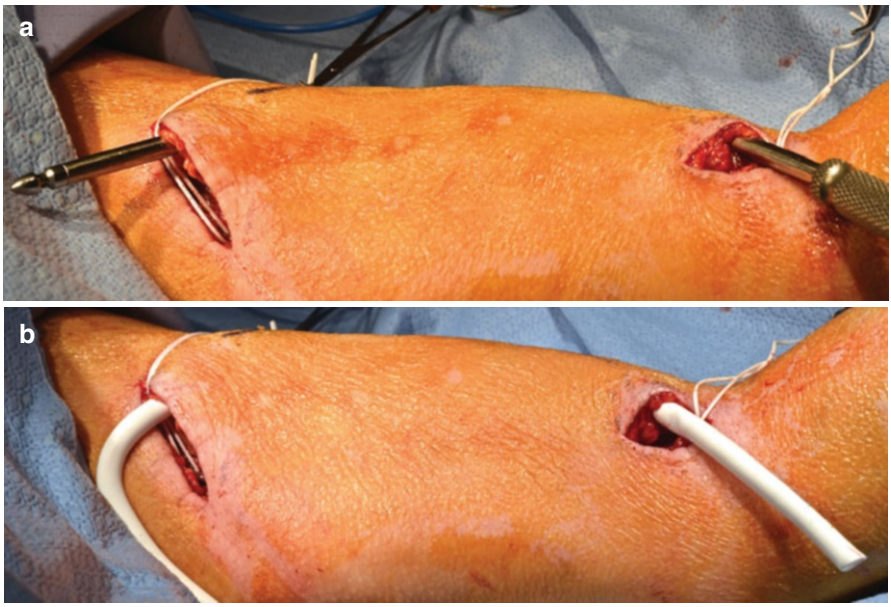

Fig. 17.10 Tunneling of graft. (**a**) A tunneling tool is passed subcutaneously between the incisions. (**b**) The graft is pulled through the tunnel with the tunneling tool

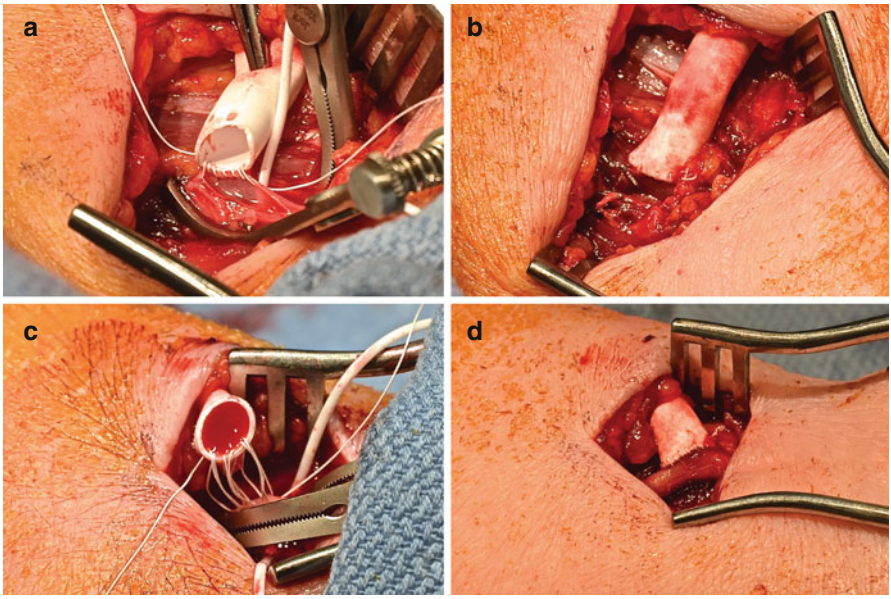

Fig. 17.11 Graft-vessel anastomoses. (**a**) Graft-basilic vein anastomosis – suturing the posterior anastomosis with CV-6 Gore-Tex™ suture. (**b**) Finished graft-basilic vein anastomosis. (**c**) Graft-brachial artery anastomosis – suturing the posterior anastomosis with CV-6 Gore-Tex™ suture using the parachute technique. (**d**) Finished graft-brachial artery anastomosis

13. The graft is trimmed to the proper length for anastomosis. A somewhat oblique trim of the venous end of the graft (beveled) is desirable to increase the circumference of the anastomosis. The venous anastomosis is typically performed first so that the flow through the graft will be immediately established after finishing the arterial anastomosis and there will be no excessive pressure buildup at the arterial anastomosis.
14. Two Bulldog clamps are applied on the basilic vein proximally and distally to control blood circulation. A longitudinal venotomy is made on the basilic vein using a No. 11 blade followed by Potts scissors to match the graft end. Care is taken not to damage the posterior wall. The anastomosis is accomplished using an over-and-over continuous CV-6 Gore-Tex™ suture. The suturing is started at the toe or heel of the anastomosis. The use of parachute suture technique will enable accurate placement of sutures. The remaining anastomosis is completed using the continuous suture. The suture is tied snugly, avoiding "purse-string effect" on the anastomosis (Fig. 17.11a, b).
15. The Bulldog clamps are removed. The graft is flushed with saline from the arterial end. A DeBakey vascular clamp is applied on the graft to prevent back bleeding. Mild oozing at the anastomosis often will stop spontaneously. Any significant leakage at the anastomosis may be repaired with interrupted CV-6 suture. Subcutaneous fat may be sutured to the leakage site to facilitate hemostasis.

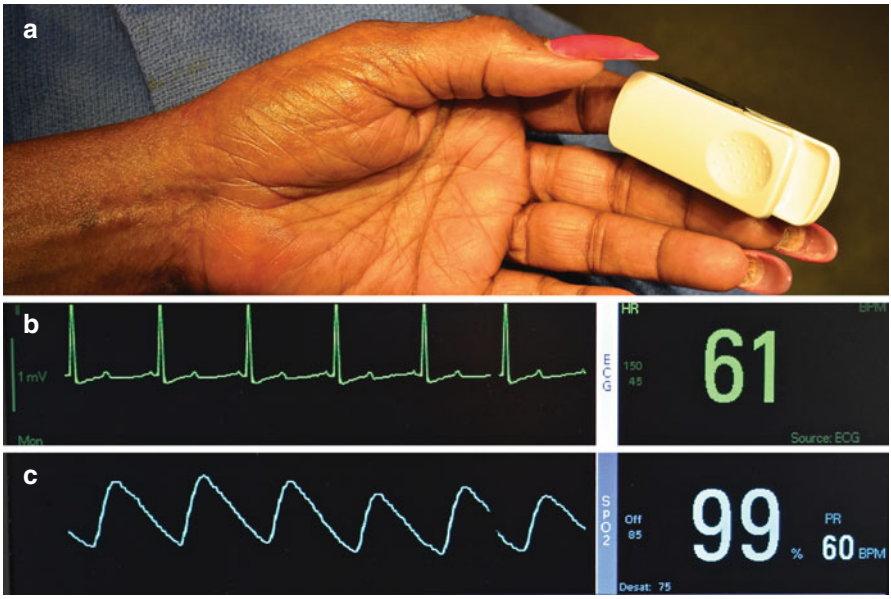

Fig. 17.12 Evaluation of distal circulation. (**a**) A pulse oximetry probe is placed on a finger. (**b**) Electrocardiographic monitoring. (**c**) Corresponding plethysmography wave and oxygen saturation reading

16. Two Glover Bulldog clamps are applied on the brachial artery proximally and distally to control blood circulation. A longitudinal arteriotomy is made on the brachial artery using a No. 11 blade followed by Potts scissors to extend the arteriotomy to 6 mm in length. Care is taken not to damage the posterior wall. The anastomosis is accomplished using an over-and-over continuous CV-6 Gore-Tex™ suture. The suturing is started with the posterior anastomosis. The use of parachute suture technique will enable accurate placement of sutures. The remaining anastomosis is completed using the continuous suture. The suture is tied snugly, avoiding "purse-string effect" on the anastomosis (Fig. 17.11c, d).
17. The DeBakey vascular clamp on the graft is released first, followed by releasing the Bulldog clamps on the brachial artery. Now blood flow through the graft is established. Check the arterial and venous anastomoses for any significant leaks. Palpate the graft for a smooth thrill.
18. Palpate radial pulse if it is palpable preoperatively. Unwrap the hand and check oxygenation on the fingers using oximeter. Good plethysmography wave and oxygen saturation well above 90 % indicate sufficient hand circulation (Fig. 17.12).
19. Check the incisions to assure good hemostasis. The incisions are closed with 3-0 Vicryl sutures in layers: subcutaneous and subcuticular (Fig. 17.13). Sterile strips and dressings are applied, or a skin glue such as Dermabond™ is utilized.

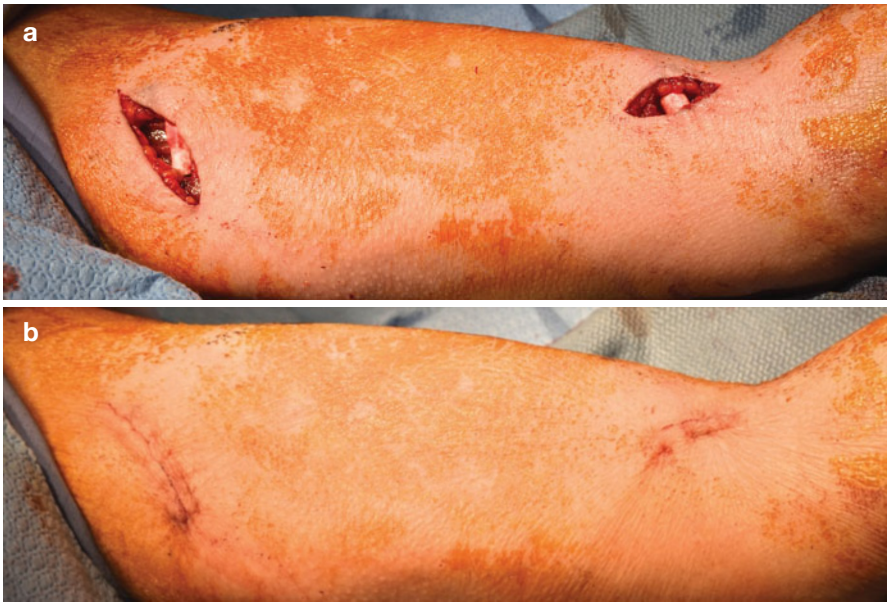

Fig. 17.13 Closure of the incisions. (**a**) Before closure of the incisions. (**b**) After closure of the incisions

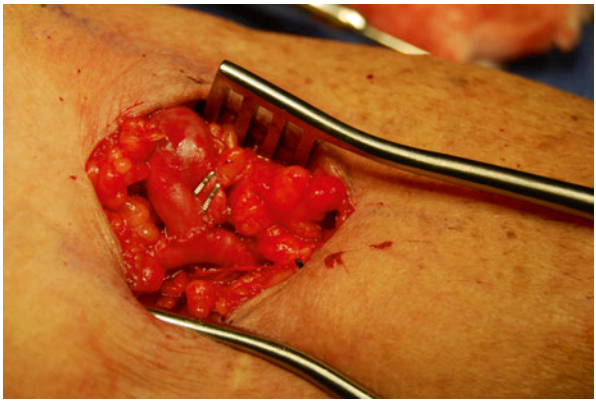

Fig. 17.14 Reduction of fistula vein near the arterial anastomosis with clips

Tips and Troubleshooting

Potential issues and complications that may be encountered during and shortly after surgical creation of AVF and AVG are discussed in Table 17.4.

Table 17.4 Potential issues and complications

Problem	Trouble shooting
Prophylactic antibiotics	Prophylactic antibiotics are not required for most AVF creation. A single preoperative dose of an antibiotic with Gram-positive coverage is standard of care for clean surgical cases. Prophylactic antibiotics are essential given the more extensive nature of the AVG placement and the introduction of prosthetic graft material
Intraoperative heparin	There is no established role of intraoperative intravenous heparin during surgical creation of vascular accesses. However, in patients with history of thrombogenic disorders or early fistula failure, intraoperative heparin may potentially be helpful
Leaks at the anastomosis	Minor oozing at the anastomosis usually stops a few minutes after completing the anastomosis. Significant leaks need to be suture repaired. An interrupted suture or U-shaped suture is typically sufficient. For larger leaks, especially at the corners, a piece of subcutaneous fat may be applied over the leaking hole when additional sutures are applied
Distal ischemia: during surgery	When arteries proximal to the radial artery are used as inflow, the arteriotomy needs to be limited to 4–6 mm in length. Also, the arterial anastomosis is completed with a continuous suture to limit excessive future increase of the anastomosis. These maneuvers decrease the incidence of steal syndrome and future development of excessive access flow [3]. After completion of the arterial anastomosis, it is recommended that hand circulation be evaluated before incision closure. A simple approach is to check the plethysmography and digital pulse oximetry after the supplemental oxygen is turned off. If the oxygen saturation is below 90 % and the plethysmography wave is flat, insufficient distal circulation is suggested. The fistula or graft may be compressed to see if the oxygen saturation and wave recovers. A simple technique to enhance the distal flow is to band down the fistula vein or graft with vascular clips (Fig. 17.14). A return of oxygen saturation to >90 % and reliable plethysmography wave suggest sufficient distal circulation
Ischemic monomelic neuropathy (IMN)	IMN is a rare early complication of vascular access surgery. The key feature of IMN is the presence of neurological deficit in the absence of circulatory insufficiency. Timely recognition is crucial and the AVF or AVG needs to be ligated immediately [3]
AVF creation without tourniquet	For AVF creations without pneumatic tourniquet, Bulldog clamps or vessel loops need to be applied on the vein and artery to control blood circulation before performing the anastomosis
Metal clips for graft-venous anastomosis	Besides sutures, specially designed clips may also be used to complete the graft-venous anastomosis. Limited study suggests that they may be associated with reduced anastomosis stenosis [7]

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Surgical Management of Deep Fistula Veins

18

Shouwen Wang

Introduction

Deep veins are increasingly used for creations of arteriovenous fistulas. Not uncommon in patients with chronic kidney diseases, the cephalic veins are too small or have been damaged by repeated phlebotomy or cannulations or have been used for arteriovenous access. In these patients, the usually undamaged basilic veins become preferred for arteriovenous fistula creations [1]. However, the basilic veins usually cannot be cannulated directly and require transposition before use. Additionally, the prevalence of obesity is increasing, causing the cephalic veins too deep for direct cannulations. These deep veins pose additional challenges for creating functional autogenous arteriovenous fistulas. The goal of surgical management is to render these fistula veins easily cannulatable for hemodialysis therapy.

The basilic vein is located in the medial-posterior aspect in the forearm, making it awkward for cannulation. A transposition to the anterior aspect of the forearm will facilitate its use. The basilic vein is located deep in the medial aspect of the upper arm and is always accompanied by the medial cutaneous nerve; therefore, it should not be cannulated without transposition.

Various surgical techniques have been used to transpose the basilic vein, which is discussed further in the ensuing sections. The author prefers basilic elevation transposition approach for its potential advantages: reduced procedure time and reduced incidence of swing segment stenosis (the author's unpublished data).

There has been debate on one-stage versus two-stage basilic vein transposition in the literature. In one-stage transposition, the native vein is transposed and the arteriovenous anastomosis is created during the same surgical session. In two-stage

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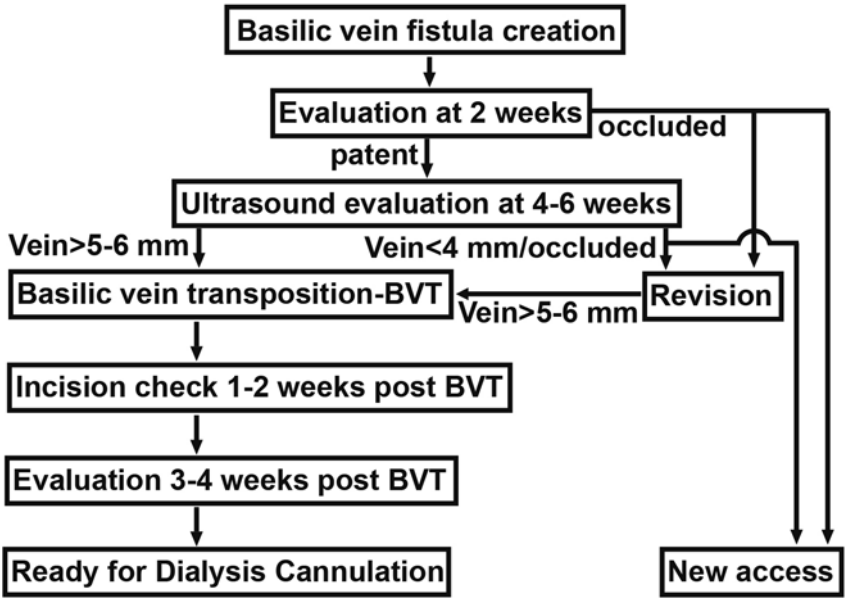

Fig. 18.1 A flow-chart of two-stage basilic vein fistula creation. Similar flow chart may be applied to managing deep cephalic veins

transposition, an arteriovenous anastomosis is created first to allow the vein to grow and the vein transposition is performed several weeks later. Most data support that two-stage approach is associated with improved clinical outcomes, even though it takes longer time for the fistula to be functional. One-stage approach may be considered if the native basilic vein is already 5–6 mm in diameter [2]. The author prefers two-stage approach, a flow chart of which is presented in Fig. 18.1.

Deep vein transposition can be safely performed in an outpatient setting or same-day surgical suite of a hospital. General anesthesia or regional nerve block has often been employed for these surgical procedures. Additionally, local anesthesia plus conscious sedation generally provides sufficient comfort for patient going through these procedures. One advantage of conscious sedation is that nerve injury can be minimized as the patient can still respond to nerve stimuli during surgery, with a caveat of some patient discomfort when nerves are stimulated. The following section describes basilic vein transposition as a second stage procedure performed under local anesthesia plus conscious sedation.

Equipment for Basilic Vein Elevation Transposition (Fig. 18.2)

1. Syringes (10 and 20 ml), needles (25 gauge)
2. 1 % lidocaine solution (without epinephrine, may also use 1 % lidocaine + 2 % prilocaine + 8.4 % sodium bicarbonate in a 10 + 10 + 2 ml combination)

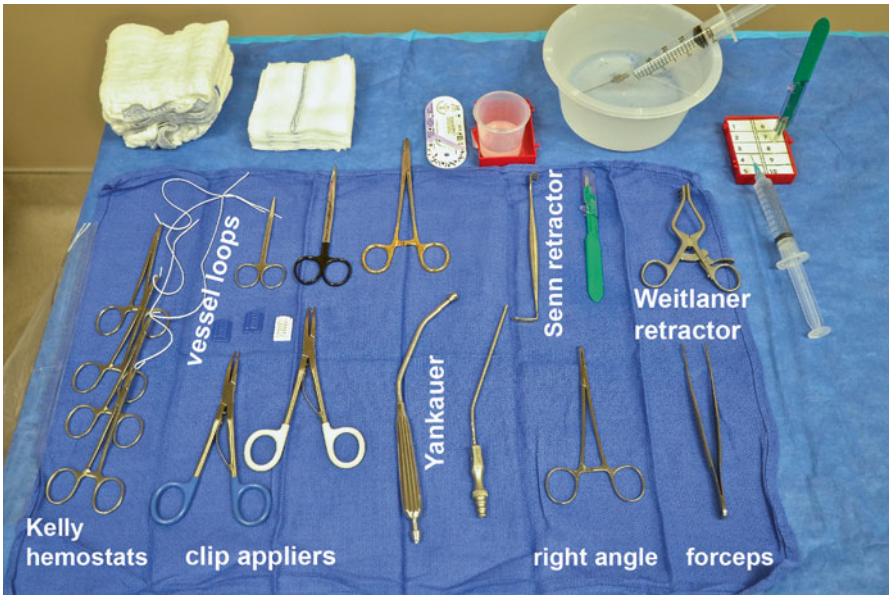

Fig. 18.2 Equipment for basilic vein transposition. Main sterile tools used during vein elevation transposition surgery

3. Gauze (4″×4″) and Lap sponges
4. Surgical blades (No. 15)
5. Scissors (Tenotomy scissors for tissue dissection; suture scissors)
6. Forceps (DeBakey)
7. Electrocautery unit, grounding pad and monopolar handswitch pencil
8. Vessel clips and clip appliers (small and medium, Ethicon™)
9. Vacuum suction equipment, tubing and tips (Yankauer and Frazier)
10. Retractors (Weitlaner with dull jaw; Senn)
11. Kelly hemostats, right-angle hemostat, and needle holder
12. Vascular loops (round rubber band for holding vessels or nerves)
13. 2-0 silk suture with needle and 3-0 silk tie suture
14. Jackson-Pratt drain set (optional)
15. 3-0 suture for skin (Vicryl™ – absorbable)
16. Sterile strips
17. Coban™ elastic bandage.

Steps of Basilic Vein Elevation Transposition (Second Stage)

1. Preoperatively, the patient is examined and relevant history is reviewed.
2. The basilic vein is visualized with ultrasound and its path is marked (Fig. 18.3a).
3. The surgical instruments are organized on a sterile table (Fig. 18.2).

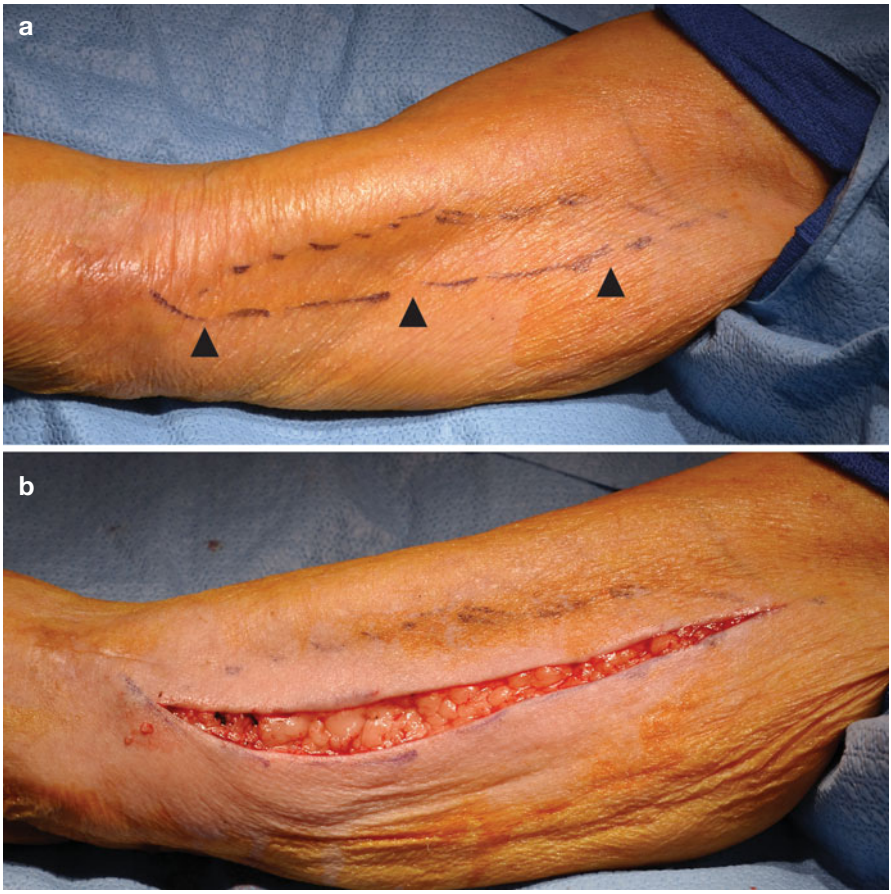

Fig. 18.3 Surgical planning and incision. (**a**) The basilic vein is marked based on preoperative ultrasound (*lower line*) and the planned new location of the basilic vein is indicated (*upper line*). (**b**) An incision is made over the basilic vein after lidocaine infiltration

4. The arm is prepared and draped to create a sterile surgical field.
5. Sedation medications (midazolam and fentanyl) are given intravenously. The starting doses of these medications need to be tailored to an individual patient. A dedicated nurse monitors continuous electrocardiogram, pulse oximetry, and intermittent blood pressure.
6. Local anesthetic (1 % lidocaine) is infiltrated along the incision site.
7. A longitudinal incision is made over the basilic vein (Fig. 18.3b).
8. Blunt and sharp dissections are carried out to free the basilic fistula vein from surrounding tissues. The dissection is extended several centimeters proximal to the incision to ensure a smooth transition when the vein is transposed. Care is taken to preserve the accompanying medial cutaneous nerve (Fig. 18.4).
9. The anterior subcutaneous tissue is infiltrated with 0.5 % lidocaine (Fig. 18.5a). The subcutaneous tissue is then dissected with scissors to create a pocket (Fig. 18.5b).

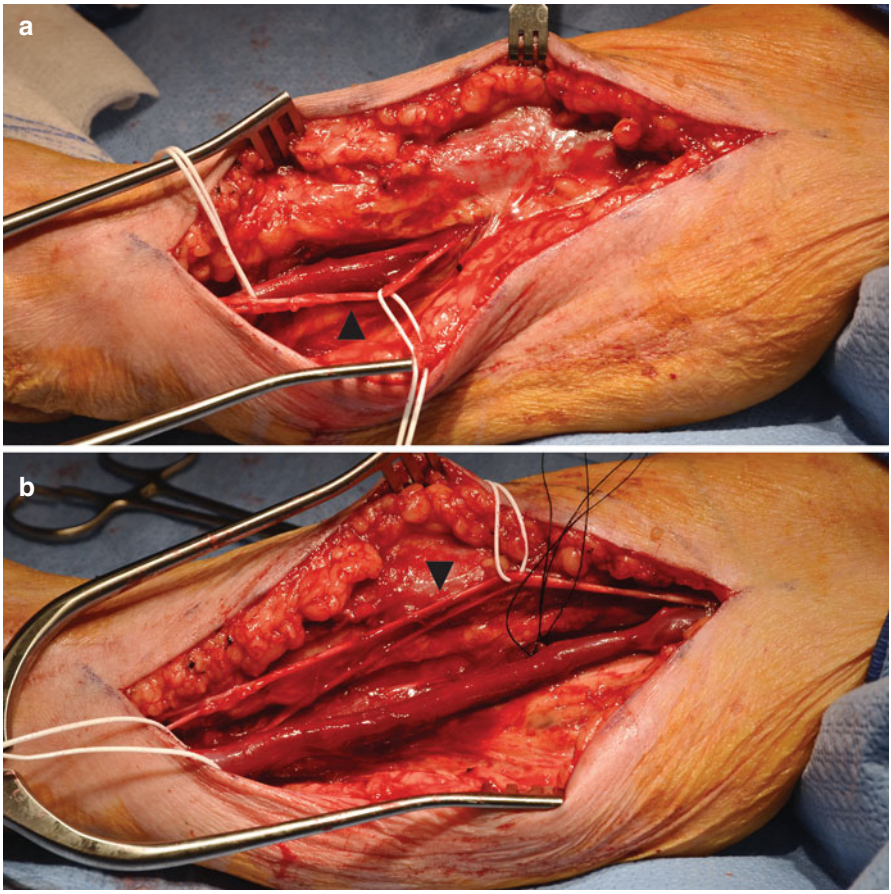

Fig. 18.4 Isolation of the basilic vein. (**a**) Careful dissection is carried out in the lower portion of the upper arm to isolate the basilic vein. (**b**) Further dissection is performed to free up the proximal basilic vein, and side branches are tied off or clipped. The medial cutaneous nerve is separated away from the basilic vein (*arrowheads*)

10. The excessive subcutaneous adipose tissue may be carefully trimmed along the intended basilic vein path (Fig. 18.6). Hemostasis is achieved by cauterization.
11. The basilic fistula vein is swung anteriorly to the subcutaneous pocket and fixed in position by suturing the subcutaneous tissue to the lateral soft tissue or fascia of the biceps muscle with non-absorbable silk sutures. It is preferred to start the fixation distally (Fig. 18.7). Care is taken that the sutures will not cause compression of the basilic fistula vein and the swing segments both distally and proximally have smooth transitions (Fig. 18.8a).
12. The proximal basilic fistula vein is compressed to make sure that the basilic fistula vein is easily palpable from the skin along its transposed path (Fig. 18.8b).
13. A Jackson-Pratt drain is placed along the incision to prevent postoperative fluid accumulation (Fig. 18.9).

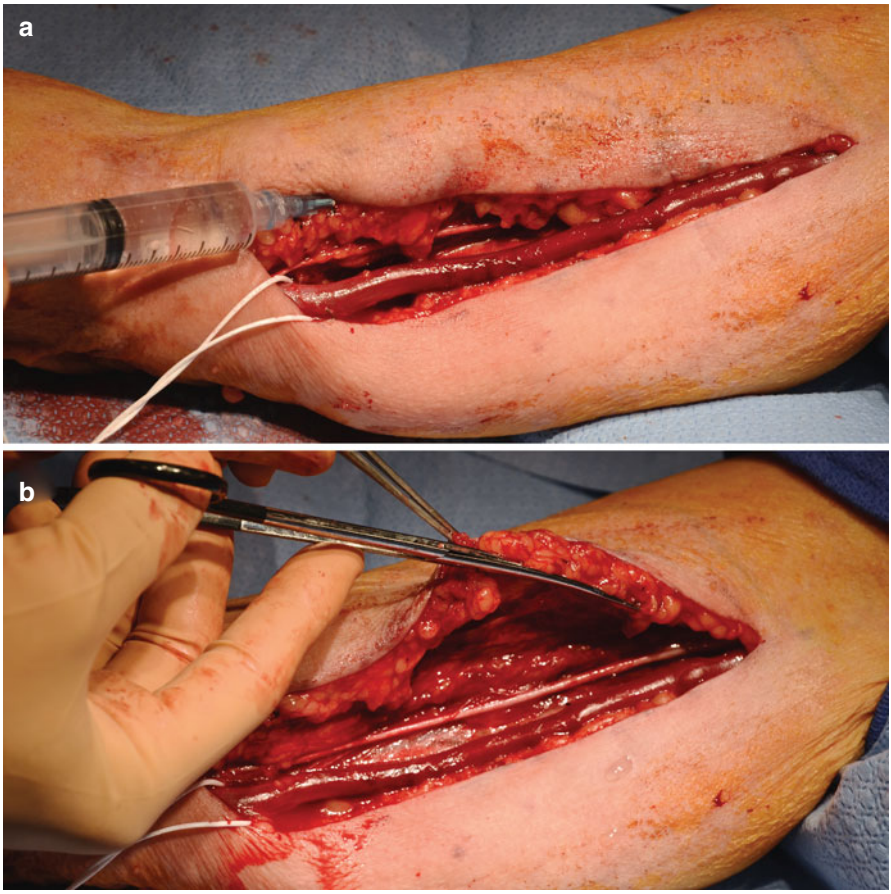

Fig. 18.5 Creation of anterior pocket. (**a**) The subcutaneous tissue is infiltrated with 0.5 % lidocaine. (**b**) The subcutaneous tissue is separated with scissors

14. The subcutaneous layer is closed with intermittent 3-0 Vicryl™ suture (Fig. 18.9). Care is taken not to puncture the transposed basilic fistula vein.
15. The skin is closed with a continuous subcuticular 3-0 Vicryl™ suture (Fig. 18.10a). The bulb reservoir is then attached to the Jackson-Pratt draining tube and suction is applied (Fig. 18.10b).
16. Sterile strips and dressing are applied.
17. An elastic bandage may be applied snugly on the arm to minimize minor blood oozing and provide support to the surgery site. Care is taken not to cause significant compression of the basilic fistula vein.
18. The Jackson-Pratt drain is removed in 2 days.

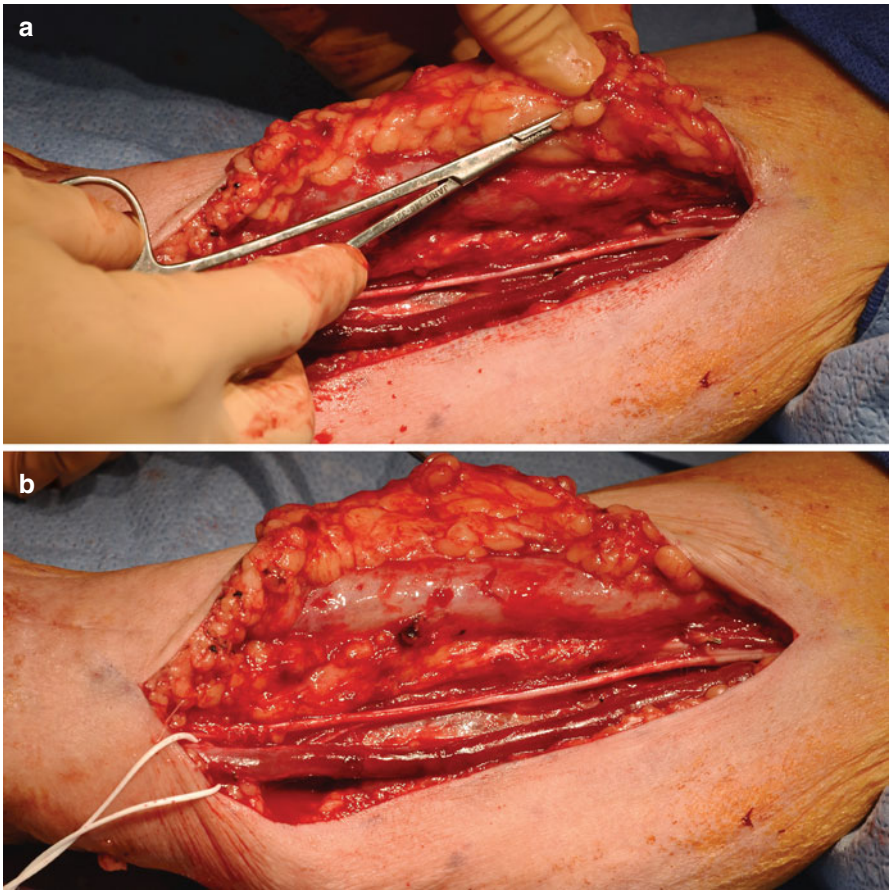

Fig. 18.6 Creation of anterior pocket – continued. (**a**) Hemostasis is achieved by cauterizing small bleeders. Excessive subcutaneous adipose tissue along the new vein path is carefully trimmed if needed. (**b**) The anterior subcutaneous pocket is ready to accommodate the basilic vein

Other Surgical Techniques for Superficialization of Deep Fistula Veins

Transposed basilic vein fistula is one of the preferred autogenous arteriovenous access types [1, 2]. Traditionally, the basilic vein is transposed by tunneling it through a subcutaneous track (Fig. 18.11). While it is effective, a common complication associated with tunnel transposition is proximal swing segment stenosis that often causes dysfunction of a fistula [3]. The development of such lesion may be partially due to twist (axial torsion) and kink of the swing segment produced during the tunneling process. A simple fistula elevation approach was reported to be useful

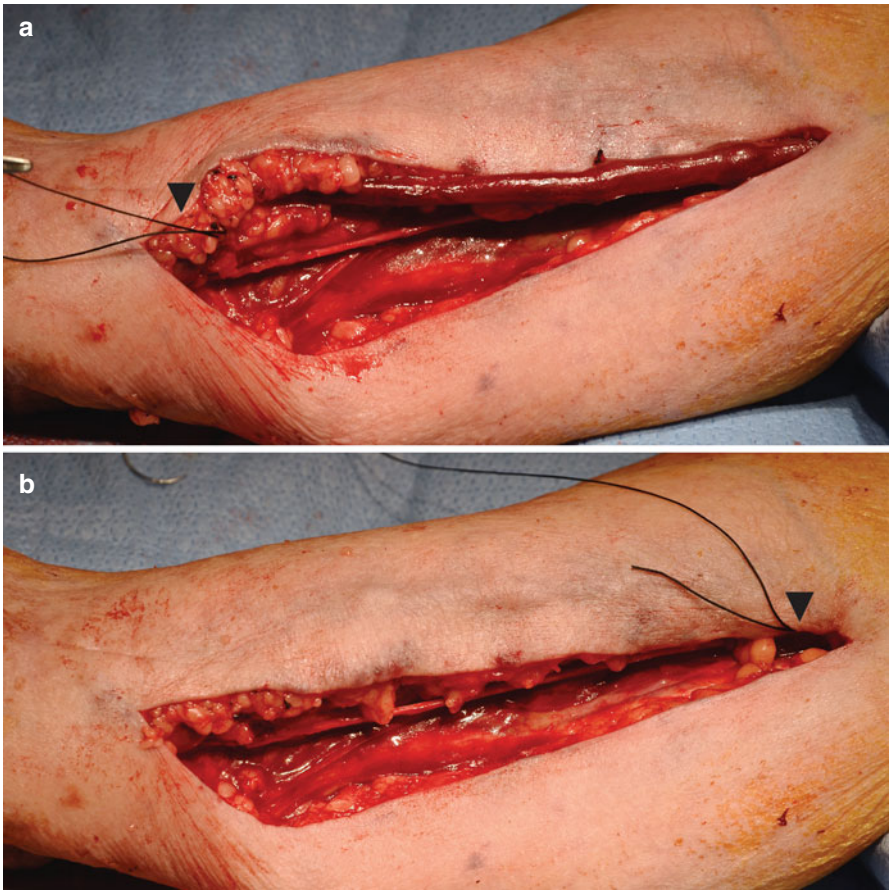

Fig. 18.7 Fixation of the basilic vein. (**a**) The basilic vein is fixated to the anterior pocket by approximating the subcutaneous tissue to the lateral soft tissue or the fascia of the biceps, starting distally. (**b**) several more sutures are applied to secure the basilic vein in the anterior pocket. Care is taken not to compress the basilic vein and not to produce kinks

for superficialization of both basilic and cephalic veins [4]. However, this approach leaves the fistula vein directly under the surgical incision, which may be less desirable for repeated cannulations. The basilic anterior elevation transposition as described in the above section does not require transection and tunneling of the basilic vein, as such the twist and kink in the proximal swing segment is minimized. Based on the author's experience, the typical swing segment stenosis is significantly reduced and the procedure time is reduced as compared with tunnel transposition (the author's unpublished data). Furthermore, since the basilic fistula vein is transposed away from the skin incision, the incision scar will not be in the way of cannulation. Given these advantages, the author prefers the elevation transposition approach (Table 18.1).

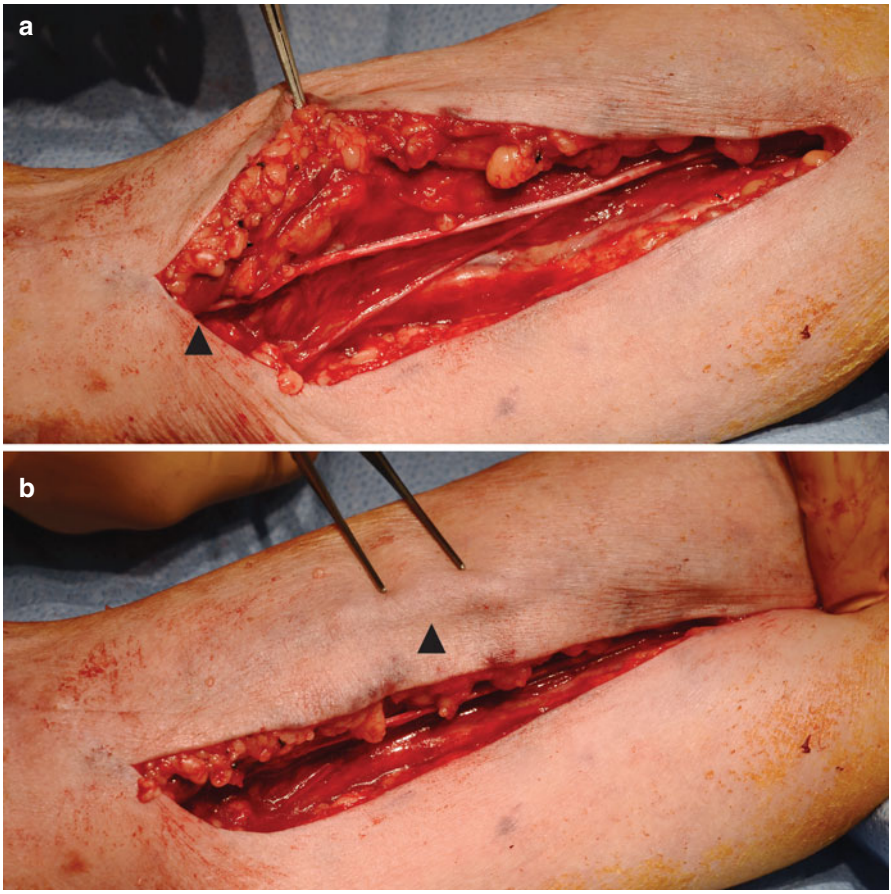

Fig. 18.8 Assessment of the transposed basilic vein. (**a**) The distal and proximal swing segments of the basilic vein are examined to assure smooth transition (*arrowhead*). The fistula thrill should be smooth, soft, and easily palpable along its path. (**b**) The proximal basilic vein is compressed to assess the palpability of the basilic vein along its path. Notice bulging of the basilic vein (*arrowhead*)

Surgical approaches for superficializing basilic veins have been employed to superficialize deep cephalic veins: tunnel transposition [2], simple elevation [4], and elevation transposition (Fig. 18.12). Additionally, lipectomy (Fig. 18.13) [5] and liposuction [6] have been utilized to superficialize cephalic veins since there is no significant nerve trunk superficial to the cephalic veins (Table 18.2). Lipectomy is relatively easy to perform. Since the fistula vein is not manipulated, future fistula vein stenosis may potentially be avoided. However, it may leave some disfiguration of the extremity and may not be suitable for very deep fistula veins. Different from the initial report of using multiple transverse incisions [5], the author prefers a single longitudinal incision lateral or medial to the fistula vein that is easier for

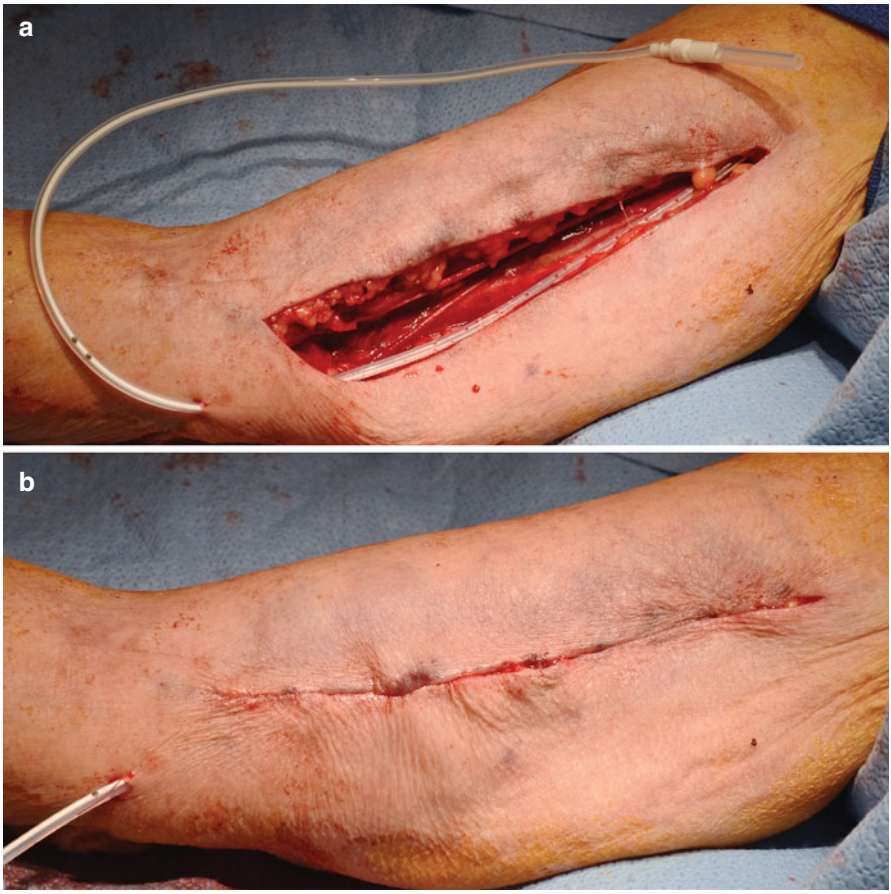

Fig. 18.9 Placement of Jackson-Pratt drain. (**a**) A draining tube is placed to prevent fluid accumulation. This is optional. (**b**) The subcutaneous tissue is approximated with 3-0 Vicryl™ sutures. Care is taken not to puncture the fistula vein during suturing

exposure and leaves no scar on top of the fistula vein. Liposuction has recently been used for removing adipose tissue over cephalic fistula veins and appears to be a less invasive approach. However, clinical data are very limited and more clinical experience is needed to evaluate its safety and effectiveness.

When other veins in the upper extremity are exhausted, the brachial veins may be utilized for arteriovenous fistula creation. Similar to the basilic veins, the brachial veins need transposition. A two-stage approach is preferred since the brachial veins are usually small [2, 7].

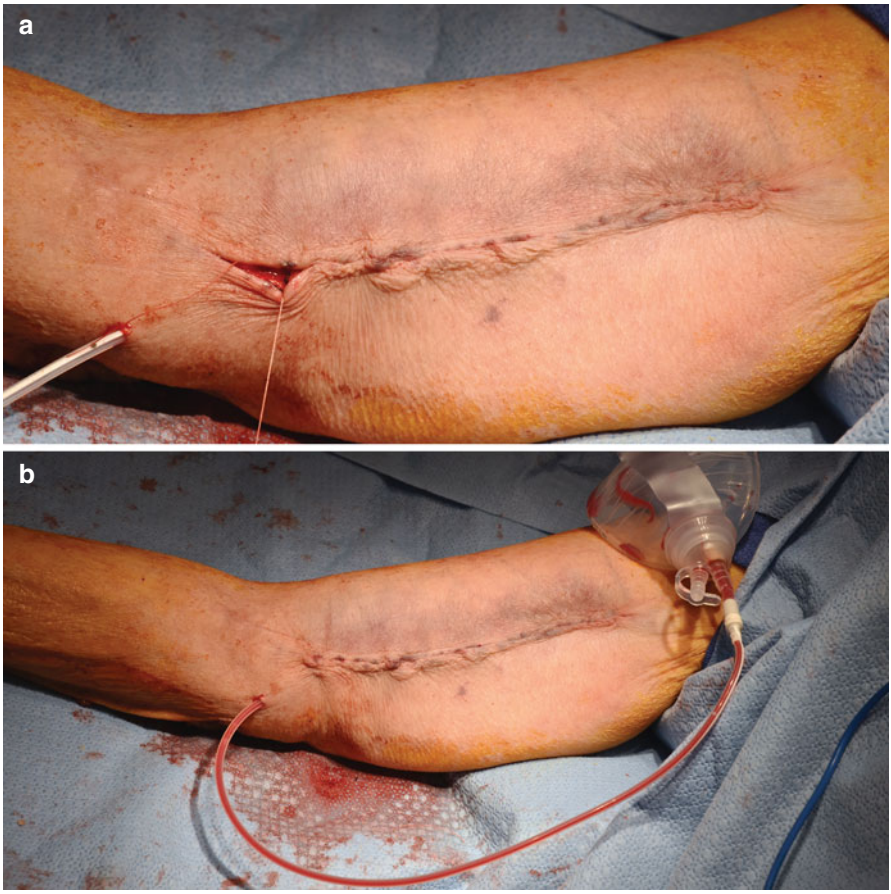

Fig. 18.10 Skin closure. (**a**) The skin is closed with a continuous subcuticular 3-0 Vicryl™ suture. (**b**) The suction bulb of the Jackson-Pratt drain is attached to the draining tube and suction is applied. The draining tube is secured to the skin with sterile strips

Tips and Troubleshooting

Potential issues and complications that may be encountered during and shortly after surgical management of deep fistula veins are discussed in Table 18.3.

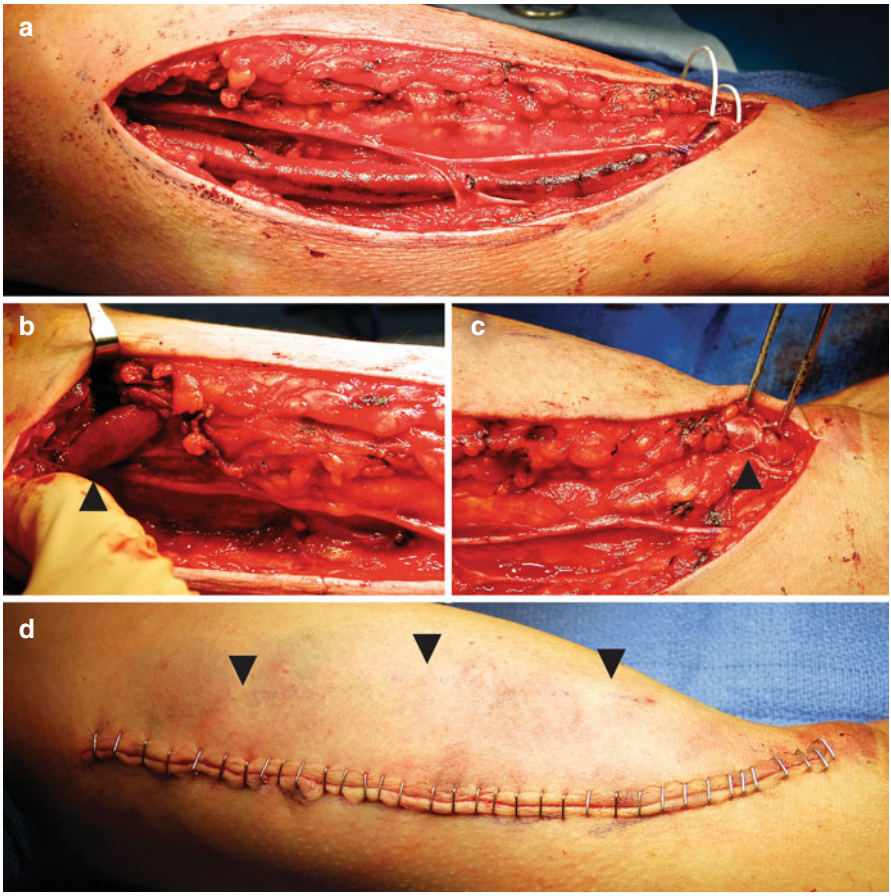

Fig. 18.11 Basilic fistula vein tunnel transposition (second stage). (**a**) The basilic fistula vein is isolated. Notice its relationship with the medial cutaneous nerve. The front surface of the vein is marked with marking pen to aid alignment during tunneling and anastomosis. The basilic fistula vein is then transected distally and tunneled subcutaneously with tunneling tools. (**b**) The proximal swing segment of the basilic fistula vein. (**c**) the distal end-end venous anastomosis after tunneling. (**d**) The incision is closed with sutures and staples. The *arrowheads* point to the location of the transposed basilic fistula vein in its tunnel

Table 18.1 Surgical approaches for superficialization of basilic fistula vein

Surgical approach	Comments
Tunnel transposition	Commonly used approach
	Technically more challenging
	Longer procedure time
	May use multiple small incisions for vein isolation
	Axial torsion and kink of proximal swing segment may cause local fistula vein stenosis
Elevation	Less commonly used
	Easier procedure
	Incision scar on top of fistula vein, less desirable
Elevation transposition	Easier and shorter procedure than tunnel transposition
	Incision scar away from fistula vein, more desirable than elevation alone
	No axial torsion, minimal kink, therefore potentially reduced future swing segment stenosis
	A preferred approach

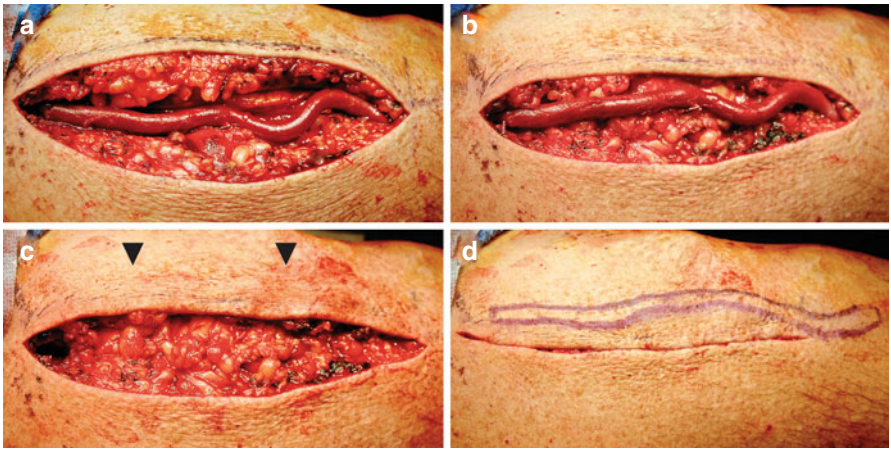

Fig. 18.12 Cephalic fistula vein elevation transposition (second stage). This is a forearm arteriovenous fistula. (**a**) The deep fistula vein is isolated. (**b**) A lateral subcutaneous pocket is created and the subcutaneous tissue is approximated with 2-0 Vicryl™ sutures, leaving the cephalic fistula vein superficial. (**c**) The cephalic fistula vein is fixated to the lateral subcutaneous pocket by suturing the subcutaneous tissues (*arrowheads* indicate the new vein location). (**d**) The skin is approximated with intermittent sutures and subsequently closed with a subcuticular suture. The marking highlights the cephalic fistula vein segment that is easily palpable

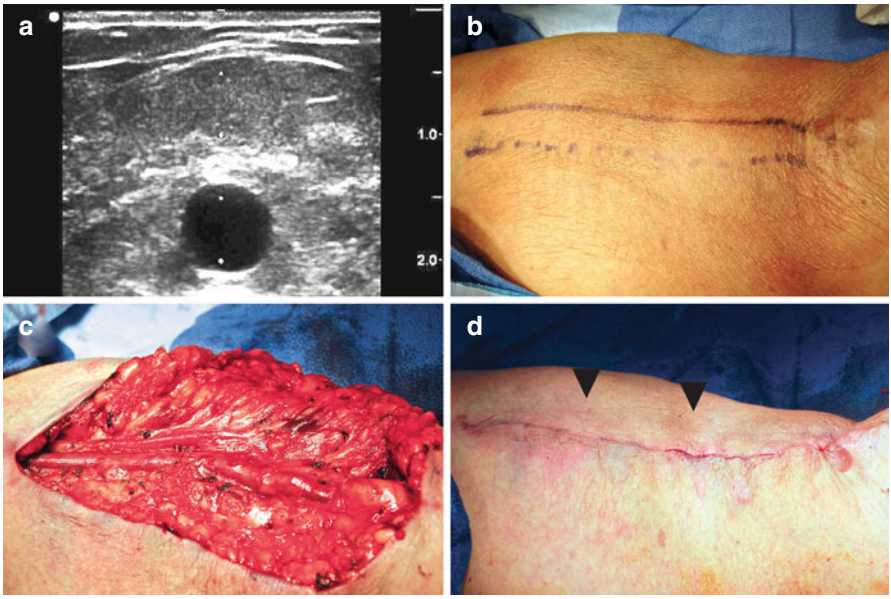

Fig. 18.13 Lipectomy for superficialization of cephalic fistula vein. (**a**) A preoperative ultrasound image shows fistula vein about 13 mm deep. (**b**) An incision is planned (*dotted markings*) medial to the fistula vein (*solid marking*). (**c**) The subcutaneous adipose tissue over the fistula vein is resected carefully. (**d**) The skin is closed. The fistula vein is now just underneath the skin (*arrowheads*). A Jackson-Pratt drain may be used to prevent fluid collection over the fistula vein

Table 18.2 Surgical approaches for superficialization of cephalic fistula veins

Surgical approach	Comments
Tunnel transposition	See corresponding comments in Table 18.1
Elevation	See corresponding comments in Table 18.1
Elevation transposition	See corresponding comments in Table 18.1
	A reliable alternative to other approaches
Lipectomy	Easier procedure, more suitable for forearm fistula
	The fistula vein is not moved, avoiding future lesions
	May cause some disfiguration of the extremity
	Not suitable for very deep fistula veins
	Different from the initial report of using multiple transverse incisions [5], a single longitudinal incision lateral or medial to the fistula vein may be preferred based on the authors' experience
Liposuction	Newer approach, not commonly used
	May be performed through very small incisions
	Ultrasound guidance may be needed for safety
	May leave some disfiguration
	Importantly, more clinical experience is needed to evaluate its safety and effectiveness

Table 18.3 Potential issues and complications

Problem	Trouble shooting
Prophylactic antibiotics	Prophylactic antibiotics are needed given the more extensive nature of these surgical procedures. A single dose of an antibiotic with Gram-positive coverage (such as 2 g of cefazolin or 1 g of vancomycin intravenously) is administered preoperatively
Intraoperative heparin	Since the fistula flow is not interrupted, no intraoperative heparin is needed for elevation transposition
Medial cutaneous nerve	The medial cutaneous nerve is typically located on top of the basilic vein in the upper arm. This nerve needs to be isolated from the basilic vein. The basilic vein can generally be elevated and transposed anteriorly after being separated from the nerve. If necessary, the nerve fiber may be gently separated longitudinally to give way to the basilic vein
Distal ischemia	Occasionally, distal ischemic symptoms may develop after the first stage creation of a basilic arteriovenous fistula. Plethysmography and digital pulse oximetry may be used to confirm the decreased distal circulation. Doppler ultrasound may be used to evaluate the arterial circulation and fistula blood flow. If excessive fistula flow contributes to the distal ischemia, a simple technique to limit fistula flow is to band down the fistula vein close to the arterial anastomosis with external Dilator-assisted Banding (e-DAB) or clips during second stage vein transposition. E-DAB is achieved by tying a 3-0 silk suture over the vein and a dilator placed external to the vein (typically 10 French = 3.3 mm). The internal diameter of the vein lumen will be similar to the outside diameter of the dilator after removal of the dilator. The concept is similar to the internal Dilator-assisted Banding as reported before [8]. A return of oxygen saturation to >90 % and reliable plethysmography wave suggest sufficient distal circulation
Minimizing wound complications	A long incision is generally required to isolate sufficient length of basilic vein for transposition. One concern of long incision is potentially increased incidence of incision complications: infection, delayed healing, or skin necrosis. These complications may be minimized with prophylactic antibiotic use, meticulous surgical techniques during surgery and incision closure, and limited dissection when creating the anterior or lateral pocket. A Jackson-Pratt drain can reduce fluid accumulation and may potentially reduce incision complications. Some authors suggest using multiple small incisions when isolating the fistula vein. However, small incisions are more suitable for tunnel transposition approach

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Preoperative and Postoperative Care for Hemodialysis Vascular Access Surgery

19

Shouwen Wang and Nahel Elias

Introduction

Preoperative evaluation and postoperative care are integral parts of successful hemodialysis access surgery [1]. Clinical information pertinent to vascular access selection and creation are essential to proper planning and operative success. Likewise, organized postoperative care is required in order to minimize surgical complications and achieve a functional dialysis access, as well as avoiding unnecessary futile procedures that would not yield to a functional dialysis access.

Preoperative Evaluation

Creating a functioning arteriovenous (AV) access requires careful preoperative evaluation and planning. The scope of preoperative assessment is: to obtain patient history and to perform physical examination relevant to vascular access selection, to select vascular image studies needed for a patient, and to formulate a patient-specific plan for creating a proper long-term dialysis access or protecting vasculature for future dialysis access creation.

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Equipment for Preoperative Evaluation

1. Sphygmomanomter for blood pressure measurements.
2. Duplex Doppler ultrasound machine for vessel mapping and evaluation (Fig. 19.1a).
3. Pulse oximeter for assessing peripheral circulation (Fig. 19.1b).

Components of Preoperative Evaluation

1. **Decide when a patient needs surgical evaluation.** It is recommended that patients with advanced CKD (late stage 4, eGFR < 20–25 ml/min) who have elected hemodialysis as their choice of renal replacement therapy, and are candidates for it, be referred to an access surgeon in order to evaluate and plan construction of AV access [1].
2. **Obtain patient history relevant to vascular access.** Certain clinical factors are associated with increased difficulty of establishing a functional AV access (Table 19.1).
3. **Perform physical examination relevant to vascular access.** Physical examination may reveal important clues that may affect access planning (Table 19.2).

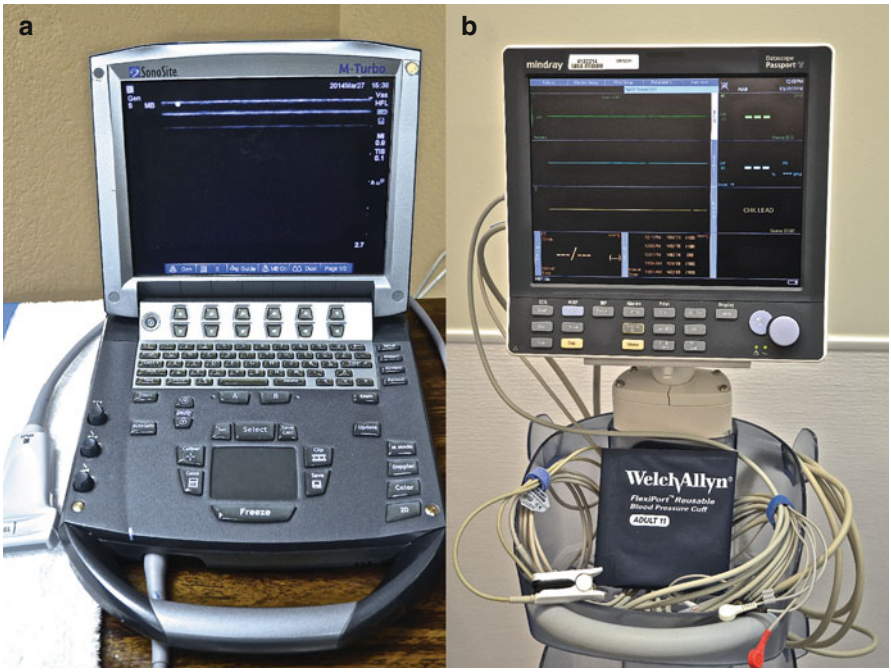

Fig. 19.1 Equipment for preoperative and postoperative evaluation. (**a**) Portable Duplex Doppler ultrasound machine. (**b**) Data monitor, for monitoring electrocardiogram, blood pressure, plethysmography and oximetry

4. **Use ultrasound imaging to assess vasculature relevant to dialysis access.** Ultrasound vessel mapping of both veins and arteries of the upper extremity is of critical importance for access planning. An understanding of the anatomy of the upper extremity vessels is required for documentation and planning [3].

Table 19.1 Patient history relevant to vascular access selection

Components	Specific history relevant to vascular access
Demographic	Advanced age, female gender
Co-morbid conditions	Diabetes mellitus, peripheral vascular disease, severe congestive heart failure, stroke, lupus, sickle cell disease, skin diseases, cigarette smoking, intravenous drug abuse
Hypercoagulable states	Recurrent thrombotic events may prompt screening for: hyperhomocystinemia, factor V mutations, etc.
Medications	Warfarin, clopidogrel, aspirin, immunosuppressive medications or chemotherapy
Prior dialysis access	History of failed or failing dialysis access
Prior procedures involving related vasculature	Hemodialysis catheters, central venous catheters, PICCs, pacemakers, defibrillators, arterial catheters, cardiac surgery, trauma, breast surgery and axillary lymph note dissection
Social history and overall condition	Social support structure, working profession, overall medical condition and life expectancy

Table 19.2 Physical examination relevant to vascular access selection

Components	Specific findings and relevance to access surgery
Body habitus	Body mass index, shape and fatty tissue of the upper extremities, depth of veins: may limit access selection or dictate the need for vein elevation
Skin	Forearm eczema, extensive solar keratosis, thin and fragile skin: upper arm access may be more suitable
Neurological	Neuropathy, motor or sensory abnormality: help to differentiate with ischemic steal syndrome and may influence access planning
Cardiac	Evidence of congestive heart failure (edema, rales): need to be managed before access surgery
Central vein devices	Location of current or prior hemodialysis catheter or pacemaker or defibrillator: imaging of the central vein may be required to assess possible stenosis
Arterial examination	Palpation of brachial, radial, and ulnar arteries: evaluate the health of potential arterial inflow for AV access
	Bilateral arm blood pressure check: unequal readings suggest arterial disease
	Barbeau's test (more accurate than Allen's test): assess the adequacy of palmar arch and ulnar artery circulation for forearm access [2]
	Sites of previous arterial catheter or arterial donation for coronary revascularization: absence of radial artery or potential stenosis
Venous examination	The arm veins inspected with and without a venous pressure tourniquet: outflow veins need to be uninterrupted and distensible
	The presence of enlarged superficial veins on the chest or arms: suggesting central vein stenosis or occlusion

Ultrasound can assess the diameter, depth, patency, continuity, and distensibility of relevant veins. The distensibility of the veins may be assessed with and without a venous pressure tourniquet. The vein diameters with tourniquet applied are recorded and used as criteria for autogenous access creations (Fig. 19.2a). Both diameter and distensibility have been found to independently predict AV access success. Arterial diameters and abnormalities such as high brachial bifurcation can be easily identified by ultrasound examination. Arterial calcification and venous intimal hyperplasia or stenosis may also be easily visible on ultrasound imaging, which may substantially affect access planning [1]. Since the ultrasound images are fragmented, a freehand diagram may be employed to supplement the ultrasound images for documentation (Fig. 19.2b).

5. **Perform contrast venography if clinically indicated.** Contrast venography needs to be considered if history and physical findings suggest a central vein stenosis or occlusion. It may also be used for peripheral vein mapping, particularly when ultrasound imaging is not available. Compared to ultrasonography, venous mapping by venography provides better data on continuity, branching, and central vein patency, while it is limited in assessing distensibility and depth. Limiting the quantity of contrast and hydration are the key strategy for contrast nephropathy prophylaxis in patients with advanced chronic kidney disease. The risk of contrast nephropathy is very low when low dose contrast is used. When adequate ultrasound peripheral vein mapping has been performed for a patient, contrast venography can be limited to visualize the axillary and central veins only in order to minimize contrast quantity. Make sure the arm is fully elevated during contrast injection to enhance central vein visualization (Fig. 19.3).
6. **Formulate patient-specific surgical plans.** Arteriovenous fistulas (AVF) are generally preferred over arteriovenous graft (AVG) given the advantages the AVFs have. [1, 4] Specific recommendations should be followed in order to optimize the AV access options for a patient (Table 19.3). In some clinical scenarios, AVG may be preferred over AVF that is discussed further in a previous chapter. The guiding principle in this decision-making process is to choose the access option that will be best suited to a specific patient. A best access for a patient will provide sufficient access flow to meet the patient's long-term dialysis therapy needs while having the least potential for complications and requiring fewest interventions.
7. **Protect vasculature for future AV access creation.** Instrumentation of veins and arteries may cause damage of these vessels and dramatically affect their suitability for AV access creation. Specific guidelines or recommendations have been developed regarding phlebotomy, peripheral and central venous catheters [5], cardiovascular implantable electronic devices [6], and transarterial approaches for cardiovascular interventions [2]. Following these clinical precautions in patients with chronic kidney disease will help to preserve related vasculature for future AV access creation and minimize potential complications (Table 19.4).

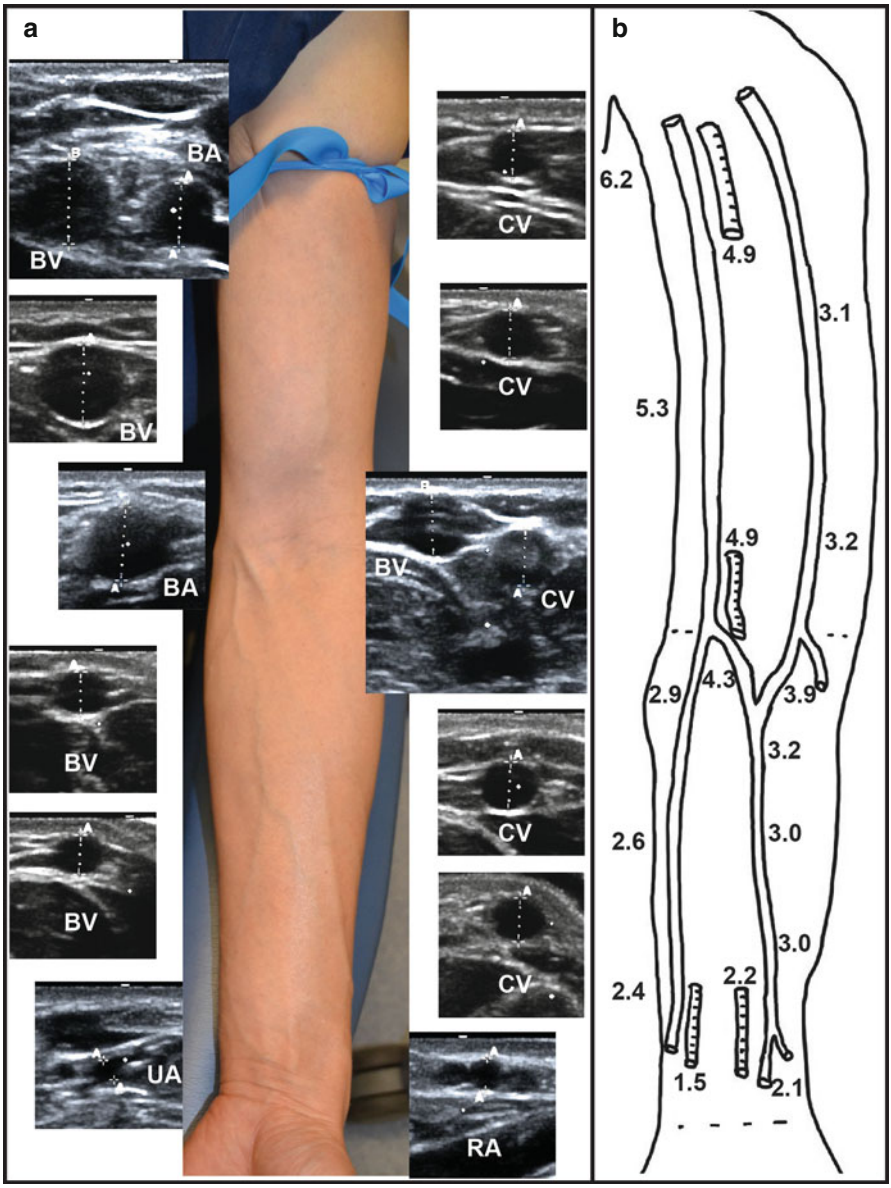

Fig. 19.2 Ultrasound vessel mapping of the upper extremity. (**a**) Photograph of a arm with a venous tourniquet applied and selected ultrasound images showing arm veins and arteries. (**b**) A freehand diagram illustrating the findings of ultrasound vessel mapping. *RA* radial artery, *UA* ulnar artery, *BA* brachial artery, *CV* cephalic vein, *BV* basilic vein. Numbers shown are vessel diameters in millimeters

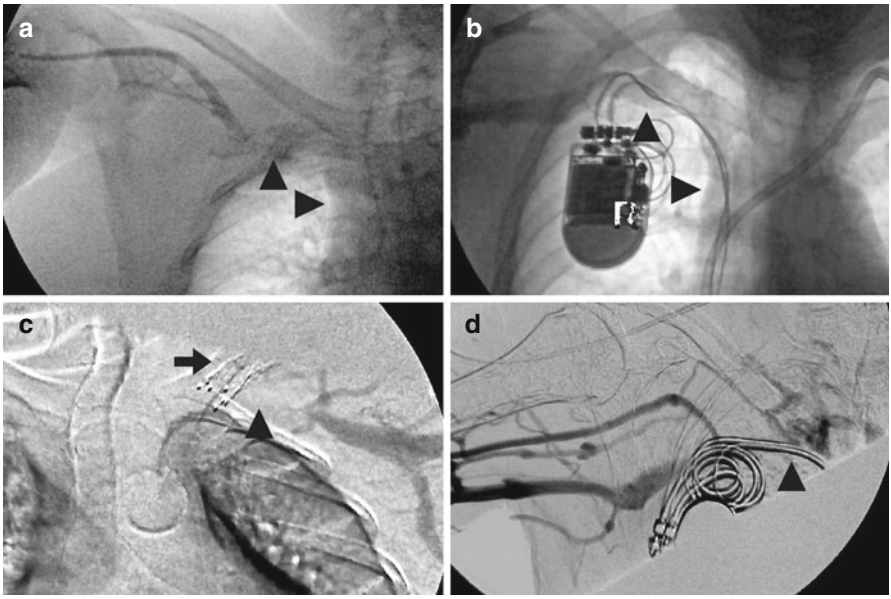

Fig. 19.3 Contrast venography for assessing the patency of central veins. (**a**) Patent central veins (*arrow heads*). Only cephalic vein is highlighted due to needle placement. (**b**) Patent central veins (*arrow heads*) in the presence of a cardiac device. (**c**) Completely occluded subclavian vein (*arrow head*) due to prior cephalic arch stent (*arrow*). (**d**) Severe subclavian vein stenosis (*arrow head*) due to cardiac device wires. Notice the presence of collateral veins

Table 19.3 Key operative strategies to optimize AV access creation [1]

Place arteriovenous accesses distally in the upper extremity in order to preserve proximal sites for future accesses
Consider autogenous AVFs first before prosthetic AVGs are placed
Use upper extremity access sites first, give preference to non-dominant arm when access opportunities are equal in both arms
Select forearm autogenous AVFs first when arterial and venous anatomy is suitable
Choose upper arm autogenous AVF or forearm prosthetic AVG when forearm veins are exhausted
Plan conversion of forearm prosthetic AVG to secondary autogenous AVF at any sign of AVG failure. This may be accomplished by using either the proximal matured outflow veins or veins of remote sites when outflow veins not suitable
Use lower extremity and body wall access sites only when upper extremity access sites have been exhausted

Table 19.4 Recommendations of vessel preservation for AV access

Identify chronic kidney disease (CKD) patients who may need hemodialysis therapy in the future. These include advanced CKD patients or patients with a functional kidney transplant
Both veins and arteries on the upper extremities need to be preserved for future access creation in these patients
The dorsal veins of the hand are the preferred location for phlebotomy and intravenous access
The internal jugular veins are the preferred location for central venous accesses
The external jugular veins are acceptable alternatives for venous access
The subclavian veins should not be used for central venous accesses
Placement of a PICC should be avoided
Cardiovascular implantable electronic devices should be placed contralateral to the side of planned AV access. Alternatively, these devices with epicardial leads need to considered in CKD and dialysis patients to avoid damage to the central veins
Transradial and transbrachial approaches for cardiovascular interventions need to be avoided in CKD and dialysis patients. If these approaches become necessary, their impact on AV access creation need to be properly assessed
Policy and procedure for vessel preservation in CKD patients in healthcare settings should be established

8. **Assess the adequacy of the ulnar artery and palmar arch.** When the distal radial artery is considered for arterial inflow of an AV access, the adequacy of ulnar artery and palmar arch circulation should be assessed prior to surgery. Allen's test has been traditionally used for this purpose. However, this test relies on subjective observation of circulation recovery after arterial compression. Recently, Barbeau's test was developed where transcutaneous pulse oximetry and plethysmography was used to assess the ulnar artery and palmer arch circulation and shown to be more accurate than Allen's test (Fig. 19.4) [2]. Given its advantage, Barbeau's test is preferred when an oximeter is available.

Postoperative Care

Proper postoperative care is a continuation in the effort of creating a functional vascular access. The scope of postoperative care is: to care for incisions, to assess access functionality, to salvage nonfunctional or failed AV access, and to manage access-associated complications.

The postoperative follow-up schedule differs for AVF from AVG. After an AVG placement, the incisions and graft patency are checked in 1–2 weeks. Depending on the type of the graft placed and clinical healing, a graft can be cannulated in 1–2 weeks post placement. Further follow-up is needed if clinical issues with using the

Fig. 19.4 Barbeau's test. An oximeter is used to assess the adequacy of ulnar artery and palmar arch circulation. After radial artery compression, if there is flattening of plethysmography wave and reduction of oxygen saturation, inadequate circulation is suggested

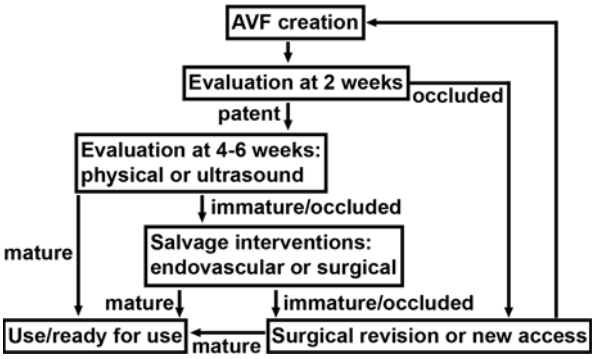

Fig. 19.5 Flow chart of postoperative management after AVF creation. If a fistula fails to mature, various salvage options need to be considered with a goal to optimize the long-term outcome of the access

AVG arise. After an AVF creation, the incision and AVF patency are examined in 10–14 days. If an AVF fails, the patient will need re-assessment for new AV access, typically with clinical and ultrasound evaluation. If an AVF remains patent, its maturation will be assessed 4–6 weeks post creation. A flow chart of management post AVF creation is presented in Fig. 19.5. A non-mature AVF may need endovascular or surgical interventions to become functional: inflow or outflow modification, collateral vein(s) ligation, transposition to more superficial position in the subcutaneous tissue, or other interventions.

Equipment for Postoperative Care

1. 1–3 of equipment for preoperative evaluation
2. Dressings: gauze (2″×2″, 4″×4″), Telfa™ non-adherent pad
3. TipStop® or other compression dressing
4. Elastic bandage wrap (Coban™)
5. Suture removal kit
6. Adhesive tapes
7. Sterile wound closure strips
8. Alcohol wipes

Table 19.5 Assessing the functionality of autogenous AV access

Components	Definitions, findings, and interpretations
Functionality	A mature AVF requires three components: adequate diameter to permit safe cannulation, adequate access flow to permit efficient dialysis, and sufficiently superficial to permit accurate and safe cannulation
	The specific requirements for these components may vary geographically (due to variation in dialysis practices and technical skills)
Physical examination	Physical examination is very valuable tool
	A normal AVF has a soft pulse and continuous bruit, collapse with arm elevation, and augments sufficiently with access compression
	May be used to estimate access diameter, its depth from the skin, the presence of accessory veins, the presence of inflow and outflow stenosis and other abnormalities
Duplex ultrasound examination	Ultrasound is helpful when physical evaluation is equivocal or abnormal findings are present
	Ultrasound may measure the three required components of access functionality
	When access diameter is ≥4 mm, access blood flow is ≥500 ml/min and access is superficial, there is 95 % likelihood of being usable for dialysis [1]
	Ultrasound may identify anatomical lesions and provide guidance for further interventions: venous, arterial, anastomosis stenosis; competing veins or large accessory branches; excessive depth from the skin
Contrast angiography	Contrast angiography can identify anatomical lesions affecting maturation and functionality of AV access
	Corrective endovascular or surgical interventions can be performed at the same time: angioplasty, stenting, obliteration of accessory veins, and surgical revisions

9. Staple removal kit, if staples are used
10. Adhesive bandage (e.g. Bandaid™)
11. Topical antibiotic ointment or cream

Components for Postoperative Care

1. **Care for the incisions.** Uneventful incision healing is generally expected after AV access creations. The incidence of incision complications is typically low. Topical antibiotic ointment or cream may be used for mild inflammation. Rarely, delayed incision healing may need cleaning and re-suturing. Necrotic or infected tissue may need debridement to assure subsequent healing.
2. **Assess the functionality of AV access.** Various methods may be used to assess the functionality of AV accesses, ranging from physical examination to invasive procedures. A prosthetic AVG can be cannulated in 1–2 weeks provided the graft remains patent, and there is no significant tissue edema, peri-graft seroma, or any evidence of infection. The assessment for the functionality of an autogenous AVF is conducted 4–6 weeks after creation and requires considerable experiences and expertise (Table 19.5, Figs. 19.6 and 19.7).

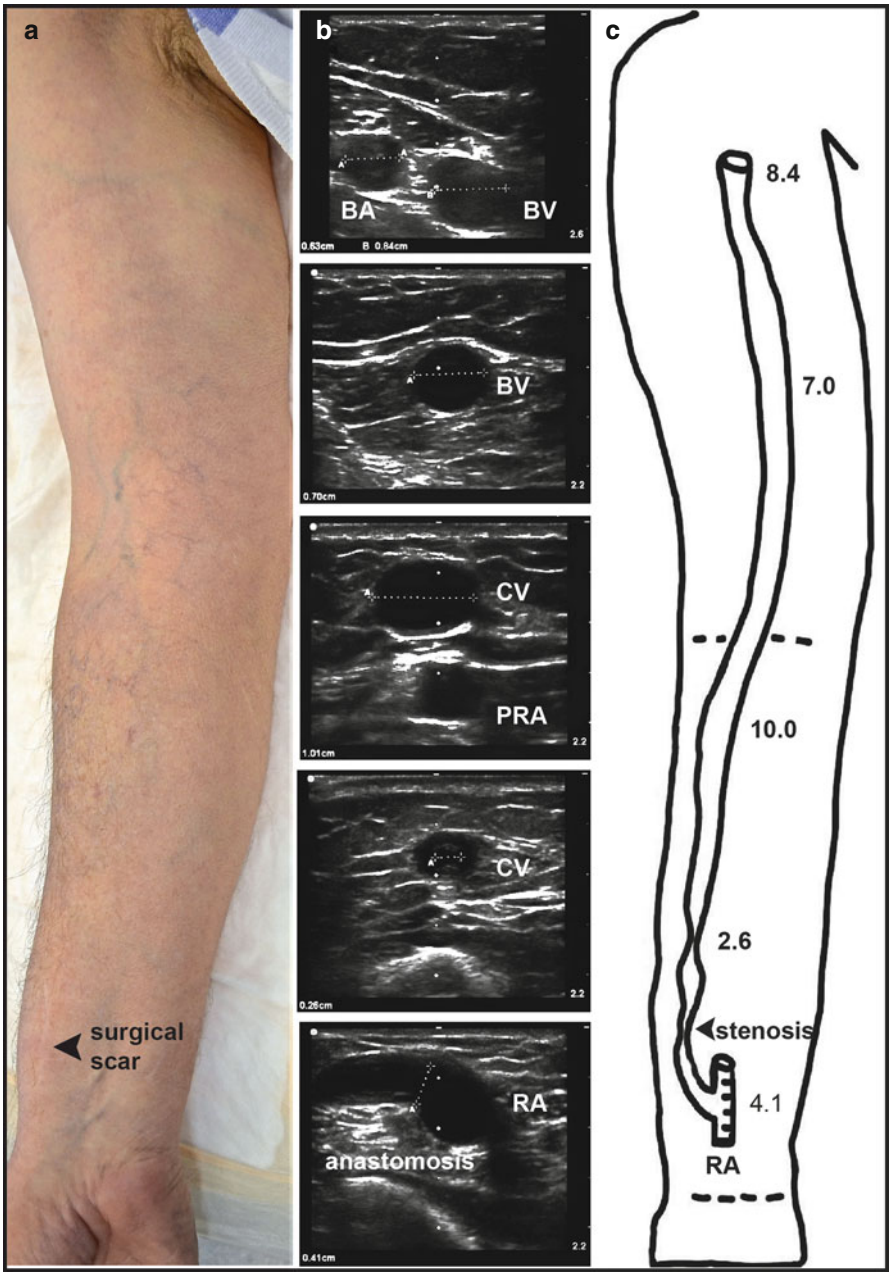

Fig. 19.6 Ultrasound evaluation of an AVF. (**a**) Photograph showing an arm with a forearm AV fistula. (**b**) Selected ultrasound images of the fistula conduit. (**c**) A freehand diagram may be used to illustrate the ultrasound findings as a supplement. Stenotic lesions of the cephalic vein are identified in this study. *RA* radial artery, *PRA* proximal radial artery, *CV* cephalic vein, *BV* basilic vein. Numbers shown are vessel diameters in millimeters

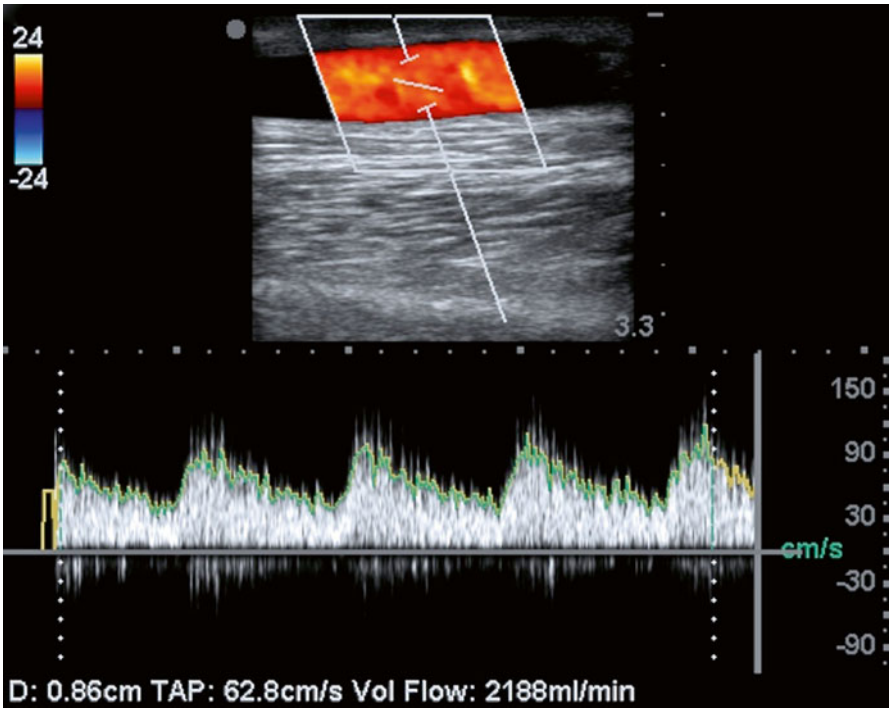

Fig. 19.7 Doppler ultrasound evaluation of AVF flow. Doppler ultrasound may be employed to measure the fistula flow non-invasively. This measurement may supplement the findings of physical examination and ultrasound imaging

3. **Salvage nonfunctional or failed AV access.** A major challenge of AV access surgery is that relatively high percentage of AV access created either fail or is nonfunctional at initial evaluation. Encouragingly, most of these AV accesses can be saved and used subsequently for hemodialysis therapy. Open surgery, endovascular interventions, or a combination of both may be employed to successfully salvage these AV accesses. The choice between open and endovascular interventions may be influenced by clinical scenario and local expertise. Specific clinical situations and management considerations, are presented in Table 19.6 [1].
4. **Manage AV access-associated complications.** AV access-associated complications may occur in the early postoperative period (<30 days) or subsequently that may require surgical attention. Common early postoperative complications may include incision complications, hematoma or other fluid collections, and distal ischemia. Common late access-associated complications may include venous hypertension, ischemic steal syndrome, aneurysm, bleeding, high-output heart failure, and infection. Brief discussions of these complications and their management are presented in Table 19.7 and 19.8 [7, 8].

Table 19.6 Management of nonfunctional or failed AV access

Clinical situations	Management considerations
Access too deep	A deep AV access needs to be managed to avoid difficulty with cannulation and trauma to the patient
	A deep prosthetic graft is typically due to technical error during placement. Consider lipectomy, graft revision or new graft
	A deep AV fistula should be evaluated with ultrasound first to identify anatomical details. Consider elevation, lipectomy, or transposition
Side branches	Large (>2 mm), patent side-branch may affect AVF maturation especially if it has significant flow (The presence of bruit while transiently occluding the main outflow vein proximally is a good indicator)
	A fistula needs to be image studied to rule out stenosis that may cause side branch dilation
	Consider surgical ligation or endovascular coil embolization if no stenosis identified
Insufficient arterial inflow	More often an issue for AVF than AVG
	Arterial anastomosis stenosis most common, followed by subclavian artery stenosis
	Consider angioplasty or surgical revision
Poor venous outflow	May locate anywhere along the access conduit
	Common locations are post-arterial anastomosis segment for AVF and venous anastomosis for AVG
	Consider endovascular intervention or surgical revision
Thrombosis	A major complication of AV accesses
	May occur for various reasons. Stenotic lesions of the artery, anastomosis, or veins often present
	Mainstay of clotted access management is clot elimination and treatment of stenotic lesions
	Endovascular techniques, open surgical management, or combination of both may be employed to restore patency of a clotted access

Table 19.7 Management of AV access-associated complications [7]

Complications	Management considerations
Bleeding	Perioperative or post dialysis cannulation
	Etiology multifactorial, platelet dysfunction, aspirin, clopidogrel, warfarin, venous obstruction
	Consider: Vasopressin, cryoprecipitate, estrogen, restore red cell volume, enhanced dialysis, direct pressure, suture, repair or revision, angioplasty
Infection	May be related to surgery (early, <30 days) or dialysis cannulations (late, > 30 days)
	Bacteria of skin origin are most common
	Much more frequent in AVG than in AVF
	Duplex ultrasound or tagged leukocyte scan may help evaluation
	AVF: may resolve with antibiotics or local surgical intervention
	AVG: requires partial or total excision of graft

Table 19.7 (continued)

Complications	Management considerations
Fluid collections (noninfectious)	Differentiate from abscess and pseudoaneurysm
	Hematoma may simply be observed or aspirated
	Seroma is related to prosthetic graft. Consider: aspiration, debridement or graft replacement
	Lymphocele or lymphorrhea may be managed by compression or surgical exploration
Pseudoaneurysm and aneurysm	Pseudoaneurysm occurs mostly in AVG, rarely in AVF. Consider observation, surgical repair or revision, stent-graft placement (avoid if possible)
	Aneurysm occurs in AVF. Only need intervention if there are associated complications
Venous hypertension	Due to outflow obstruction and increased access flow
	Often manifest as edema or access dysfunction
	Catheters and cardiac devices are major culprits
	Side-side AV anastomosis may cause incompetent valve and retrograde venous hypertension. Consider retrograde branch ligation
	Central vein stenosis: consider angioplasty, stent-graft, and surgical bypass
	Regional stenosis (such as graft venous anastomosis and cephalic arch stenosis): angioplasty, stent-graft, and surgical bypass or outflow transposition
	Superior vena cava obstruction has worse clinical consequences
Distal ischemia (steal syndrome)	Incidence higher with AVG than with AVF
	Over half develop within 30 days of surgery
	Clinical presentations vary
	Cases with mild symptoms may be observed
	Cases with significant symptoms need clinical and arteriogram evaluation and further management
	Table 19.8 lists pathologies and management options
High-output heart failure	Rare, essentially a complication of autogenous AVF
	Differentiate from heart failure not related to access
	Present as right heart failure
	AV access flow >3 L/min or >30 % of cardiac output is consistent with diagnosis, but heart failure may occur at lower access flow. Symptoms typically improve after access flow management
	Consider access flow reduction procedures, rarely access ligation
Neuropathy	Peripheral neuropathy is very common in patients with advanced kidney disease or on dialysis
	Diabetic and uremic polyneuropathy are bilateral
	Ischemic monomelic neuropathy is rare and characterized by neural deficit without arterial insufficiency. Need access ligation or revision urgently
	Entrapment neuropathy (median or ulnar nerve) is common in dialysis patients and may be incited or exacerbated by AV access creation. Consider decompression if symptoms are significant
	Electrodiagnostic studies may help differentiation and guide management

Tips and Troubleshooting

Potential issues and complications that may be encountered before and after surgical creations of AVF and AVG are discussed in Table 19.9

Table 19.8 Managing distal ischemia based on underlying pathologies [8]

Clinical pathologies	Management considerations
Excessive access flow	Flow reduction procedures (DAB or balloon assisted banding, RUDI)
	May need reconstruction of inflow segment if this segment is large (>15 mm), plus DAB
Artery stenosis proximal to anastomosis	Angioplasty, possible stent
Artery stenosis distal to anastomosis	Angioplasty, stent if possible
	Flow reduction, PAI
Distal radial artery ischemic steal	Flow reduction
	Occlusion of distal radial artery
Distal ulnar artery ischemic steal	Flow reduction
	Occlusion of distal ulnar artery
Ulnar artery lesion in radiocephalic fistula	Angioplasty, stent
	PAI
Low-normal access flow without localized lesion	PAI or DR
	Access ligation if intervention ineffective
Limb/tissue threatening ischemia	PAI
	Access ligation if intervention ineffective
Ischemic monomelic neuropathy	Differentiate from steal syndrome, access ligation urgently

DAB dilator-assisted Banding, *RUDI* revision using distal inflow, *PAI* proximalization of arterial inflow, *DR* distal revascularization (no interval ligation)

Table 19.9 Potential issues and complications

Problem	Trouble shooting
Vasoconstriction (small vessels)	Ambient temperature can significantly influence the diameter of the blood vessels. Low temperature cause vasoconstriction of both arteries and veins, while high temperature causes vasodilation. An ambient temperature of 75–80 Fahrenheit mimics typical natural environments and is recommended during ultrasound vessel mapping
Image studies of vessels relevant to vascular access	Ultrasound vessel mapping: essential, but cannot visualize central vessels
	Contrast venography: mainly used to assess central veins when central lesion suspected
	Arteriography: may consider when there is significant peripheral vascular disease
	MR angiography: rarely used

Table 19.9 (continued)

Problem	Trouble shooting
Strategies for minimizing contrast nephropathy	Limit contrast quantity is a key strategy
	Hydration, may use sodium bicarbonate solution
	N-acetyl cysteine, orally
	Carbon dioxide gas as alternative contrast material. Requires separate equipment
Ischemic steal syndrome (Post surgery)	Distal ischemia may occur any time after an AV access surgery. The incidence is substantially higher after AVG than after AVF creations
	1. Mild-moderate distal ischemia symptoms occur during the early postoperative period may be minimized with intermittent compression of the AVF or AVG by the patient or family member (<5 min at a time)
	2. For significant distal ischemia symptoms during early postoperative period after AVG placements, the AVG may be intentionally thrombosed or ligated. Distal ischemia symptoms often do not return when the graft flow is re-established later (in 2 weeks)
	3. If possible, the etiology of distal ischemia should be investigated endovascularly. The access can be preserved and distal ischemia managed based on underlying pathophysiology (Table 19.8)
	4. If distal ischemia is due to excessive access flow, various techniques may be utilized to limit the access flow to enhance the distal circulation. Dilator-assisted Banding is a simple, economical approach that may be used even without fluoroscopic guidance [8]. Distal circulation may be assessed intra-operatively with pulse oximetry
	5. In patients with significant peripheral vascular disease and the predicted incidence of distal ischemia is high, the proximal brachial artery or axillary artery may be used for anastomosis to minimize distal ischemia
Arm edema post access surgery	Arm edema occurs more frequently after AVG placements than AVF creations. Near peak access flow is produced soon after AVG placements, which is different from the gradual increase of access flow after AVF creations. Arm edema often resolves spontaneously 2–3 weeks after AVG placements, presumably due to adaptation of the vasculature. Persistent edema often suggests draining vein stenosis and needs to be investigated with venography. Arm edema can incite or exacerbate carpel tunnel syndrome, which needs to be differentiated from distal ischemia

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