In the Lab

In contrast to cardiac catheterization in adults, cases in patients with structural heart disease are seldom predictable. Even the most routine catheterization in a patient with congenital heart disease can reveal unexpected findings that completely change the expected course of the procedure. With that said, most cases start and proceed in logical sequence. All cases begin with setting up the table and getting access. Hemodynamic assessment is next, usually followed by angiography and, finally, intervention, if warranted. This is the usual sequence, although exceptions do exist.

Setting-Up the Table

Every case starts with preparing the table. This is where all your equipment is initially placed and prepared for use during the case. The contents of the table will vary from institution but usually include the following at a minimum:

- Gowns, drapes and towels (to cover the patient and physician).
- Syringes and needles of many sizes (for obvious and not-so-obvious purposes).
- A basin for sharps and waste.
- Transducers.
- In-line "closed system" for saline and contrast.
- CO_2 system (essentially a stopcock and a length of tubing).
- Your selected sheaths, catheters, and wires.
- Miscellaneous: sterile covers for imaging equipment, handle for overhead light, etc.

The actual process of setting up the table varies from person to person, and a more senior fellow should be present to help you the first couple of times. Occasionally you will have the good fortune of having the laboratory technicians or support staff set it up for you. But at the start, you should learn to set up the table yourself Fig. 1. The whole process should take less than 5 minutes when you have the hang of it. In the beginning, give yourself more time. Don't delay the case because you are still setting up the table. The following are a few final tips.

- Set up the basins and syringes early so the techs can fill the basins with saline and the cup with contrast.
- Obtain your heparin and lidocaine early and give the lidocaine to the patient sooner rather then later, because it takes time (at least 5 minutes) to reach full effect.
- Ask for bicarb for your lidocaine to decrease injection pain (admittedly, studies on efficacy are mixed).
- Do not stick the technician with the needle when getting the lidocaine.
- Drape the patient as soon as you can. The attending can walk in at any time and may want to start getting access while you finish setting up the table (or vice versa).

Vascular Access

General Considerations

There are two rules you need to remember about access:

Rule #1: You can't cath if you don't have access.

Rule #2: When you have access, don't lose it!

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Fig. 1 Equipment table

Some questions you need to ask yourself to help decide on vascular access are:

- *Where has the patient been accessed previously?* For example, if a patient has had multiple caths, has recent access been from the left femoral vein? If so, it may be because the right is occluded.
- *Are there vessels that are documented to be occluded by angiography, or is occlusion surmised because of a failed attempt?* Check previous cath reports and look at the old angios.
- *Where do I need to go?* For example, if cathing a patient with a bidirectional Glenn, you cannot usually get to the pulmonary arteries from the femoral vein.
- *What access will make the procedure I am doing the easiest?* For example, for a Brockenbrough puncture, access from the RFV is generally easier than the LFV.
- *Are there lines already in place?* Can these lines be used for the case, and what is currently infusing through them?
- *Do I need to leave the lines in post-cath?* Access "from above" (subclavian or internal jugular vein) is better in anyone but a baby if you plan on leaving lines in for care in the ICU. Umbilical lines are sometimes useful to leave in for post-cath care in the newborn.

Keeping the above points in mind, before you get access you need to know how you are going to maintain it. You have essentially two options. First, you can simply leave a catheter in the blood vessel, or second, you can place a sheath. A sheath is a tapered catheter (usually with a hemostasis valve and side-port for flushing) that stays in the vessel and permits catheter changes and exchanges without constantly passing a catheter across the arteriotomy or venotomy (i.e., causing vessel damage). All sheaths come with a removable tapered dilator that fits closely around a specified wire and minimizes vessel and soft tissue trauma as the sheath is placed. The nominal French size of the sheath is the size of the largest catheter that can fit through the lumen of the sheath. So, if you are planning to use a 7-Fr wedge catheter, you'll need at least a 7-Fr sheath (which is closer to 8 Fr in external diameter).

Venous Access

Because multiple catheter manipulations and changes are often required in the venous system we routinely use a sheath in the vein. The size (diameter) of the sheath depends on the size of the catheter you need to put through it. In general, start with the size of the catheter with which you plan to do hemodynamics and angiography, and then if a larger sheath is needed for interventions you can upsize as needed. If you are pretty sure you will need a larger sheath later, you may also consider starting with it. Otherwise, because the most common balloon endhole catheters are 5 Fr and 7 Fr this can guide your initial sheath selection. For example, if you plan on using a balloon end-hole catheter for hemodynamics, choose a 5 Fr for an infant or child (<15–20 Kg) and 7 Fr for a larger child or adult. A 4 Fr sheath also may be considered in a very small child, but recognize that this may limit your subsequent catheter choices somewhat.

If you are using a thermodilution catheter for hemodynamics, remember that there are four lumens in these catheters (end hole, side hole, balloon, and thermister) and only a really tiny (∼useless) wire will generally fit through the end hole. In addition, because there are two lumens for the same French size, the lumens are small and do not transduce pressures well. Therefore, only use the 5 Fr thermodilution catheter in infants and small children <15 kg; otherwise you probably will prefer the 7 Fr thermodilution catheter.

The other consideration in choosing a sheath is the length. We almost always start with a short sheath. The actual length of the "short" sheath varies with the Fr size. The sheaths are intended to reach the common iliac vein from the access site. So, for example, a 5 Fr sheath typically used for a newborn cath needs to be only 7.5 cm long, whereas an 8 Fr sheath in an obese adolescent will likely need to be 11 cm long. Short sheaths are available in sizes 3 Fr to >20 Fr, in increments of one Fr size up to a 12 Fr, and then in increments of two Fr sizes beyond that (e.g., 12, 14, etc.). All short sheaths have an integral hemostasis valve and sidearm. Long sheaths come in a variety of lengths, shapes, and characteristics. The most common long sheaths vary from 45 to 90 cm in length. Not all long sheaths have an integral hemostasis valve and sidearm so you may need to place one yourself. Long sheaths are most often used for the placement of stents and devices, or to secure distal access during PA dilation cases.

Arterial Access

The most common site for arterial access is the femoral arteries, although umbilical and radial are also used. For femoral arterial access, a sheath is not always necessary. If you only want to measure pressures and take angiograms with a single catheter (usually a pigtail) you can simply place that catheter over your access wire and use that for your case. In contrast, if you anticipate multiple catheter manipulations or exchanges you should probably place an arterial sheath. Either way, the most common starting arterial catheter (sheath or no sheath) is a pigtail catheter.

The two variables that determine the size of the pigtail catheter you need are:

1. The amount and rate of contrast needed for angiography, and
2. The patient's length (the pigtail must be ∼ 2/3 of the patient length to reach the apex of the ventricle in a patient with a left aortic arch, and slightly longer if there is a right aortic arch).

Consult the Appendix in this book to help determine the size of pigtail you need. If you just need arterial access for monitoring, a short pigtail of small diameter will do. If you are using a pigtail catheter without a sheath and you get access with a 0.018″ torque wire, be aware that the wire-catheter lumen mismatch can cause arterial trauma as you advance your catheter. Alternatively, if you want to monitor blood pressure during prolonged left-sided interventions, choosing a sheath size that is one to two Fr sizes larger than your catheters will allow you to transduce arterial pressure throughout the case through the side-arm of the sheath.

Technique

The techniques of access described here are all based upon the modified Seldinger technique, which obtains vascular access using a catheter over-a-wire. Seldinger first described this technique in 1953 but it took a while to catch on. Until the early 1970s, access was obtained primarily with a cut-down (surgical) technique. Now that we are proficient at the Seldinger technique, a cutdown is almost never required.

Tools of the Trade

Before you start attempting to get access you should familiarize yourself with the needles and wires commonly used in the catheterization lab, because they are different from those you are probably used to.

Needles

First you need to choose the right needle for access. Generally, we use Cook® access needles. They come in a variety of sizes, which are all color-coded. The most popular sizes are the "pink" ones (18 gauge), which accept a 0.035″

wire (needed for some 5 Fr–6 Fr and all larger sheaths), and the "brown" ones (19 gauge) which accept a 0.025″ (19 gauge) wire or 0.035″ gauge. "Yellow" ones are 20 gauge and accept a 0.018″ wire. If you use these, remember to use as short of a needle as possible, because the resistance from the small lumen can be greater than the venous pressure in longer needles—or more plainly, you may not see a "flash."

"Green" (21 gauge) needles usually come in a Micropuncture® perc kit that includes a short floppy 0.018″ torque, with an inner dilator which follows the 0.018″ wire and larger outer dilator. After the wire position is secured, the inner dilator may be removed and 0.018 ″ wire, leaving an outer dilator that accepts an 0.035″ wire compatible with 7 F sheaths. These kits are useful when you are placing a 7 F sheath but want to use a smaller needle. After the vessel is accessed, place the combination dilator over the wire. The inner dilator is then removed with the 0.018″ wire and a 0.035″ wire is placed. The outer dilator is then removed over this wire and the 7 F sheath is placed.

Usually, because many patients with structural heart disease have elevated central venous pressure, we perc with just the needle, with no syringe on the back. If you are attempting access with a syringe on the back of the needle (e.g., for an IJV) there is often no reason to use a larger needle, because you are probably already applying gentle suction. In these situations we often prefer the yellow or green needle for insertion of smaller sheaths.

All of the access needles described here have a bevel that makes them sharp. One problem with these needles is that they will give blood return even if only part of the needle lumen is in the vessel. This is particularly true for needles with long bevels. If a wire is advanced in this situation, it may not enter the vessel without repositioning. Additionally, most needles are sharpened along the distal beveled sides, so side-to-side manipulation of the needle can result in laceration of tissue or vessels. Be aware of both of these properties as you use the needles.

Wires

A more detailed description of wires is given latter in this manual, but you should be familiar with those commonly employed in obtaining access. Your options are to use the wires that come with the sheaths (if you are using a sheath), or to use more fancy (expensive) wires. The advantage of wires that come with the sheaths is that you know they work with those sheaths. The disadvantage is that they may not be as gentle or as long as you would want or need. The most common catheterization wires used for access at Children's Hospital Boston are straight wires and torque wires (both described in detail in subsequent sections) with torque wires being the more common. These have very floppy, flexible tips that allow them to find their way into small vessels quite nicely. However, you should become familiar with these expensive wires before attempting to use them since they require more technical skill and are easily damaged.

When you have your needle and wire (and catheter or sheath), you are almost ready to go, and the following sections describe access at various anatomic sites in detail. However, two common elements to access anywhere are passing your wire through your needle and exchanging your needle for your catheter or sheath.

Now, after you get that great flash of blood through your needle, you need to put a wire into the vessel. You should always use the soft end of whatever wire you have chosen (this is not always obvious with straight wires). If the wire does not go easily, it is not in the vessel. *Never, ever,* force the wire. This requires additional emphasis: ***If the wire does not go easily, it is not in the vessel, and no amount of forcing it will result in success.*** If a soft torque wire has one or more kinks in it when you take it out, you have pushed too hard. If the wire still does not go easily, make small readjustments to the needle position as you repeatedly try to gently advance the wire out the tip of the needle. Do *not* advance a needle over a wire because you can shear off part of the wire.

When the wire is finally in the vessel, check the position with fluoroscopy to ensure that it is where you think it should be (usually IVC to right of spine, aorta to left of spine). The color of the blood is not a sufficient marker, especially in patients on oxygen or those with cyanotic heart disease. Also, polycythemic patients may have less pulsatility on arterial hits due to the viscosity of their blood. It is better to check your position on fluoro than to put a 7 Fr sheath into the artery by accident! Just watch out for those heterotaxy patients.

Advance enough wire to have a secure position while still allowing enough of the wire outside the body to place your catheter or sheath. Do *not* advance a venous wire so far that it sends the patient into SVT (from atrial stimulation) or an arterial wire so far that it is in the brain or a coronary artery! Advance no wire so far that you lose the wire in the patient (this is considered bad form).

When the wire is in the correct position, fix the wire position relative to the patient and slide your needle off the back of the wire. You can hold the wire at the skin. There may be some bleeding around the wire before you get your sheath in. In this case you can push gently at the access site, but do not push down with such force that you bend the wire. Make a small skin nick with the blade at the wire entry site (not usually necessary for 3 Fr catheters), place the sheath/dilator combination on the back of the wire, and advance it over the wire until you see the wire coming out the back end of the sheath.

Always hold the distal wire fixed in place with the other hand. While holding near the leading end, gently twist the sheath as you advance it through the skin. Never push from the back of the sheath because this will often result in bending or kinking the sheath. Stop if there is resistance and find out why. *Never* attempt to push anything into the body when you meet resistance. After the dilator and sheath are fully advanced, remove the wire. If it is your practice, take 1 cc of blood from the (unflushed) dilator for an ACT and then remove the dilator. Flush the sheath. Avoid injecting air.

What do you do if you get a wire into the vessel but it does not advance very far? First check the wire course on fluoroscopy to make sure that it is not curled-up in the subcutaneous tissue or in a side-branch. If it appears to be in a vessel, try leaving the wire in place, removing the needle and inserting a 20-gauge IV cannula or 3 F dilator over the wire. When the cannula is in place, you can remove the wire and inject some contrast to see if the vessel is occluded. If, after you have removed the wire, you do not get blood return, you are probably not in a vessel. Do not inject contrast unless you can get blood return. When taking an angiogram, make sure to use biplane fluoroscopy. This is really the only sure way to demonstrate occlusion of the femoral or iliac vessels.

HINT: *This may seem obvious on paper, but in practice you will save yourself aggravation if you ensure that the perc needle accepts the wire you plan to use, and that the sheath or catheter you plan to use fits that wire. Until you are quite comfortable with establishing access, you should do a dry run of the needle, wire, sheath, and catheter on the table to be sure they are compatible* ***before*** *sticking the patient.*

Femoral Access

Positioning

There is not a great deal of room for error when establishing access in a tiny child. Positioning the patient is key for smooth femoral access. This is so important it bears repeating: ***Positioning the patient is key for smooth femoral access!*** Most cath lab technicians or nurses are excellent at doing this. Take note of how they do it so you can emulate their technique in the CICU and anywhere else you are called upon to place a line. The patient is appropriately then sedated and restrained. The pelvis is elevated just above the plane of the body, the femur is slightly externally rotated.

Landmarks (Figure 2)

1. *The inguinal ligament*

The inguinal ligament runs between the anterior superior iliac spine and the pubic tubercle. The inguinal ligament is your friend. Its major function is to keep the femoral arterial blood from entering the retroperitoneal space when you make a hole in the femoral artery. However, the inguinal ligament can only do its job if the hole you make in the femoral artery is *below* the ligament! Note as well that where you enter the skin is inferior to where you enter the vessels. The vessel *entry site* must be below the inguinal ligament!

2. *The femoral crease*

The femoral crease usually lies a few centimeters below the inguinal ligament. The femoral

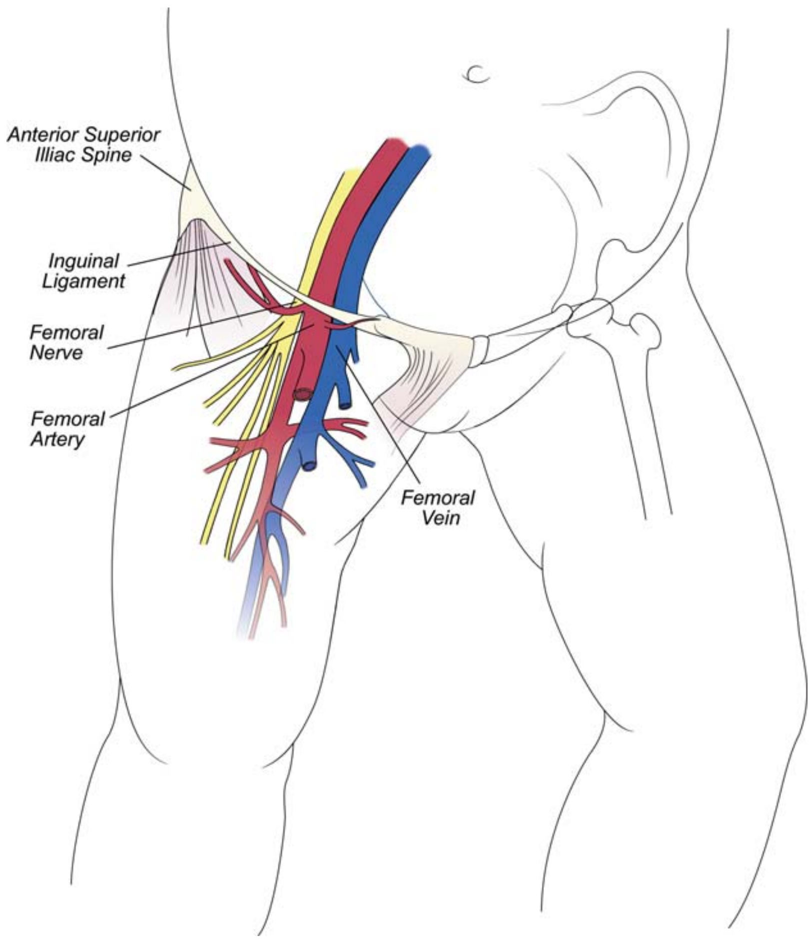

Fig. 2 Femoral access landmarks

crease is a good spot to enter the skin with the perc needle because it often lies at just the right distance from the inguinal ligament (~1 finger breadth in older children). This may not be true in adults, particularly those with weight problems.

3. *The femoral arterial pulse*

The pulse is made by the femoral artery. Always feel both sides. A pulse may feel reasonable where you are about to attempt access, but it may be bounding on the other side, suggesting that the side you are about to try on is narrowed or occluded with collateralization.

Technique

Always prep and drape both groins no matter what; it is good Karma. Feel for the femoral pulse. A *small* amount of lidocaine is infiltrated into the skin (intradermally, raising an "orange peel") and then a small amount down to the vessel to be accessed. Always withdraw on the hub of the syringe and ensure that there is not blood return prior to injecting so as not to inject lidocaine directly into a vessel. The lidocaine is massaged gently into the site to disseminate the anesthesia. Most of the pain sensation comes from the skin. Be aware that a lot of lidocaine infiltrated deep around the perc site will just make it harder to hit the vessel by distorting the anatomy or flattening the vein within the restrictive femoral sheath.

Femoral Venous Access

Usually, the venous line is placed first. An exception to this rule occurs when you have a patient in whom arterial monitoring is desired sooner rather than later.

In an older child/adult, it is usually fine to start percing just below the femoral crease at about a 30- to 45-degree angle to the skin Fig. 3. In an infant, consider percing right at the femoral crease. The femoral vein lies just medial to but touching the femoral artery. A needle angle that aims for the umbilicus is usually the right angle. Push the needle in short 1–2 mm jabs with a pause in between until you enter the vessel and blood starts flowing back in the needle hub. Short jabs are used because if you slowly and continually advance the needle you may deform the vessel, opposing the two sides, and end up perc'ing through both sides simultaneously. If you meet resistance, pull back the needle slowly *all the way to the skin*: You may have gone right through the vessel and can still get into the vessel on the way back. If suddenly you feel very little resistance, you have probably entered the pelvis! If you get urine, someone else should probably be getting access. Do not advance the needle beyond the superior ramus of the pubis!

If the central venous pressure exceeds the atmospheric pressure plus the resistance of the needle lumen, then blood will flow from the needle hub. However, if the central venous pressure is low, you may not get any blood return even if the needle lumen is in the correct location. This is common in adults, but rare in infants. In this instance, it may be helpful to attach a syringe to the back of the needle and withdraw *gently* as you advance and then withdraw the needle. When the blood flows easily into the syringe, you are probably in the vessel. Remove the syringe, advance the wire into the vessel, and you are off to the races. To take full advantage of this technique, it is important to cut the Luer-lock off the end of the syringe or use a slip tip syringe so that it comes off easily when you need to remove it.

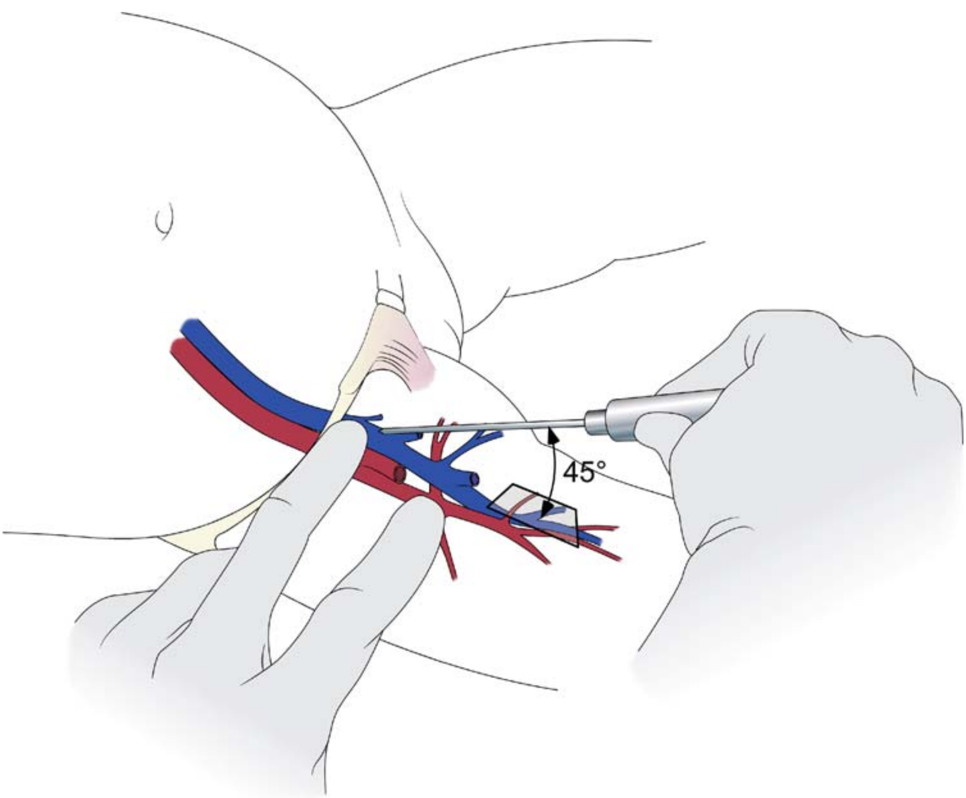

Fig. 3 Obtaining femoral arterial and venous access

Femoral Arterial Access

Accessing the femoral artery is done with a similar technique as used to access the femoral vein. Of course, the femoral artery is usually located lateral to the femoral vein just, underneath the femoral arterial pulse. The same caveats apply as before in regards to landmarks. Even more importantly, you will know when you are in the femoral artery as the blood will pulsate easily out of the vessel. If it does not, it is unlikely that you will be able to advance a wire into the femoral artery. Try to hit the femoral artery on the way in. To do this, make sure the perc needle is advanced in small short "jabs" rather than with a slow continuous motion and *not* beyond the superior ramus of the pubis. When pulsating blood returns, the hub of the needle should be brought almost parallel with the skin before the wire can be advanced. If this small motion is not made, then the wire tends to hang-up on the posterior vessel wall and may not advance up the lumen. Do not lose your cool as the blood is flying.

If you hit the femoral artery and do not succeed in cannulating the vessel, then it will often bleed and cause a hematoma. Make sure to compress the vessel until there is hemostasis before trying again.

Subclavian Vein Access

Either the left or right subclavian vein can be used; however, in practice, the left subclavian vein is usually chosen at Children's Hospital Boston because the curve to the heart and pulmonary artery is usually more favorable.

Positioning

If positioning is important for femoral access, it is even more so for subclavian access! Position the patient with the ipsilateral arm down by the side of the patient. A small towel roll between the scapulae will allow the shoulder to fall back to get it out of the way in a well-sedated patient. Be sure the shoulder is not "shrugged" as this lifts the vessel, changes the expected anatomy, and makes things much more difficult. Turn the chin away. There is no substitute for good landmarks. If necessary, you can check fluoro to assist with difficult access, but using fluoroscopy to get access is a secondary skill and should not be used primarily.

Landmarks

Technique

A small amount of lidocaine is infiltrated into the skin and down to the clavicular periostium just lateral to the junction of the medial one-third and lateral two-thirds of the clavicle Fig. 4.

A syringe with or without a Luer Lock is placed on the hub of the needle for this access approach. The perc needle enters the skin aiming for the suprasternal notch. Get the needle just deep enough to be under the clavicle, then continue to advance the needle in a plane parallel with the floor so as to enter the subclavian vein over the first rib Fig. 5. Continuously aspirate as you advance the needle. When you enter the vein, remove the syringe from the hub of the needle, make sure it is not bright red or pulsatile,

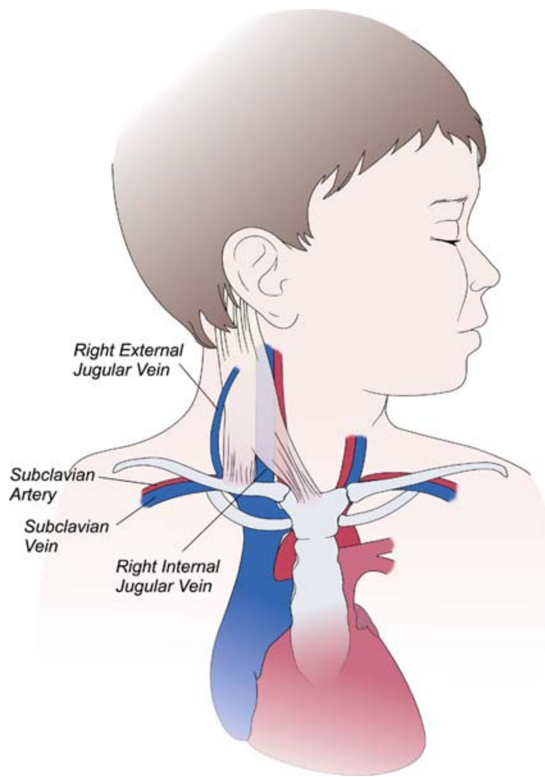

Fig. 4 Subclavian and jugular vein access landmarks

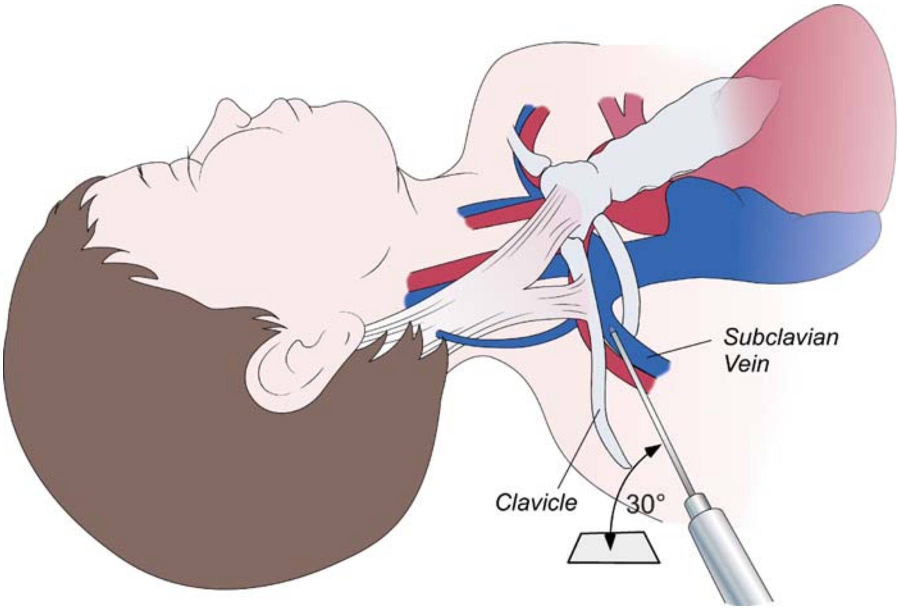

Fig. 5 Obtaining subclavian vein access

and then advance the wire. Check on fluoroscopy to ensure that the wire is taking the course that you expect. Verify that the wire is not in the subclavian artery. Place the sheath over the wire and continue.

Pointers

- The subclavian artery runs deep and cephalad to the subclavian vein. If the needle is advanced too deep to the plane of the intended target (the subclavian vein) one risks hitting the artery. A bit deeper than the artery is the pleura. Hit both and you will get a hemo/pneumothorax! Not exactly the best way to start a case.
- The subclavian vein should be entered just above the first rib to allow the puncture site to be compressed against this rib at the end of the case.
- Do not enter the left subclavian vein too medially (especially if this is a patient with a Glenn). If one enters the innominate vein, it will be difficult to do the necessary angiogram to exclude a left superior vena cava and even more difficult to get a catheter into an LSVC or other decompressing venous collateral for coil occlusion. In addition, a hemothorax is more likely when the sheath is removed if the vessel is entered too medially.
- In a small child the sheath may advance all the way to the SVC or beyond. Catheter manipulations may require you to pull back the sheath. Be careful when performing catheter exchanges and be sure to re-advance the sheath prior to removing the catheter; otherwise you risk losing access.
- Always use a long torque wire for subclavian access. When you are sure you are in a vessel, push the wire (under fluoroscopy) until it is clearly in a venous structure (e.g., a branch PA in a Glenn or the RA, IVC, hepatic vein, or RV in a patient with an intact SVC). Follow this rule and you should never put a sheath in the subclavian artery.
- If difficulty is encountered when you are attempting subclavian access, there are two tricks that may be useful:

1. Verify the landmarks and the course of the needle fluoroscopically.
2. If there is an IV in the arm on the same side you wish to cannulate, do a venogram. To do this, put a three-way stop-cock on the peripheral IV. On one port, put 10 cc of contrast, and on the other port, 5–10 cc of saline. Ten cc's of

contrast is appropriate for an adult. For smaller children, a smaller amount of contrast should be used. If you have enough foresight, you can ask the catheterization lab nurses to try to put the peripheral IV for the cath in the arm that you want before the case even starts. Position the "camera" over the area of interest (the subclavian vein). While watching on fluoro, ask an assistant to inject the contrast, then the flush, as quickly as possible. When the contrast first becomes visible on the fluoroscopy screen, switch to the cine record pedal and you will end-up with a beautiful subclavian vein angiogram (this can, and probably should be done with store fluoro if available). Now you can use this image as a roadmap.

Internal Jugular Vein Access

Positioning

More than any other approach, successful cannulation of the internal jugular vein depends on finding the correct anatomic landmarks before starting (you may have noticed a theme here). Place a small roll under the scapulae to allow the head to fall back and expose the neck. Turn the patient's head $\sim 45^\circ$ to the contralateral side. Prep the area but be sure before the area is draped that the landmarks are identified because it may be more difficult to do so after the area has been draped.

To better identify the sternocleidomastoid if the patient is awake, ask the patient to lift his or her head off the table. This will contract the sternocleidomastoid muscle and make it much easier to identify. The right IJV is preferred over the left because the apex of the lung is lower on the right side, the path to the atrium is more direct, and there is less chance of damaging the thoracic duct.

Because there are important structures in the neck and superior mediastinum in addition to the internal jugular vein (e.g., carotid artery, trachea, and apex of the lung) it is generally a good idea to perc using a smaller needle so that less damage is done if you hit an unwanted structure. It is almost always a good idea to have a syringe on the back of your needle. Gentle suction should eliminate issues with lumen resistance and prevent an air embolus. After you enter the appropriate vessel, advance your wire, confirm position, remove the needle, and place a sheath.

Anterior Approach

The anterior approach is useful in the intubated patient or in those whom you are expecting to place a large sheath. The entry site of the needle is lateral to the carotid artery in the middle of the triangle formed by the carotid artery, the sternocleidomastoid, and the mandible. Angle the needle at $\sim 45^\circ$ to the skin and aim towards the ipsilateral nipple Fig. 6.

Posterior Approach

This may seem like a strange way to enter the internal jugular vein, but it is amazingly effective in the awake patient. Identify the sternocleidomastoid muscle by asking the patient to raise his or her head. Enter the skin inferior to the sternocleidomastoid muscle at the junction between the lower one-third and the upper two-thirds of the muscle Fig. 7. Avoid hitting the external jugular vein. Stay just under the muscle and aim towards the suprasternal notch (or just a bit more lateral than that). If you stay just under the muscle, then you should not hit the carotid. Note that the sternocleidomastoid muscle comes quite posterior in the older child/adult. The head may need to be turned all the way to the contralateral side in order to get behind the muscle.

Central Route

Usually this approach is avoided in the cath lab as the entry site of the vein is under the clavicle and it may be difficult to get good hemostasis after the sheath is removed. However, sometimes this approach is necessary and may preferable when placing large sheaths in small children.

Fluoroscopically Guided Approach

This technique is preferred when you already have access in one of the femoral veins and want additional venous access from the IJV. An end-hole catheter is passed from the femoral vein to the junction of the SVC and right IJV. The balloon is

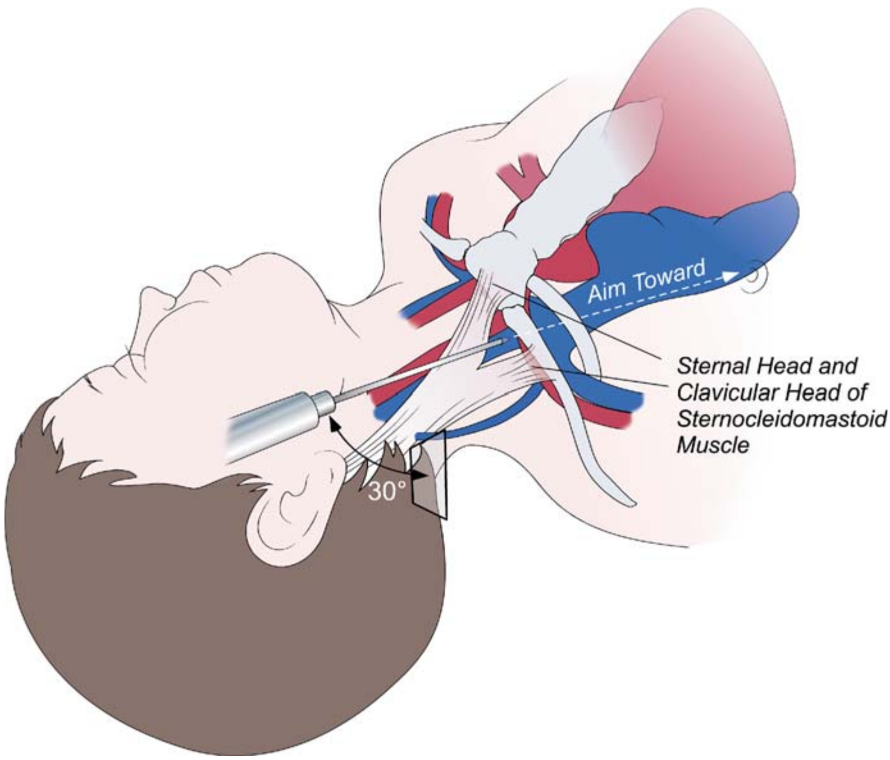

Fig. 6 Internal jugular vein, anterior approach

inflated and a small amount of contrast is placed in the vessel to define the vessel position. The perc needle enters the skin in the neck in the same position as would be used for an anterior approach and advanced towards the IJV as seen on fluoro. It may be helpful to have an assistant keep the balloon inflated on the end-hole catheter (to distend the IJ and give a bigger target) until the vessel is entered, and then deflate the balloon so it won't be punctured by the needle. NOTE: Index finger compression in the "groin" also does this for the femoral vein and artery. The wire is placed in the vessel and the sheath is placed as usual.

Ultrasound Guided Approach

In principle you can use ultrasound (US) to locate and guide access to just about any vessel, but we most commonly use ultrasound for internal jugular vein access. The process is relatively simple and is a good idea if you are unfamiliar with IJV access. There are sterile sleeves that can be used with most US probes. Once the patient is prepped and draped you can grab the probe (in the sleeve) and get a feel for the anatomy. We usually start with a quick cross-sectional look, profiling the relation of the carotid artery and internal jugular vein at the level you expect to perc Fig. 8A. The carotid usually can be seen to pulsate. If this is not immediately obvious, make sure your patient has a pulse, then try application of gentle compression by the probe. This should compress the vein but not the artery. NOTE: This is not advised in adults with atherosclerotic disease. Now center the probe on the IJV and rotate the probe 90°. This should give you a view of the IJ in the "long axis" Fig. 8B. Now you can either mentally or literally mark your trajectory and remove the probe or perc under direct US visualization.

Umbilical Vessel Access

We will not review here the technique of umbilical vessel cannulation in neonates. Using these

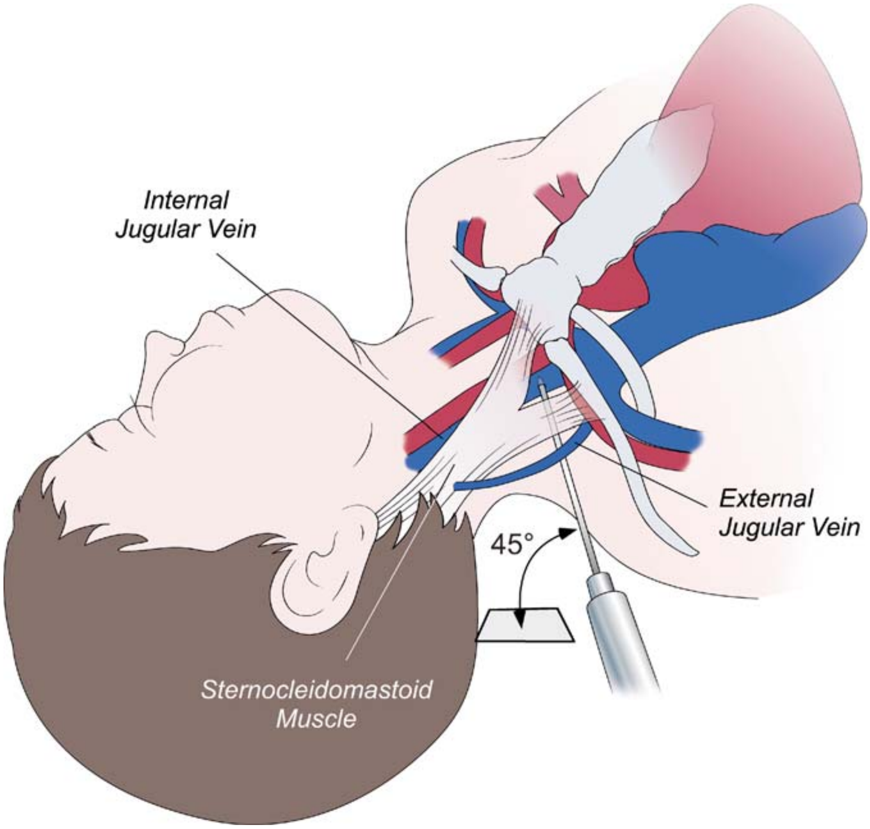

Fig. 7 Internal jugular vein, posterior approach

sites for catheter access, however, deserves some attention. The usual catheters that are placed in the umbilical vessels are the 3.5 Fr or 5 Fr Argyle® umbilical vessel catheters. The 5 Fr Argyle® catheter accepts a 0.025″ in guide wire, whereas the 3.5 Fr catheter accepts a 0.021″ guide wire. If the catheters are already in-place, the area including the catheters is prepped and draped. The catheter is cut close to the skin, and the wire is advanced into the body through the catheter. The umbilical catheter is removed over the wire, and then the appropriate-sized sheath or pigtail catheter can be advanced over the wire into the body.

Ideally a regular straight wire should be used, as the shaft of a torque wire is much too stiff to be putting around the anatomic bend of the umbilical artery where it enters the internal or common iliac artery.

For umbilical venous access, it is often possible to cannulate the umbilical vein, only to encounter difficulty getting through the ductus venosus into the IVC. If this is occurring, then the catheter ends up in the portal venous system. To negotiate the ductus venosus, it is helpful to pull the umbilical catheter back into the umbilical vein and then inject a small amount of contrast, recording the injection on AP and lateral cine. The ductus venosus can then be seen and the roadmap used to negotiate a wire and catheter. You can set up a 4 F Berenstein™ with a 0.018″ or 0.014″ wire through the catheter with a sidearm of contrast filling the catheter. Insert the wire and catheter into the vein and simply inject contrast as you navigate the anatomy to the RA.

Transhepatic Access

Transhepatic access is used when there is no other venous access to the right heart, or when

(A)

(B)

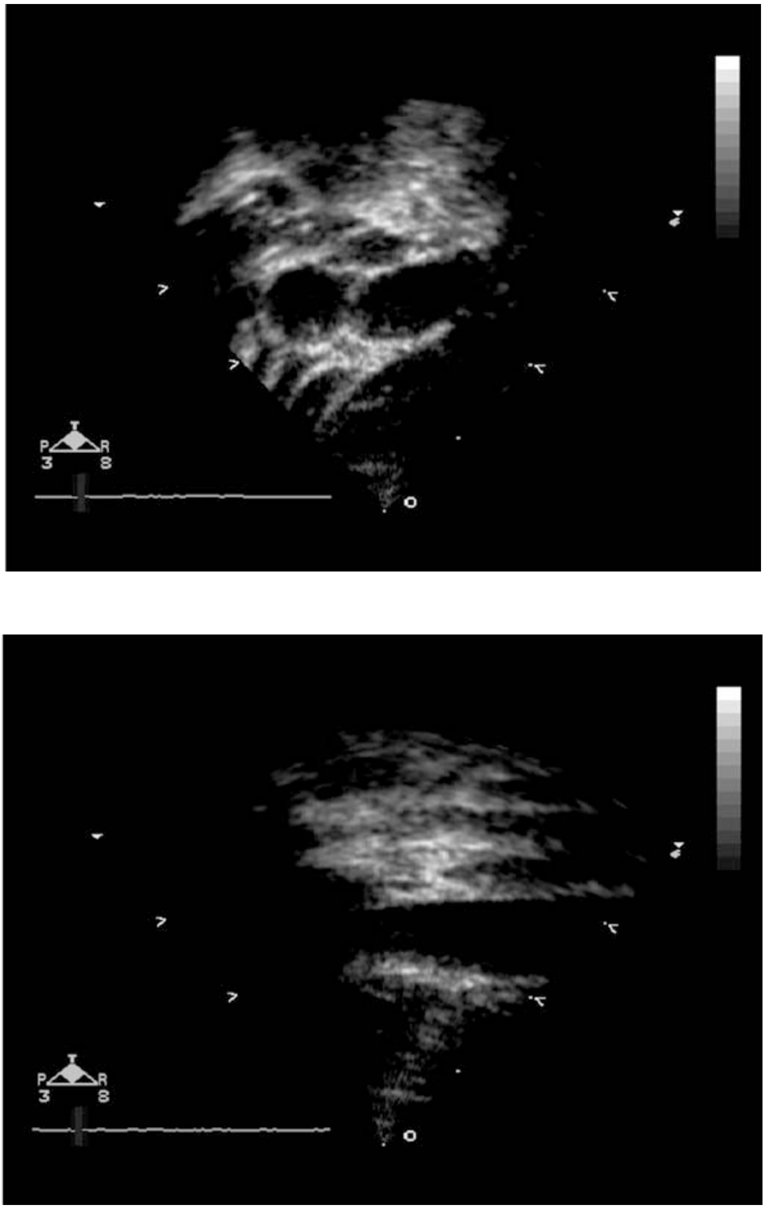

Fig. 8A, B Cross-sectional ultrasound of the right neck in a supine patient shows a round common carotid artery medially and an adjacent, slightly flattened internal jugular vein, A. After centering the probe on the IJ rotation of the probe provides a "long axis" view, B

access from below is desired for a procedure where there is no other access from below (e.g., Brockenbrough needle puncture or atrial septal defect closure in the setting of IVC occlusion).

The major risks of the procedure are damage to the liver including the bile ducts, and bleeding in the abdominal cavity. Generally, if this procedure is to be done, the patient is placed under general anesthesia to minimize patient movement. Coagulation parameters such as PT/PTT/INR should be checked during the pre-catheterization work-up.

Technique

There are two techniques for hepatic access: ultrasound-guided and fluoroscopic-guided. At Children's Hospital Boston, most cath attendings prefer to do their own transhepatic access using fluoroscopic guidance, with or without ultrasound guidance. This technique will be described below:

To make the procedure easier, if one has alternate venous access to the RA (e.g., from the right IJV), consider placing a catheter in an anterior and rightward hepatic vein and taking an angiogram to outline a good target vessel. Otherwise the procedure can be done "blindly" using anatomic landmarks.

The skin in the right subcostal region is prepped and draped. If a standard needle is too short, a 22 g Chiba® needle can be used for this access; this is a very long (15 or 22 cm), thin-walled needle with an obturator. The skin is entered just medial to the mid-clavicular line and angled quite deep to aim for the IVC-RA junction as seen on fluoroscopy. The needle is advanced on fluoroscopy. When the needle approaches the IVC-RA junction, the obturator is withdrawn and a syringe with contrast is placed on the end of the needle. The syringe is aspirated and the needle is withdrawn slowly until there is blood return. A small amount of contrast is injected to verify that the needle is in a venous vessel that returns to the heart. The syringe is removed and a 0.018″ torque-wire is passed through the needle into the vessel and (hopefully) into the RA. If the wire passes into the liver and cannot be advanced into the RA it is likely in a portal vein. In this instance the wire and needle are withdrawn and another attempt is made. After the torque wire is in the heart the needle is removed and a 5 Fr long sheath (45 cm) can be passed over the torque wire into the right atrium. If one desires a larger sheath, the wire and dilator can be removed, and a larger stiff wire passed through the sheath (e.g., a 0.035″ J-tipped Rosen®). The 5 Fr sheath can then be exchanged over the wire for a larger sheath.

The catheterization is completed as usual including routine heparinization. When finished, the tract through the liver should be closed in order to prevent bleeding. A 4 or 5 Fr Berenstein® catheter or suitable facsimile is advanced through the long sheath. The long sheath is then withdrawn to the border of the liver as seen on fluoroscopy. A small amount of contrast flushed through the side-port of the sheath will verify the position of the sheath with respect to the liver edge. The Berenstein® catheter is withdrawn while injecting contrast until the catheter is no longer in the hepatic vein but in the tract through the liver parenchyma. One or (usually) more coils about 120% the diameter of the sheath are placed into the tract to seal it (see section on coiling collaterals). When the tract is sealed, the catheter and sheath are removed.

Post-cath care consists of carefully monitoring the patient for abdominal bleeding complications. An abdominal X-ray is obtained to verify the coil position post-cath. Prophylactic antibiotics may be administered.

Angiography

Introduction

When you have your hemodynamics, you will usually proceed with angiography. Interpreting angiography correctly takes practice—lots of practice—and often this is one of the most intimidating parts of the cath experience for new fellows. You will learn it before the case (in pre-cath conference), during the case, and after (at midnight while you do your reports). You *will* learn. The following are some tips:

1. Ask. In the case, after the case, anytime.
2. When you are not cathing, try to watch cases as they happen. This is the next best thing to being in there.
3. If you see senior cardiologists reading angiograms, sit down with them. There is a bit of a time investment involved in this type of learning, but it is well worth it in many ways.

Table 1.

Frontal "Camera"		Lateral "Camera"	
Frontal/posteroanterior (PA)	0°	Straight lateral	90°
Right anterior oblique (RAO)	Usually –20–30°	Left anterior oblique (LAO)	20–70°
"Sitting Up"	0° frontal +20–30° cranial	Long axial oblique (*not* LAO)	70° lateral +30° cranial
"Laid Back"	0° frontal +30° caudal	Hepatoclavicular (4-chamber)	45° lateral +45° cranial
		Aortic orifice view	100–120° lateral +20–30° caudal

Standard Angiographic Projections

Before you can learn the standard angiographic projections you need to confront some minor confusion about the reference points for the "camera" angles. First, the "camera," such as it is, is actually an X-ray source and is *not* what people are usually referring to when they talk about imaging angles, which are commonly expressed with reference to the image intensifier or flat-panel detector (on the other side of the patient). So, while 0° is customarily called straight "AP," it is technically PA since the image intensifier is above the patient (0°) and the X-ray tube is underneath the patient (180°).

The rest is less confusing. Rotation of the image intensifier to the patient's left is considered a positive degree of rotation (also referred to as "*x*° of LAO"), while rotation to the right is negative (also referred as "*x*° of RAO") Fig. 9. Cranial and caudal tilt is self-explanatory (it refers to the position of the image intensifier). Viewed from this perspective, it becomes clear why "shallow LAO" is usually between +1° and +30°, while "steep LAO" is between +61° and +89° LAO.

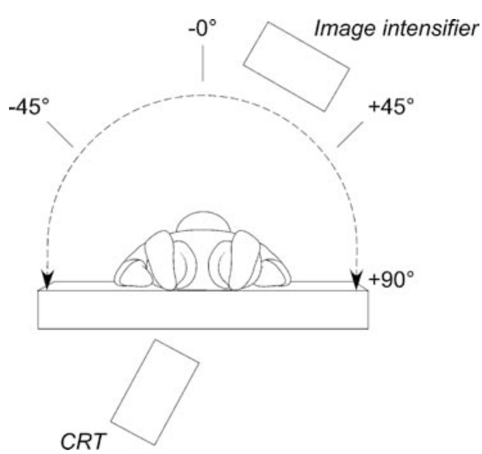

Fig. 9 Imaging angles

These angles are not set in stone. As you understand angiography better, you will make alterations from these numbers based on the patient's anatomy and on the image you are getting from the screen. Table 1 contains some basic guidelines.

When to Use Which View

Frontal/ PA View

Best used for:

- Systemic venous anatomy (RSVC, LSVC, IVC).
- Pulmonary venous anatomy.
- RV anatomy and distal PA anatomy.
- Descending aortography, aortopulmonary collaterals.
- Single ventricular morphology (especially initial imaging).

Detriments:

This is not an "axial" view. There is commonly superimposition of structures of interest. That is, the RV outflow tract overlies the branch PAs, and the ventricular and atrial septa are poorly outlined.

Right Anterior Oblique (RAO) (Fig. 10)

Superimposes normally positioned atrioventricular valve annuli. Used in electrophysiology lab for mapping.

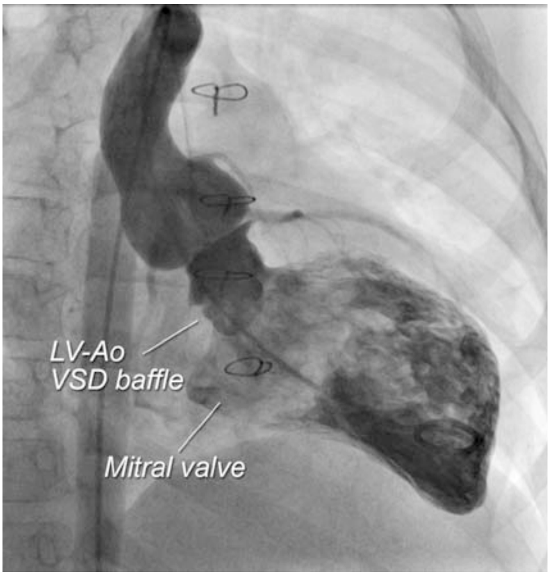

Fig. 10 RAO ventriculogram

Best used for:

- Good delineation of outlet/anterior muscular VSD's and the infundibulum.
- LV outflow tract imaging for sub-AS (including AV canal gooseneck).
- LV function and quantification of MR and AR.
- An alternative view for measuring PDAs.
- Aortic valve annulus measurements.

"Sitting Up" (Fig. 11)

Based on the old practice of moving the patient's position rather than cameras

Best used for:

- Improved imaging of MPA and branch PAs, with less superimposition.
- Pulmonary stenosis, for annulus measurements.
- Seeing full length of RPA (especially with RAO 20–30°).

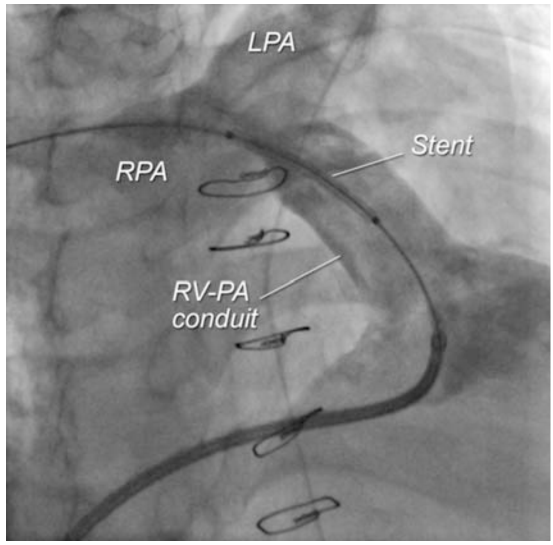

Fig. 11 Sitting up angiogram

"Laid Back" (Fig. 12)

Best used for:

- Alternate view to image proximal branch PAs.
- PAs arising from conduits (up to 60° caudal).
- Coronary arteries from Ao, e.g., D-TGA.

Fig. 12 Laid back angiogram

Lateral (Fig. 13)

Best used for:

- Excellent view of RV outflow tract/pulmonary valve/MPA.
- Good imaging of PDA and coarctation.
- Coronary artery origin and course.
- Distal PA anatomy.

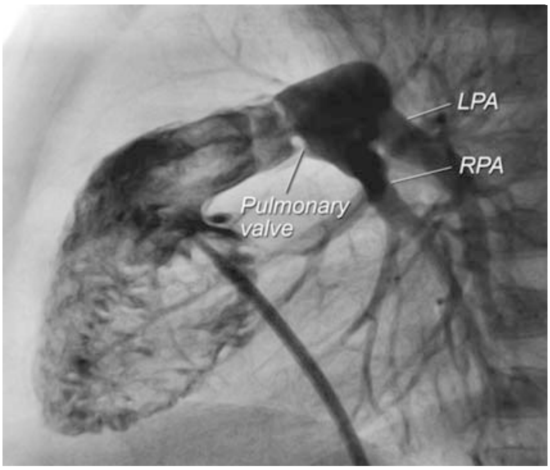

Fig. 13 Lateral angiogram

Left Anterior Oblique (Fig. 14)

This is not to be confused with long axial oblique. Generally refers to the rotation along the lateral plane, and does not denote use of cranial or caudal angulation.

Best used for:

- Elongating aortic arch, which may help for PDA or coarctation,
- Lengthening LPA (caudal angulation may help),
- Truncal valve anatomy,
- Proximal LPA anatomy.

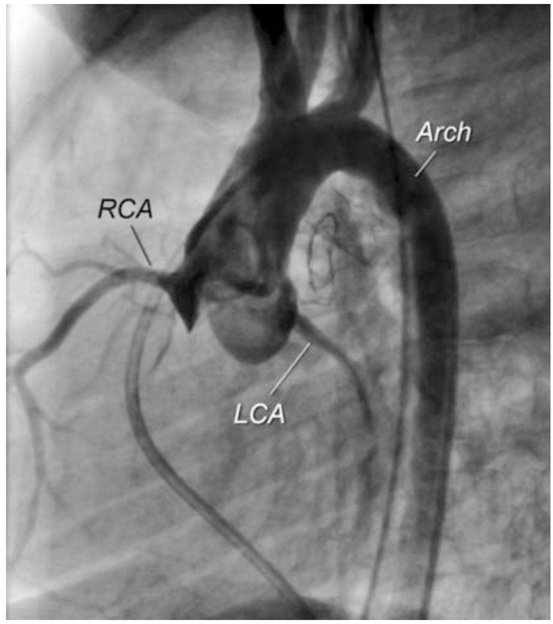

Fig. 14 Left anterior oblique

Long Axial Oblique (Fig. 15)

Gives LV image similar to that found in parasternal long axis view by echo.

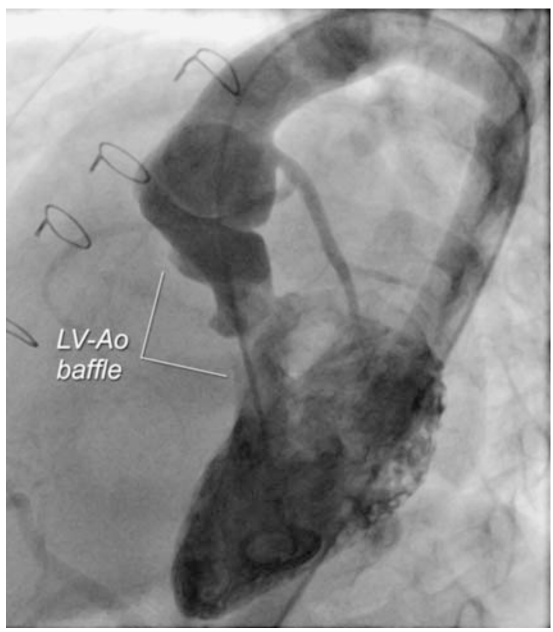

Fig. 15 Long axial oblique angiogram

Best used for:

- LV function and MR.
- Sub AS, AS, and supra-AS.
- Annulus measurement for aortic valve dilation.
- VSD imaging (membranous/conoventricular/anterior and mid-muscular).

Hepatoclavicular (4-Chamber) (Fig. 16)

Gives image analogous to that found on apical 4-chamber echo view. Looks at the crux of the heart.

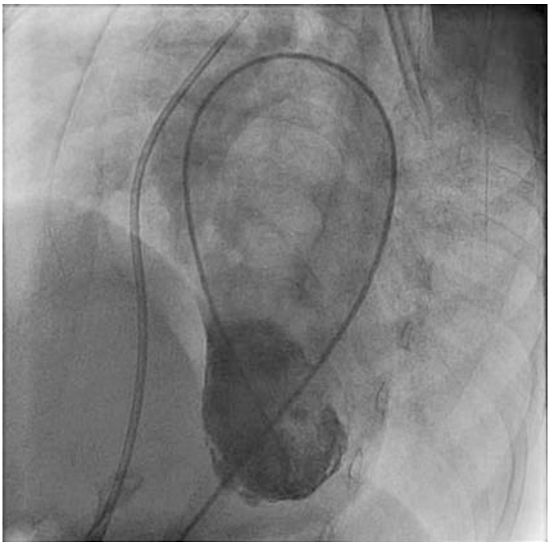

Fig. 16 Hepatoclavicular angiogram view

Best used for:

- ASDs (especially with catheter in RUPV).
- Endocardial Cushion Defects (ECD).
- Inlet/posterior muscular VSDs.
- AV valve anatomy and regurgitation.
- LV to RA shunt.
- The origin of the LPA.

Aortic Orifice View (Fig. 17)

Similar to parasternal short axis echo view.

Best used for:

- Looking at coronary artery origins, especially with antegrade ascending aorta injection with an inflated Berman catheter.
- Gives nice view of aortic valve cusps.

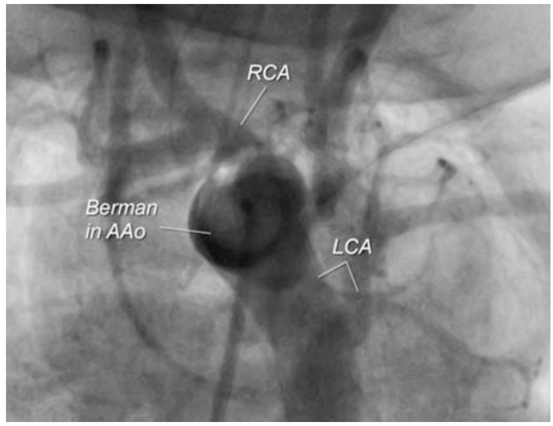

Fig. 17 Aortic orifice view

Common Catheters for Angiography

The catheters used for angiography will vary from institution to institution, and the maximum flow rates will vary by manufacturer. Listed below are several of the more common catheters, their characteristics, and the most current flow rates.

Berman® Catheter

This flow-directed catheter has a distal balloon, several proximal exit sideholes, and no endhole. Its use is sometimes limited by the difficulty in maneuvering it, mostly because it cannot be placed in location over a wire. There are many tricks to helping steer a Berman into position. We often shape the stiff end of a straight wire in an angle such that we can "peel off" the Berman into a desired location. Although this catheter has multiple ports for ejection of contrast, it is still important to ensure that it is not entrapped in myocardium, as it can rarely cause injury or staining in this situation, Table 2.

Table 2. Berman Catheter Sizes and Injection Rates

Size (F)	Length (cm)	Max Injection (cc/sec)
4	50	5
5	50	15
5	80	12
7	90	22

You can inflict significant harm by accidentally using an end-hole catheter for a power injection. Although we do use end-hole catheters for *hand injections* in the pulmonary arteries, coronary arteries, arterial collaterals, and venous vessels, we do not use them for any form of power-injection angiography.

Caution:

Berman catheters are very similar in appearance to pulmonary wedge end-hole catheters. You should always verify that you have the right catheter before using it or handing it to anyone. (This is critical to your survival!) This is most easily done when flushing the catheter. If flush exits via an end-hole, it's *not* a Berman.

Pigtail Catheters

This catheter is narrow-walled, made of ultrathin white teflon (i.e., the lumen is relatively large), and has numerous side-holes just proximal to the curled end. It also has an end-hole, which aids in placement over a wire. This is important, because the catheter is difficult to place in position on its own. In fact, pigtails should not be advanced without a wire, as they easily kink at the proximal side-hole. This may make the catheter prone to burst at the external junction of the hub and shaft with power injection, Table 3 outlines common sizes and injection rates. You need to know the maximun injection rates for the catheters stocked in your lab.

Table 3. Pigtail Catheter Size and Injection Rate

Manufacturer	Size (F)	Length (cm)	Wire	Max Injection (cc/sec)
merit	3	40	0.021″	5 cc/sec
merit	3	50	0.021″	4 cc/sec
merit	4*	80	0.025″	10 cc/sec
merit	4	50	0.025″	13 cc/sec
cook	4*	70	0.035″	20 cc/sec
merit	5	100	0.035″	18 cc/sec
merit	5*	80	0.035″	20 cc/sec
cook	5*	100	0.035″	27 cc/sec
merit	6	80	0.035″	35 cc/sec
merit	6	100	0.035″	31 cc/sec
merit	7	100	0.035″	42 cc/sec

* Delivers contrast at higher flow rates for the relative size.

Table 4. Halo Catheters

Size (Fr)	Length (cm)	Max Injection (cc/sec)
4	65	20
5	65	33

We commonly use these catheters for aortograms and LV injections. They can also be guided in over a previously placed wire, which is useful when maintaining wire position is essential (such as in recently dilated pulmonary arteries or coarctations, or when you are in a difficult-to-reach position). An angiogram can be taken without removing the wire, if the pigtail is of sufficient size. Make sure the wire is securely held at the side-arm diaphragm. If this is loose, smaller wires may be injected into the patient and catheter recoil may occur with larger wires.

A cousin, the Halo catheter, can be used in similar situations, and has the added benefit of directing flow centrally, diminishing the amount of ectopy caused by the injection, Table 4.

Contrast

Type of Contrast

Historically, imaging was performed with ionic contrast, with an iodine-containing benzene ring coupled with either sodium or meglumine cations. The rates of contrast-related side effects were high, especially when using compounds with sodium salts. However, the sodium salts were less viscous, improving contrast delivery and resulting in more rapid removal from balloons. Iodine allergy is extremely uncommon as a cause for contrast reactions, because very little iodine is free in solution. Most of the problems result from rapid fluid shifts and the effects of the solutions on vascular tone.

We currently use contrast that is non-ionic, iso-osmolar and relatively low in viscosity. The non-ionic compounds have a lower rate of side effects, such as increased PA pressure, feeling of intense pain or heat on injection, and reflex tachycardia. These effects continue to be present, but to a lesser degree, and other side effects may include myocardial dysfunction, hypotension, renal dysfunction, and hyperthermia. Most of these effects are compounded by the presence of pre-existing LV dysfunction, renal impairment or small patient size.

Amount of Contrast

In patients requiring long procedures or in small babies, pre-cath planning is vital. You should be sure to take the most vital angiograms first. In some situations, you may wish to divide procedures over a couple of days. Many angiographic injection volumes will be limited by the rate of delivery for the catheter in question. This can be optimized by using the shortest catheter with the largest French size, within limits of practicality. There are no solid rules about the amount or rate of contrast delivery. People frequently quote a dose of 1 cc/kg as a guideline for most areas of the heart. However, there are several important variables that factor into the equation:

General: Higher flow rates allow for smaller contrast volumes because dye replaces unopacified blood acutely, whereas increasing volumes at very slow flow rates are ineffective, especially in volume-overloaded lesions such as a VSD.

Patient size: It is easy to reach high levels of contrast in small patients. It may be wise to use a lower volume delivered at a faster rate to opacify the chamber in question.

Catheter location: Catheters in low flow regions (i.e., veins) do not need much contrast to get good opacification. Also, you need less contrast the further you get out into a branching vessel, such as a pulmonary artery. High volumes or rates of delivery in ventricular chambers may cause ectopy and transient AVVR.

States of high flow: You will need to increase the amount of contrast in situations of high flow or dilatation, such a ventriculograms in patients with VSDs or in other volume-loaded areas. Also, tachycardic patients may clear contrast more quickly, and generally need a larger amount of contrast. In contrast, in patients with slow heart rates, slow injection times are often sufficient and may cause less ectopy.

Layering: In some circumstances, you can decrease the amount of contrast used in hand injections by using layered injections. Because contrast is denser than NS, you can maintain separation of the two solutions in a syringe if you first draw up the saline, then the contrast (slowly), and maintain the syringe with the plunger pointed at the ceiling. This can be very useful for injections in low-flow regions, or when balloon occluding the vessel proximally.

Levophase: Levophase is the term for the phase of an angiogram (usually performed in the RV or PA) when the contrast returns from the pulmonary veins and opacifies the left heart. Levophase is your friend. You can glean a lot of information through appropriate imaging during levophase. No need to waste all of that good contrast! You should decide before starting the angiogram how long you want to image because some fluoroscopic systems time-out after a specified period of time. You should also factor increased radiation exposure into using levophase imaging.

It is better to take one good-quality image with slightly more contrast, and be able to have confidence in your diagnostic capabilities. You do not want to repeat angiograms unnecessarily or miss important information.

Minimizing Radiation Exposure (for the patient and staff members)

You will all be given a radiation safety lecture, as mandated by government regulations. Some states also require fluoroscopy licenses. Please pay attention during your training, because the pointers can be very helpful for your time in the catheterization lab. You are responsible for protecting yourself and those around you, to the best of your ability, while stepping on the fluoroscopy or cine pedal.

To remind you, here are 12 steps to reducing radiation exposure:

1. *Reduce use time*: Avoid redundant images, step off of the pedal when not acquiring a useful image, and try to use single-plane fluoro when possible. Continually ask

yourself whether you are actually using the fluoro information that you are acquiring.

2. *"Store fluoro"*: Some labs have the ability to store routine fluoroscopy as a playable loop, just like cine. If you do not need fine detail, simply step on the biplane, inject your contrast or do your intervention, step off and press "store fluoro" on the control screen.
3. *Reduce frame rate*: Available frame rates for both fluoro and cine in many labs are 7.5, 15, and 30/sec. A rate of 7.5/sec can be maddeningly stutter-like, but you can get used to it. A rate of 15/sec will provide sufficient temporal resolution for most tasks. A rate of 30/sec provides the best images, but at an obvious cost.
4. *Increase distance*: Be aware of situations where you can increase distance, such as stepping back when performing cine-angiography. Use the mobile shield, and place it between the patient and your body (not beside the lateral X-ray tube!) Make sure that other staff members are aware when a cine is about to be taken, so they can step back. Remember the inverse square law, where radiation dose is inversely proportional to the square of the distance from the source (i.e., four times less exposure at two feet vs. one foot from the source).
5. *Room lighting*: Lower ambient light levels will improve your ability to see image details, so you do not need to alter the image to do so.
6. *X-ray tube position*: Try to avoid getting direct exposure to X-rays, when possible (i.e., hands in the field). It is actually safest to stand on the left side of the patient, because most of the radiation reflects to the same side as the X-ray tube.
7. *Reduce air gaps*: A lower patient dose translates to lower operator exposure, because most occupational exposure is reflected off of the patient. You can decrease the patient dose by raising the bed as high as comfortable above the X-ray tube (the part below the table) and by lowering the image intensifier as much as possible. As an added bonus, this will also improve your image quality.
8. *Minimize magnification*: Contrary to folklore, magnification actually increases the patient dose and focuses the beam on one area, making tissue injury more likely to occur. Use only when necessary.
9. *Collimate primary beam*: Collimation is the process of bringing in dense radiation shields on the radiation source ("framing the image") and limits extraneous radiation to areas not being imaged, thereby decreasing the area of exposure for the patient. By excluding areas of vastly different density (e.g., air), the machine will not overdose the patient to improve resolution. This will also improve your image quality. You can often do this off of fluoro.
10. *Use alternate projections*: Most angled views require that the X-ray beam travel through a greater amount of tissue than the standard views, causing the machine to automatically generate more X-rays. If possible, use non-angled views.
11. *Optimize tube voltage*: Use the highest kilovolt possible to maintain adequate images. At higher kilovolt settings, more of the radiation beams pass through the patient to the image intensifier, resulting in less radiation exposure for the patient and staff.
12. *Shielding*: Wear your lead and ensure that others have theirs on before stepping on a pedal. Use the scatter shield as possible.

Catheters and Wires

There are tools for every task, and there are many tasks to be performed in the catheterization lab. The important point in pediatric and congenital cardiac catheterization is that you remain flexible with respect to the use of your tools. For example, you are more likely to use a coronary catheter to get to a PA than to actually perform coronary angiography.

You should not attempt to memorize the endless list of catheters, balloons, and devices. You should, however, be familiar with the most commonly used catheters, the general principles of these materials, and their preparation for use. The following is an introduction to catheters commonly used in pediatric catheterization laboratories. There will be institutional variation. Expect a substantial amount of on-the-job training).

Catheters

There are dozens of catheters in the lab, few of which have intuitive names. It is easiest to think of them in two large categories: end-hole catheters and angiographic catheters. End-hole catheters are used to obtain blood samples, measure pressures in discrete locations, and selectively cannulate small vessels such as coronaries. When used in conjunction with a probing wire or hand injection of contrast, they can get to almost any location. Because they have an end-hole, they can be exchanged over wires. Angiographic catheters have multiple side-holes over a length of catheter. Multiple side holes allow for delivery of a large volume of contrast rapidly, without the creation of an end-hole jet. Although they are great for measuring pressures as well, they will measure the pressure over the length of the catheter in which side-holes are present, not at a discrete point.

Pulmonary Wedge Catheter

4 Fr-60 cm, 5-60, 5-110, 6-110, 7-110

This is a flow-directed end-hole catheter. The flexible shaft allows blood flow to carry the inflated balloon naturally through the ventricle and into the pulmonary artery. This is the catheter most commonly used at our institution for right-sided hemodynamics, including the pulmonary capillary wedge pressure. With the balloon inflated, this catheter can also be used for balloon occlusion pictures such as pulmonary venous wedge pictures, innominate vein to rule out LSVC, and so on.

Berman® Catheter

4 Fr-50 cm, 5-50, 5-80, 6-90, 7-90

This angiographic catheter is also flow directed. It looks very similar to the wedge catheter, but it does not have an end-hole. Proximal to the balloon there are several holes through which you can sample blood or inject contrast. Because there is no end-hole, the Berman cannot be guided to position over a wire, nor can it be exchanged over a wire for another catheter. It is used primarily for angiography in the ventricles where the balloon keeps the catheter away from the myocardium, reducing the incidence of arrhythmia, myocardial staining, and perforation during power injections. (NOTE: See angiography section for injection rates.)

Thermodilution Catheter

5 Fr, 6 Fr, 7 Fr catheters

This is an end-hole catheter with an additional lumen terminating in a proximal side port. There is a thermistor (temperature monitor) at the tip of the catheter, which aids in cardiac index assessment using cold saline injections via the proximal port. On the 5 Fr catheters the proximal port is 15 cm from the tip (generally used in children <15 kg), and in the 6 Fr and 7 Fr catheters, the proximal port is 29 cm from the tip. The two small lumens not only make it a poor catheter for transducing pressures, they also make the catheter relatively stiff. The end-hole lumen accepts only a very small guide wire, so for positioning you are mainly at the mercy of this stiff, flow-directed catheter.

Double Lumen Wedge Catheter

7 Fr

These catheters have the standard end-hole that can be used for pressure readings and for the taking of samples. In addition, there is a second port for pressure recording at 1 cm in the 5 Fr catheter, 2 cm in the 6 Fr catheter, and 3 cm in the 7 Fr. The double lumens allow for the simultaneous measurements of two areas of pressures, such as transchamber pressure measurements, and can be used to record pressure gradients across valves.

Multipurpose Catheter

4 Fr, 5 Fr, 7 Fr

The multipurpose catheter is a relatively stiff end-hole catheter that has a terminal bend. In addition to the end-hole, there are two side-holes near the tip Fig. 18. This

Fig. 18 Multipurpose catheter

catheter is versatile, as its name implies, and can be used for many tasks including right heart cath, probing the atrial septum, pressure measurements over a wire, angiography by hand, and so on. Generally, it is not recommended for coil placement unless the tip with the side-holes is cut off.

Berenstein® Glide Catheter

4 Fr 0.035″ 5 Fr 0.038″

The Berenstein is a soft, low-torque, end-hole catheter that has a small bend on the end. Using this catheter and probing with the floppy end of the torque wire, one can get into most branch vessels, collaterals, etc. Because they track small wires well, but accept a much larger wire, they are extremely useful for multiple catheter exchanges. They can also be used for coil delivery.

Bentson® Glide Catheter

4 Fr 0.035”

The Bentson is also a relatively soft, low-torque endhole catheter with a bent end and a large secondary curve Fig. 19. It is also used to enter small vessels or advance wire position. The primary bend can help to stabilize the catheter. The Bentson can also be used for coil delivery.

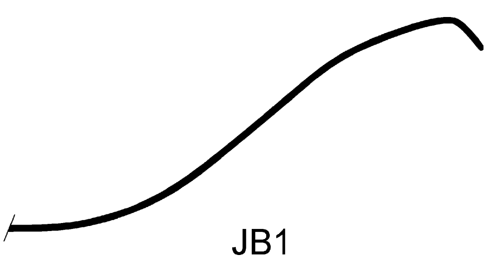

Fig. 19 Bentson catheter

Cobra Catheter

4 Fr, 5 Fr, 7 Fr

The Cobra has a larger secondary curve than the Bentson catheter, directing the tip of the catheter more than 90° back toward the primary direction of the shaft Fig. 20. This curve provides it with greater stability of position along some tortuous catheter courses; however, it does not track as well as the Bentson or the Berenstein.

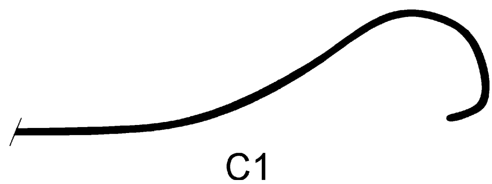

Fig. 20 Cobra catheter

Judkins Right and Left Coronary Catheters

4–7 Fr with 1–5 curves

The coronary catheters are designed to get into the corresponding coronary artery. The choice of curve depends on the width and length of the aortic arch Fig. 21 and 22. They can also be used for entering a variety of collaterals or shunts. The tips can be cut to customize the curvature and reach, but care should be taken not to create sharp catheter tips, which may cause vascular damage.

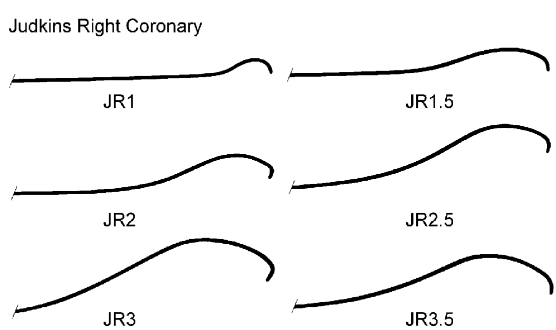

Fig. 21 Judkins right catheters

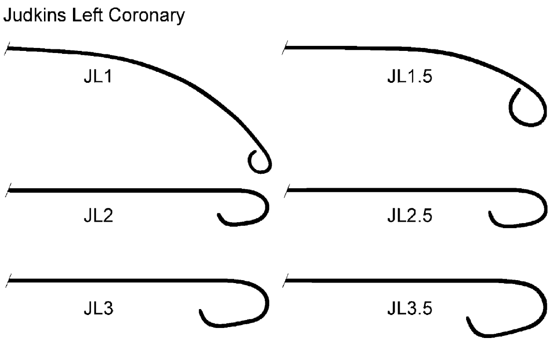

Fig. 22 Judkins left catheters

Amplatz Right and Left Coronary Catheters

4.5–7 Fr with curves AR1 and Ar2 or AL2 and Al3

The Amplatz catheters are also designed for entry into the coronary arteries Fig. 23. Again, we frequently cut these catheters for customized curves and reaches for catheter-directed access to various locations.

Pigtail Catheters

3–7 Fr with lengths of 40–110 cm

These are generally considered angiographic catheters, due to their ultra-thin walls and multiple side-holes Fig. 24. Although they do have an end-hole, the pigtail shape and the taper of the catheter down to the end-hole prevent a terminal jet of contrast when large volumes of contrast are injected rapidly. You must still take care to keep the end of the pigtail out of smaller vessels such as coronary arteries during power injections, as a forceful jet of contrast can still cause injury. They will track a wire, and should be advanced over a wire in order to prevent

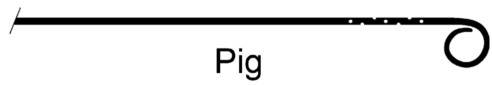

Fig. 24 Pigtail catheter

kinking of the pigtail. The pigtail will automatically reform when the wire is removed. The multiple side-holes are all positioned close together to give single-chamber injection. They are used for angiography in the ventricles (especially the LV) and the ascending aorta, and they are good for pressure measurements as well. Each individual French size and length combination has its own maximal burst pressure (be aware of the injection rate for the pigtail you are using), above which the catheter does actually burst at the junction of the shaft and hub (generally all over the fellow!).

There are pigtails that have radiographic markers of distance and size, which allow them to be used to more accurately determine angiogram magnification. They can also be used for angiograms themselves, but they are made from a stiffer material so that they generally do not tolerate as large a volume and flow rate as the same-sized regular pigtail. The marker pigtails are often not used for angiography. but are placed somewhere else in the field to provide a reference for measurements.

When the tip of a pigtail catheter is cut off, the catheter becomes much less curved, and the end-hole becomes larger, so there is room for contrast to exit the end-hole even if there is a wire present. This modification is extremely important, and was made so frequently in our lab that a former fellow actually convinced the manufacturer to make a "Cut-off Pig" and got his name put on the catheter! (discontinued recently) Cut pigtail catheters will track a stiff wire relatively well. When in position, a Y-adapter

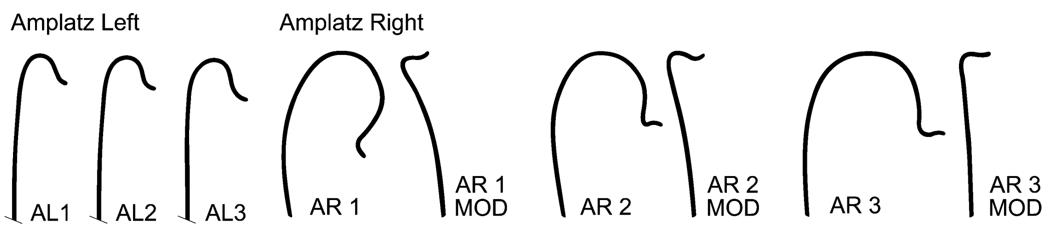

Fig. 23 Amplatz catheters

allows you to measure pressure and take pictures using the multiple side-holes and the end-hole. The presence of the wire prevents a terminal jet.

Wires

Wires serve three basic functions: probing, guiding, and exchanging. All wires have a stiff end and a soft end. Most of the time, the soft end of the wire is the business end. In some situations, the stiff end of the wire can be very useful, but it must not be advanced into the body alone. *Beware*: Advancing the stiff end of wire out the end of a catheter risks perforating the heart or vessel, or more commonly lifting an intimal flap.

The guide wire is a vital part of the catheterization procedure. A perfect guide wire would be strong enough to allow catheters to track over it without kinking. It would be steerable and have a floppy torqueable tip. In addition, it needs to be radio-opaque. All guide wires really consist of two parts: a mandrel core and a spring guide that is wrapped around it. The mandrel is a solid wire that runs the length of the wire. It can be fixed or moveable. If it is fixed, the core is welded to both ends of the outer coil Fig. 25. The moveable mandrel is only welded at one end. The mandrel can then move in relation to the end of the spring guide changing the stiffness of the tip of the wire (this is true for most J wires).

Fig. 25 Wire core

Straight Wires

These wires have, as the name suggests, a soft, straight tip. These are the wires that are used for arterial access, for advancing pigtail catheters, and so on. They are relatively good, cheap guide wires. Although the tips are soft, these wires are not "floppy" and they are not very good for probing for vessels. They are not very long, and so are not ideal for catheter exchanges. The stiff end of the wire will hold any bend you give it, so these wires can be shaped and used to guide catheters through relatively simple courses. These wires come in a variety of sizes and lengths, Table 5.

Table 5. Sizes and Lengths of Straight Wires

Wire	House	Length (cm)
0.018″	Green	145
0.021″	Black	145
0.025″	Blue	145
0.035″	Purple	145
0.038″	Red	145

Torque Wires

The torque wires have a stiffer mandrel than the straight wires. The core is made of stainless steel, and the tip is made of platinum, making it very radio-opaque. The last few centimeters are extremely shapeable. The floppy end has great steerability and great torquing capabilities. The torque wires are available in 0.018″ (blue case) and 0.035″ (purple case), Table 6.

Table 6. Torque Wires

Wire	Length (cm)	House
0.018″	145	Blue
0.035″	180	Purple
0.035″ "exchange"	260	Purple

ThruWay® Wire

0.018", 190 cm

These wires are much like the usual 0.018" wire; however, this wire is a bit longer and can be used as an exchange wire for most catheters and balloons taking a 0.018" wire. There is a 5-cm tapered "floppy" end, with the remainder of the wire being moderately stiff.

V-18 Control Wire®

0.018″, 200 cm

The V-18 is somewhat similar to the 0.018” torque wire. It has an 8-cm flexible tip with a hydrophilic coating. It is 200 cm long and the remainder of the wire is quite stiff which makes exchanges easier, but it also requires fairly precise preshaping to not distort cardiac or vascular structures.

Cook Deflecting Wire

The deflecting wire has a movable core, that is, the mandrel is only fixed at one end and the spring guide can move along it. These wires come out of their houses straight. At the stiff back end, they have two steel markers, which are used to seat the wire into the handle. These also come preassembled Table 7 and Fig. 26. When the wire is in a position in the heart where you would like it to bend, you pull the trigger on the handle and it progressively bends the wire by pulling the steel markers apart from each other. Often, after the catheter is pointing in the desired direction, the catheter can be advanced into the desired position. The distal tip of the wire is quite stiff and should not be advanced out of the catheter. When using the deflector, it is very easy to break the distal end when applying a lot of pressure especially the 0.025″.

Table 7. Cook Deflecting Wire

Wire Size	Length (cm)	Radius of Curve (mm)
0.025″	125	5
0.035″	145	5

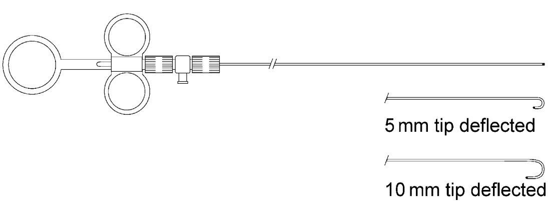

Fig. 26 Cook wire

Rosen® Wire

0.035″, 220 cm

The Rosen wire is an exchange-length wire. It is a long wire with a heavy-duty mandrel to within 2 cm of the tip, making it a very good tracking wire. The soft tip is flexible with a “J” on the end, Fig. 27. This wire is very useful for PA dilations. The catheter comes with a little purple introducer to help you get the J tip into the hub of your catheter. You will invariably lose the introducer or not have enough time to put it back on the wire before you are expected to put the wire through a catheter. A neat trick is that if you pull back on the part right after the “J” the tip will straighten out and you will be able to load the wire.

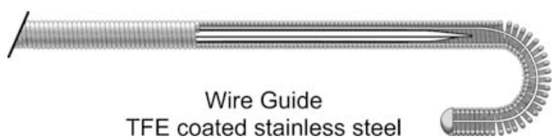

Fig. 27 Rosen wire

Amplatz Super Stiff® Wires

0.025″ and 0.035″ 260 cm

This is another exchange-length wire. It is very long, making it possible to exchange long catheters or sheaths over them in even the tallest patients. The Amplatz wires are great guide wires because they are very stiff. The inner mandrel is large and the exterior coil wire is flattened, causing the wire to be very strong. The distal ends are relatively soft. These wires can be bent into shape and continue to hold that shape after being passed through a floppy catheter. They have very good trackability, even when bent. They are often used for angioplasty of difficult-to-reach sites with difficult bends. Because of their stiffness, they can cause hemodynamic problems related to propping open traversed valves.

Stabilizer® Wire

0.014″, 300 cm

Although many 0.014″ wires exist, the stabilizer wire is the only exchange length wire carried at Children’s Hospital Boston in an 0.014″ size. They are very hard to see when on the table.

They are incredibly long as well–300 cm (because they have to make it all the way to the adult coronary arteries). Your challenge will be to find them and then load them with balloons in a dimly lit cath lab. Also, you will need to try very hard to distinguish them from the 0.014″ seeker wires.

How to Hold a Wire

You will spend a great deal of time holding wires during cases. As you might suspect, this provides many opportunities for mishap. We offer the following tips to aid you in your experience.

Try to keep track of what wires you have, and organize them on the table while the case is proceeding. When wires are removed from the body it is your job to wipe them down with gauze dipped in the flush. This will take the blood off of the wires and make them less sticky. Try to put the wires back in their houses if they are not going to be reused immediately. This will help hours later when there are 12 wires on the table. Be sure you don't put away a wire that is still in the patient!

Half of your time will be spent getting wires into tricky places. The other half will involve placing catheters in or removing them over the wire. The goal here is not to lose wire position. Losing wire position is one of the worst things you can do in the cath lab. The seriousness of this offense increases exponentially in relation to the time that it took to get to that vessel. Of course, the harder it was to get to that vessel, the easier it is to lose wire position.

So, let's start with getting a catheter removed over the wire. A wire will finally be in whatever position you need it, after you have spent some interminable time getting there. Now you need to take a catheter out over this wire so you can advance a new catheter (often a balloon).

To remove a catheter over a wire, you need to use both hands; one goes on the wire, the other on the catheter. Your eyes (it is hard to believe at first, but it is true) need to be ***on the screen*** watching the tip of the wire. Do not look at your hands! You will place the hand on the wire a short distance from the hand on the end of the catheter and then pull the catheter until it meets the other hand. (If you only look at your hands, you will move the tip of the wire even though it does not seem like you did.) It usually helps to rest your wire hand on the table, for a point of stability. You then reposition the wire hand and repeat this maneuver until the person at the groin (usually the attending) says they have the wire. When they have the wire securely in their hands, one of you can then pull the catheter the rest of the way off the wire a bit more quickly. If you are alone, you can do this as well, but it will probably take a while longer.

So now the wire is going through the sheath to somewhere you are very interested in, and you need to get something (another catheter) over the wire. Many catheters are relatively stiff and sometimes give you trouble going around the turns that the wire traverses, but you are going to get your catheter there. Your first job will be to place the catheter on the tip of the wire. Usually, especially when you are new, the attending will be holding the end of the wire near the sheath through this procedure, but it is your responsibility to see if anyone is holding the wire. *Always* know if someone is holding wire. Your catheter can be loaded either way, but you need to adjust your methods a little and be a bit gentler if no one is holding the other end of the wire.

You place the catheter on the free end of the wire and then you need to advance the catheter until you see the wire come out the back end. When you have the end of a wire in your hand, ensure that the wire is being held near the sheath, and then pull the wire taut. It is very important while you are pulling the wire taut that you do not also advance the catheter: *This will cause you to lose wire position*. When you have the wire taut (often you should plant your hand on the table to be sure it does not move), the catheter can be advanced forward, Fig. 28.

Fig. 28 Holding a wire

Generally, you want to hold the wire until the catheter is exactly where you want it, but there are times when you need to let go of the wire. How do you tell the difference? Again, you need to be looking at the screen. Occasionally, when you hit a certain curve the catheter will get hung up. If you continue to push the catheter the tip of the wire will start to come back; this is the point when the attending will "vigorously instruct" you to let go of the wire. Let go. From here you can either advance wire or push both to allow the wire to move forward. As you get used to it, you will be able to tell when this is happening and let the wire go at the right time. You can often feel this when you are the one advancing the catheter.

The other problem that can happen is that the wire can be advanced with the catheter. This generally means that you are not holding the wire tight enough, although it can happen when a stiff catheter straightens out the more curved course that the wire was taking. If you are watching the screen, you can adjust the wire to compensate for this. Otherwise you will get "firm suggestions" to hold the wire or move the wire. You will repeat this procedure many times in every case, especially when dilating pulmonary arteries.

You will have to hold wires sometimes when inflating balloons. This is usually when there is risk that the balloon will be milked forward with the dilation thereby also pushing the wire forward, particularly with valve dilations. Pushing the wire forward is not a good thing because you don't know where it will go, especially if you already have it in a small branch pulmonary artery. The wire's shape is also distorted with dilation. These two things combined can cause quite a bit of damage to the small distal vessels.

Another time you commonly will be holding the wire is when you take an angiogram through a pigtail that is over a wire. You need to hold the wire and the Y-connector firmly—the wire so that it is not also injected forward with the power injection, and the Y-connector because they break a lot.

At the End of the Case

At the end of the case, it is time to pull the lines. If you have sheaths in both the artery and vein you can just pull the sheaths without any other manipulation. If, however, you have a pigtail catheter (or other shaped catheter) in a vessel (or still in the sheath), you should remove the catheter over a wire (the soft end of a straight wire will do), taking care that the wire straightens out the catheter such that when you pull both out neither the wire nor the catheter damage the vessel by being "hooked" around the sheath or vessel wall.

Balloons, Stents, and Devices

The available catheterization lab armamentarium is ever changing, and varies not only over time but also from institution to institution. The following section describes general principles on the use of the most common of these items at the time of this writing.

Balloons

Selected Terminology and General Principles

Balloon Profile: The diameter of the deflated balloon

- Dictates sheath requirements.

Balloon Length: The length of the parallel portions of the inflated balloon (does not count the taper).

- Long balloons improve stability during inflation; often preferred in dilation of aortic valves in older children. They take longer to inflate and deflate fully.
- Short balloons cause less straightening of curved cardiac or vascular structures, and thus may cause less injury at the tips of the balloon.

Compliance: The degree of stretch at low pressure.

- Very compliant balloons preferentially enlarge within the normal part of the vessel, applying less pressure to the stenotic segment. These balloons may tear or rupture the normal vessel with minimal dilation of the stenosis.
- Noncompliant balloons increase their diameters more equally across the stenotic lesion and normal vessel.

- Noncompliant balloons have more predictable maximum inflation diameters compared to compliant balloons.
- Very compliant balloons are primarily used for sizing defects.
- Noncompliant balloons are preferred for stent placement or tight stenoses.

Dilating Radial Force Vector (tight waist vs. shallow waist):

- If the balloon diameter is small compared to the lesion, only a subtle waist is produced and the dilating force is small. The dilating force can be increased by increasing the inflation pressure, but this puts the balloon at risk for rupture.
- If the balloon diameter is large compared to the stenosis, the waist will be very tight and the dilating force will be large. In this setting, the normal vessel (proximal and distal to the stenosis) is at greater risk of injury. Also, when the balloon is under pressure, when the vessel begins to tear, it will rapidly tear all the way to the full balloon diameter (i.e., the bigger the balloon, the deeper the tear).
- Intermediate waists are the most effective and safest for nearly all lesions. Visualizing the waist and reacting appropriately is one of the most important skills in interventional cardiology.
- During inflation, the dimensions of the waist must be determined and a decision made whether or not to fully inflate the balloon. As a general rule, if the waist is $< 75\%$ the diameter of the proximal and distal balloon, it is too tight; the balloon should not be fully inflated, and the dilation should be repeated with a smaller balloon.

Sample Balloon Inventory and Specific Characteristics

See the Appendix. (p. 155–162)

Preparing a Balloon and Using a Gauge

You will prepare a thousand balloons during your fellowship. Try to modify your technique each time based on the specific needs of the case you are doing.

Caution: *Inappropriate balloon preparation can result in poor balloon visualization, air embolism or prolonged circulatory occlusion.*

How to Prep a Balloon

Remove the catheter from the packaging using sterile technique, and lay it on the table. To prepare the balloon, a 10-cc syringe (for balloons less than 10 mm) or a 20-cc syringe (for larger balloons) is filled with a combination of contrast and saline. The ratio of contrast to saline differs for each type of balloon and intervention. For small coronary balloons and cutting balloons less than 4 mm, the syringe should be highly concentrated with contrast, nearly 100%, so it will be easily visible by fluoroscopy. As the size of the balloon increases, and therefore the depth of contrast material in the balloon increases, adequate visualization can be achieved with more dilute mixtures. A typical mixture for, say a 5–10 mm balloon, is one-third contrast and two-thirds saline. A high concentration of contrast increases the viscosity of the fluid and therefore the inflation and deflation times of the balloon (long inflation/deflation times are unwise if you are obstructing cardiac output, e.g., dilating an aortic valve). However, the balloon will be easily seen, and any waist in the balloon will be easier to appreciate. A low concentration of contrast will flow into and out of the balloon more readily, but may make it difficult to see a waist.

A syringe with the appropriate amount of contrast/saline is attached to the balloon lumen of the catheter. The balloon lumen is always the one that comes off the shaft at an angle. It is also marked “balloon.” The other lumen is the end-hole lumen, and should be flushed with saline. After the syringe is on the balloon lumen, pull the plunger back and lock it—three times if you have time. The syringe is locked by pulling the plunger to the end of the syringe until it “catches,” and it will maintain some negative pressure without being pulled on. Between pulls, tap the hub of the balloons to free up any air bubbles that have been withdrawn. **Do not** push the plunger. This will start to inflate the balloon and increase its profile, making it more difficult to get into the body and to the dilating site. After you have fully prepped the balloon, leave the syringe locked and get the tip of the catheter in your hand, ready to load on the guide wire.

Using a Gauge

Gauges allow you to apply a specific amount of inflation pressure. Generally, hand inflation is ≤ 8 ATM, although obviously the stronger you are and harder you push, the higher the pressure (a hard push can approach 12–14 ATM). If you are pushing hard. it is a good idea to know how hard, and for that we use a gauge.

There are many varieties of gauges, but they all work in a similar manner. Most allow you to freely push the plunger, then lock the plunger and twist a handle that gradually increases the pressure. A manometer allows you to follow your progress. To use a gauge you first have to prep it. This essentially means filling it with saline and/or contrast. The ratio of saline to contrast depends on whether you intend to start inflation with the gauge or with a prepped balloon and then swap out for a gauge. If you are starting with a gauge, fill it with a saline/contrast ratio as you would a syringe for the balloon. If you are just swapping in the gauge after the balloon is essentially fully inflated with contrast, then the ratio in the gauge matters less because little will actually enter the balloon.

When you have locked the gauge, start turning the handle clockwise to increase the pressure. Call out your inflation pressures. You cannot usually simultaneously watch the screen and the manometer, but try and also listen carefully to your attending to tell you when to stop. When you are ready to deflate the balloon, you can just turn the plunger counterclockwise, but this takes forever. Instead, it is much quicker to unlock the gauge and pull back as you would a normal syringe. Then you can lock the gauge with negative pressure. Remember that some gauges have no backstop on the plunger, so you can easily pull the plunger all the way out and lose all of your negative pressure. *Don't do this*. If you do, the easiest solution is to disconnect the tubing from the catheter and attach a standard 10-cc syringe to the catheter, pull it back, and lock it. This empty syringe should always be easily accessible for any balloon dilation/deflation.

Optimal Balloon Selection: Lesion

NOTE: *The following are guidelines. The ultimate decision to inflate a balloon is based on the appearance of the waist as it begins to form in the lesion.*

Coarctation of the Aorta

- Initial balloon diameter 2.5–3× the diameter of the coarctation.
- At most, 120% of the diameter of the aorta proximal and distal to the coarctation.
- Shortest balloon available (2 cm for infants/children; 3–4 cm for adolescents).
- Smallest possible arterial or venous sheath size (low-profile balloon).
- Higher inflation pressures and high-pressure balloons are often needed for re- coarctations (less compliant lesions)

Branch Pulmonary Artery Stenosis/Hypoplasia

- Initial balloon diameter 3–4× the lesion diameter.
- $\leq 2\times$ the diameter of the normal distal PA.
- Adjust the balloon size to the degree of waist observed during dilation.
- Prefer short balloons with minimal tip length (short taper).
- High-pressure balloons usually preferred.

Homograft/Conduit Stenosis

- Balloon diameter up to 110% of the implanted conduit diameter.
- Prefer shorter balloons to minimize straightening of calcified conduit.
- High-pressure balloons are required.
- Stenting frequently necessary.

Pulmonary Valve Dilation

- Balloon diameter 120–130% of the annulus (lateral view, RV angiogram).
- 2 cm long for infants/young children; 3–4 cm for older children/adults.
- Low-profile balloon and short taper are an important feature for newborns.

- For critical PS in neonates: initial balloon 2–4 mm, 1 cm long; then dilate up to 120–130% of the measured valve annulus.

Aortic Valve Dilation

- Initial balloon diameter 80–90% of the valve annulus (LV angio; long axial oblique and RAO).
- Valve damage increases significantly at balloon: annulus ratio ≥ 1.10.
- Stiff guide wire and longer balloons help stabilize the balloon across the valve.
- Low-profile balloons allow smaller sheath sizes.

Mitral Valvotomy

- A general guide to initial balloon sizing is based upon BSA:
  - 8 mm in patients $\leq 0.4\,m^2$
  - 10 mm in patients $\sim 0.4–0.8\,m^2$
  - 12 mm in patients $\sim 0.9–1.2\,m^2$
  - 15 mm in patients $\geq 1.2\,m^2$
- Adjustments in balloon diameter are made according to waist on inflation.

Stents

Indications

Intravascular stents have been used in children since 1989. Specific indications include lesions unresponsive to conventional balloon dilation (compliant obstructions, stenoses due to kinking, external compression or intimal flaps), stenotic anastomoses in the early postoperative period, recanalized vessels/baffles or thrombosed shunts, and following significant tears or aneurysmal formation during balloon angioplasty.

CAUTION: *Stents are not well suited for a number of situations, either because of lack of efficacy or undesirable characteristics*. Some of these include:

- Stent placement in young children is avoided when possible. With newer, higher-pressure balloons, some stents may be broken, but at this point it remains wise to not rely upon this.
- Stents within stenoses in the distal pulmonary arteries often cover and may obstruct side branches.
- Stents placed within pulmonary veins usually produce good immediate results; however, restenosis and occlusion can be anticipated within weeks to months.
- Stents placed across the transverse aortic arch may cover and possibly obstruct brachiocephalic vessels.

Stent Inventory

Stent inventory will vary from institution to institution. We currently carry four types of bare metal stents, which roughly divided by size, are:

1. Coronary Express® stents (Boston Scientific)
2. Palmaz Genesis® pre-mounted stents (Cordis);
3. Palmaz Genesis® XD stents (Cordis) Fig. 29
4. Palmaz XL stents (Cordis) Fig. 30
5. Palmaz Blue® stents (Cordis)
6. ICAST® pre-mainted covered stents (ATRIUM)

Fig. 29 Genesis stent

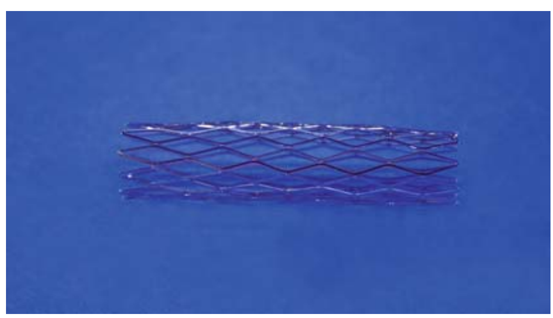

Fig. 30 Palmaz stent

Each type of stent has its own set of characteristics, with advantages and disadvantages, which are beyond the scope of this manual. You should know that some stents "shorten" in length the more they are dilated, so be aware of the stent characteristics prior to placement.

Covered Stents

There are a variety of premade balloon-expandable and self-expanding covered stents on the market. Additionally, "hand-made" stents can be prepared by sewing surgical Gortex Gore-Tex® into a cylinder of a required diameter and then attaching this to the outside of a stent of the desired size. This requires some know-how and is not advised for the inexperienced. Some indications for covered stents include simultaneous dilation of baffle obstruction and closure of baffle leak/fenestration, closure of a Potts' shunt or aortopulmonary window, vessel recanalization and as rescue for significant vascular injury.

How to Load and Deliver a Stent

After it has been determined that stent placement is appropriate, a stent size is chosen based on the balloon size used for dilation and the desired final size of the vessel. The length of the stent is decided upon based on location of the stenosis and the risk of compromise of adjacent vessels. In general, we choose the shortest possible stent that is likely to address the stenosis.

If you do not have an appropriate premounted stent available you must mount it yourself. Traditionally, a stent is hand-crimped onto a balloon that is delivered through a long sheath that has previously been positioned across the lesion. A front-loading technique can be used as well.

Equipment

Balloons

- The balloon profile should be large enough to prevent slipping of the stent.
- Scratch-resistant balloons minimize the risk of balloon rupture.
- Nonslippery/hydrophobic balloons minimize stent instability during inflation.
- Longer balloons maximize stent stability during expansion.
- Shorter balloons reduce the risk of the stent puncturing the balloon, especially if the course involves a curve.

Wires

- Depends on the balloon/stent being used. For large stents one of the following:
  - 0.035″ Rosen—moderately stiff/curved end—usually used if the wire course is relatively straightforward.
  - 0.035″ Super Stiff®–very stiff/soft end—provides more stability; must be pre-bent to conform to bends within the heart or vasculature.

Procedure and Techniques

Back Loading

A stiff wire (e.g., Amplatz Super Stiff) is secured in position across the area to be stented. Shaping the wire to accommodate the curves during its course is helpful in stabilizing its position. The long sheath and dilator are then advanced over the wire to beyond the area of stenosis. A balloon catheter is chosen for stent delivery. Be sure the balloon shaft is longer than your long sheath! Before the dilator of the sheath is removed, the balloon must be prepared. If the long sheath lacks a hemostasis valve, some sort of side arm or adapted short sheath must be placed on the balloon catheter shaft, preferably before the stent is crimped on it. The dilator is then withdrawn slowly and the balloon/stent/side arm apparatus is loaded onto the wire and into the long sheath. The balloon/stent is then advanced over the wire until the stent is centered across the area of stenosis.

If there is difficulty advancing the balloon/stent the last few millimeters around a curve in the sheath, the entire apparatus may be moved forward. The sheath is then pulled back off of the balloon, remembering to allow some distance for the balloon taper. A hand injection can be done through the side port of the long sheath to confirm stent position relative to the lesion, and then the balloon is inflated and stent delivered. If the stent has slipped back on the balloon during positioning, the balloon can be partially inflated to release the stent into the vessel, and the end of the sheath used to buttress the stent while the balloon catheter is deflated and pulled back to straddle the stent. The procedure is then continued with full inflation of the balloon deploying the stent in position. The balloon catheter is then removed and the results are assessed, with the possibility of re-dilating the stent with a larger balloon or to flare poorly apposed ends.

Front Loading

Front loading is an alternative technique. It involves placement of a stent directly in the distal aspect of the long sheath. In this technique the balloon catheter carrying the stent acts as the dilator for the long sheath as it is passes up to and through the stenosis. Because the balloon and stent do not have to travel through the long length, and possibly multiple curves, of the long sheath, this technique decreases the likelihood of stent "slippage" during delivery. It also generally allows a slightly smaller long sheath, as there is not as much need for room around the balloon/stent within the sheath. However, unless the balloon tip is to be passed bare through the groin, it does not end up saving much in terms of sheath size in the groin.

An exchange length wire (Rosen or Amplatz Super Stiff)is placed in the desired position. The long sheath is flushed. A short sheath that will accommodate the long sheath is chosen (1–2 sizes larger) and their compatibility is tested. The short sheath is inserted into the site of venous access over the guide wire. The desired balloon is advanced through the long sheath until it extends beyond the end of the sheath. The stent is mounted on the center of the balloon by compression with moderate pressure; rolling between the fingers. Avoid severely crimping the ends of the stent, which may puncture the balloon. The proximal and distal portion of the balloon can be sequentially partially expanded while compressing the opposite end of the balloon to assure equal trouble free inflation of each end of the balloon. This can be crucial for stent stability during inflation because if only one end expands it can "milk" the stent off the balloon.

The stent/balloon combo is then withdrawn into the end of the long sheath without dislodging the stent (this is usually a tight fit). Check to see that the stent/balloon combo comes out of the sheath smoothly by advancing the balloon catheter out enough to partially uncover the stent. Leave about 1 cm of the balloon catheter tip extending beyond the end of the sheath for smooth transit through the heart. The balloon/stent/long sheath combo is then advanced over the guide wire through the short sheath (or skin). Take care to keep the relationship of the balloon catheter and the long sheath constant by holding both together at the hub of the sheath. Advance the combo to the area of interest. When the stent is appropriately positioned the long sheath can be pulled back leaving the stent position unchanged. Hand injections of contrast through the sidearm of the long sheath are valuable in assessing stent position and should be recorded for use as reference images. The position is adjusted as necessary.

Peri-Stent Care

Specific recommendations are included in the sections on typical lesions. In general:

- Although general anesthesia is not usually required, stent implantation requires sufficient sedation so as to eliminate patient movement.
- We usually recommend that an appropriate antibiotic be administered.
- The ACT should be maintained at > 200 during the procedure.
- Unless specifically contraindicated, a Heparin infusion should be considered overnight for stents in low-flow areas (Fontan baffles, pulmonary vessels, etc.)
- Consider anticoagulation therapy asprin, plavise, or coumadin as appropriate.
- CXR (PA/Lateral) should be reviewed post-catheterization to assess stent position and integrity

Complications

Embolization

This is one of the most feared complications as it may require surgical removal. If the stent is not secure after it is expanded, re-expanding the balloon in the stent and maneuvering the balloon/ stent combination proximally may allow fixation of the stent in another portion, or in non obstructive position in the systemic venous system, Fig. 31.

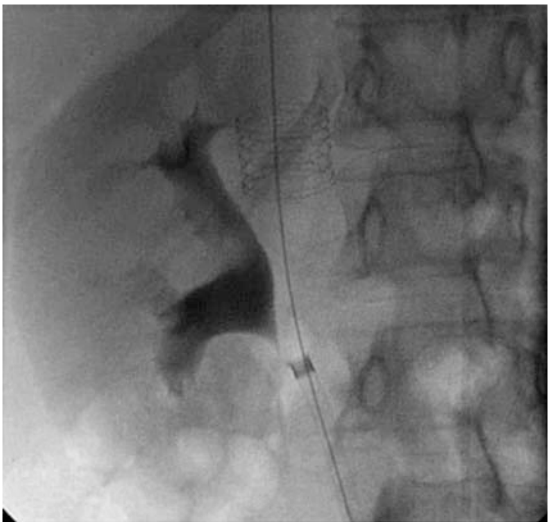

Fig. 31 Angiogram stent secured in SVC after free from Atrium

Side Branch Compromise

Although the open stent is more than 90% free space, side branch compromise may occur if the orifice of the branch is straddled by the stent Fig. 32. This is more common when the branches take off at an acute angle and their opening is compromised by the expanded stent overlying the vessel proximally. Choice of length and positioning of the stent helps in avoiding this complication; however, this complication may be unavoidable and its consequence should be weighed against the gain in improvement of flow in the stented vessel. Simultaneous stenting can be performed in certain situations. In some stents (especially "open-celled" stents), the cells leading to side branches can be dilated and result in improved flow in the event of side branch compromise.

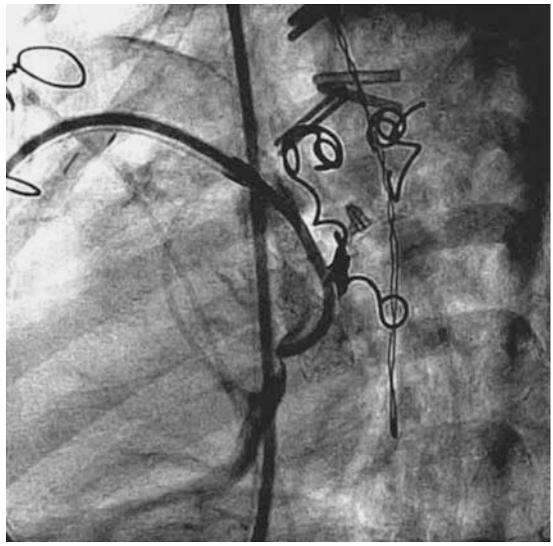

Fig. 32 Angiogram of side branch occlusion after stent placement

Fracture

Although more commonly seen when stents are placed in dynamic obstructions Fig. 33, this

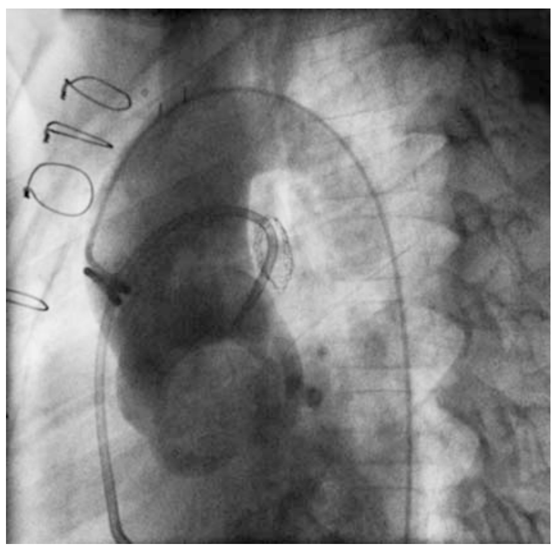

Fig. 33 Stent fracture

Table 8. Occlusion Devices for Atnal Septal Defects

	AMPLATZER®	Helex®	CardioSEAL®	STARFlex®
Manufacturer	AGA	GORE	NMT	NMT
Device design	Double mesh caps Nonferromagnetic woven Nitinol (nickel–titanium alloy) mesh, two mushroom caps set end-to-end with 4-mm long connecting waist	Double spiral discs Nonferromagnetic spiral Nitinol (nickel–titanium alloy) wire with attached Gor-Tex® (PTFE) fabric	Double umbrella. Nonferromagnetic MP35n® (nickel–cobalt–chromium–molybdenum) alloy radial arms (4) with Dacron (polyester) fabric	Double umbrella Nonferromagnetic MP35n® (nickel–cobalt–chromium–molybdenum) alloy radial arms (4), spring (Nitinol) coil design, with Dacron (polyester) fabric
Centering method	Rigid, central disc	None	None	Microsprings adapt to variations in defect shape and septal morphology
Delivery method	6–12 Fr sheath, sequential disc deployment	9 Fr sheath, sequential disc deployment	10–11 Fr sheath, sequential umbrella deployment	10–14 Fr sheath, sequential umbrella deployment
Retrievability	Difficult after release	Limited data	Difficult after full deployment or release	
Conformability	Reported as not very conformable when defect is not round	Reported as very conformable	Occluder arms move independently from one another, enabling device to adjust to various septal morphologies	
FDA status	Approved for ASD and muscular VSD closure	Approved for ASD closure	Approved for VSD and Fontan fenestration closure	Pending

could also happen in stented pulmonary arteries especially if high-pressure balloons are used to place the stents. To avoid this, it is recommended that high inflation pressures be used for angioplasty prior to stent implantation allowing the stent to be positioned with relatively low pressures.

MRI Considerations

Many of the most common stents are made of 316 L stainless steel, which is a non-ferromagnetic material. In studies to date there appears to be no risk of movement or displacement of the stent during an MRI, even immediately after implantation. The stents may cause artifact due to distortion of the magnetic field.

Occlusion Devices

There is an ever-expanding list of vascular and septal occlusion devices available for use in the catheterization lab, a detailed discussion of which is beyond the scope of this manual. We will present some of the more common occlusion devices that are either FDA approved or available as part of FDA-approved clinical trials, Table 8. However, the Helex® device has not been used by the editors at the time of publication and therefore will not be discussed in detail.

Septal Occlusion

The purpose of this section is not to describe in detail which devices can or should be used where, but rather to provide a description of the general characteristics of the more commonly available devices.

CardioSEAL®/STARFlex®

These devices are self-expandable with a double-umbrella design. Each of the umbrellas has four spring-loaded arms which are flexible and attached to one another in the center

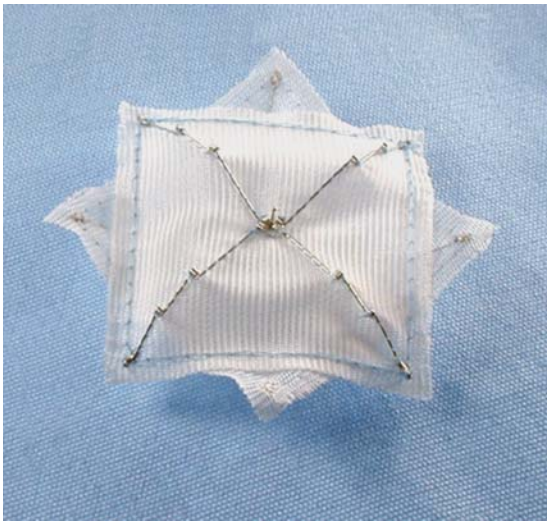

Fig. 34 NMT Cardioseal device

Fig. 34. This design allows arm separation when the septum is thick and arm overlap when the septum is thin, maintaining a low profile against the septum. The metal arms are covered with a woven Dacron fabric to promote early endothelialization.

ClamShell I: First-generation double-umbrella device available in 1989. The design was modified due to a high rate of arm fractures.

CardioSEAL®*:* Second generation; first used in 1996. This device is FDA approved for muscular VSDs and Fontan fenestration closure. Refer to chart in appendix for available sizes.

STARFlex®*:* Third generation. Major modifications include a flexible self-centering mechanism consisting of four flexible microsprings attached between the opposing umbrellas, a pin-pivoting delivery mechanism that allows pivoting of the device along the septal plane during delivery, and a smaller delivery profile. As of July, 2008 this device has not been FDA approved.

AMPLATZER®

The AMPLATZER devices are self-expandable, double-disc devices made from a Nitinol wire mesh. The two discs are linked together by a short connecting waist. The discs and waist are filled with polyester fabric that is secured to each disc by a polyester thread. There are several AMPLATZER® devices, each with a design specific for transcatheter closure of specific defects.

The AMPLATZER *Septal Occluder* (ASO) is FDA approved for transcatheter closure of secundum ASDs and fenestrations, and comes in sizes ranging from 4 mm to 38 mm. The two discs are linked together by a connecting waist, the diameter of which corresponds approximately to the stretched diameter of the ASD. The LA disc is larger than the RA disc (see chart in the Appendix).

The AMPLATZER *Multi-fenestrated "Cribriform" Septal Occluder* is currently available in four sizes (18 , 25, 30, and 35 mm). It has a similar design to the ASO described above but with a narrow central connecting stalk, and the LA and RA discs are each the same size. Ostensibly, it is designed for closure of multi-fenestrated ASDs such that the smaller central stalk allows placement through holes of relatively small size, but the more generous RA and LA discs allow coverage of a greater portion of septum, Fig. 35.

The AMPLATZER *Muscular VSD Occluder* is similar in design to the atrial septal occluder, except the central core is longer (7 mm) and the retention discs are the same diameter on both the RV and LV sides, with the diameter of the retention discs usually being 8 mm larger than the central core (except in the 4-mm device, where the difference is 5 mm).

The AMPLATZER *Ductal Occluder* is available in a variety of sizes (see chart in the

Fig. 35 AMPLATZER Multi-fenestrated septal occluder device

Appendix), with an aortic disc and narrower intraductal base. The device is placed transvenously. It is recommended that the size of the smaller end of the ductal occluder be 2 mm greater than the smallest dimension of the PDA.

The AMPLATZER *Vascular Plug* is available in a variety of sizes (see chart in the Appendix).

How to Load a Device

CAUTION: Loading devices correctly is critically important, because a loading failure can result in device embolization. If you have any doubt that the device has been loaded properly, let the attending know. It is always easier to pull another system off the shelf than to try to recapture and remove a device.

NMT Delivery System

The NMT delivery system consists of a long sheath and dilator, a delivery catheter/cable assembly, a "quick loader," and the device. The device is attached to the delivery catheter/cable using a pin-to-pin mechanism.

Loading a CardioSEAL/STARFlex® is a two-person task. One person holds the delivery catheter in the right hand, and the device in the other. The device should be oriented so that the pin at the end of the delivery cable and the pin on the device are side-by-side and are only overlapping by the length of the head of the pin. The second person will withdraw the delivery pin into the cupped sleeve at the end of the delivery cable. The pin of the device will then be trapped in the cupped sleeve, and cannot be released until the delivery pin is advanced out of the cupped sleeve.

Advancing and withdrawing the pin is accomplished by pushing or pulling the small black cylinder at the back end of the delivery cable. After the pin is withdrawn and the device has been attached, the relationship of the pin to the sleeve can be fixed by locking the black cylinder in position. Now that the device is on the delivery cable, it must be collapsed into the loader.

Person 1 will hold the buttoned thread of the distal arms of the device and pull as if pulling the device off the delivery cable. Person 2 will provide counter traction by pulling the delivery cable in the opposite direction. This will lengthen the entire system, and will collapse the distal arms of the device. While these arms are collapsed, Person 1 will slide the loader over these arms and then continue sliding until the entire device is collapsed into the loader. At this point, the buttoned thread can be cut away.

With the device attached to the cable, collapsed in the loader and free of the thread, it is almost ready to go. The only thing that remains is to flush the device and loader with some saline. Finally, Person 2 advances the blue catheter along the cable up to the loader and fixes the relationship by screwing down the black cylindrical vise. The purpose of the blue catheter is to add support to the delivery cable as the device is pushed up to its destination through the long sheath. When it is near the end of the long sheath the blue catheter can be withdrawn, exposing the cable within the sheath. The device is now ready for delivery.

AMPLATZER Delivery System

The AMPLATZER delivery system is similar for most of the devices and consists of a long sheath and dilator, a delivery cable, a loader, and the device. The device is attached to the delivery cable using a screw-in mechanism.

First, pass the delivery cable through the loader. Hold the cable in one hand and the device in the other. The device should be oriented so "male" and "female" parts of the screw-threaded release mechanism are lined up coaxially. Appose the two parts and start to attach the device by turning the cable a bit clockwise. When the cable and device can hold themselves together gently spin the device counterclockwise until it is fully screwed onto the end of the cable. You will feel a little resistance and then a "clunk" that indicates that the device is locked to the cable. Immerse the device, attached to the delivery cable, into a bath of flush solution. Holding the cable firmly with one hand and the loader firmly with the other, pull the cable and device back into the loader in one quick, smooth action. The device should collapse into the loader. Flush the loader. You are now ready to introduce the collapsed device into the long sheath for delivery.

Retrieving a Device

Not everything goes as smoothly as you would like in the catheterization lab, and if you spend enough time in the lab you *will* have to retrieve a device. In general, there are two types of device retrieval: retrieval of a device you have control of (delivery system still attached) and retrieval of a device that you don't have control of (malpositioned or embolized and not attached to a delivery system).

NMT Retrieval

CardioSEAL and STARFlex devices exist in one of four states in the body. They are either entirely within the delivery sheath, partially deployed ("LA" arms out, "RA" arms still in the sheath), fully deployed (all arms out, still attached to delivery cable), or released. Recapturing a partially deployed NMT device is straightforward. Depending on your situation you may either carefully pull on the delivery cable or slide the delivery sheath forward (or both). Either will easily recapture the "LA" arms, after which you may either reposition and redeploy or remove the device through the long sheath.

In contrast, after both sets of arms are delivered, things get somewhat more difficult. As discussed briefly above, the NMT devices cannot be pulled back into the usual delivery sheath in their entirety. They can, however, usually be pulled back partially (the pin and central body of the device typically may be pulled into the sheath, but the "RA" and "LA" arms will evert and overlap and not all come within the sheath). It is for this reason that we advocate for a 14 Fr short "safety sheath" in most situations because you can usually pull the device and delivery sheath combination out through a sheath of this size (and not lose access!).

To use this technique you can either place the 14 FR short sheath primarily and perform the intervention as planned through this, or before you place your long delivery sheath you can slide it through the short sheath and slide this all the way back to the hub of the long sheath. Depending on the patient's size, you may be able to leave the short sheath back and out of the body and only advance it over the long sheath if you need to retrieve the device. Note that rarely when trying to retrieve a fully deployed NMT device into the long delivery sheath the device can dislodge from the delivery cable (and embolize). This may occur if the delivery cable has not been appropriately attached or locked onto the NMT device pin, so you should always exercise extreme care when loading your device! Finally, retrieving a released and either malpositioned or embolized NMT device is difficult and usually requires some combination of large long sheaths and snares.

Tips:

- When attempting retrieval of either a fully deployed or released NMT device, try to avoid recapture in the vicinity of cardiac or vascular structures that may become entrapped in the device/sheath (e.g., Eustachian valve, etc.), and *never* pull a device across a valve.
- When attempting retrieval of a fully deployes NMT device move to a secure position such as the IVC before aggressively trying to pull the device into the sheath therefore if the device becomes detatched from the cable it will be less likely to embolize.
- Always keep an eye on your ACT when resheathing and recapturing devices as thrombus may form on them and be embolized with manipulations.

AMPLATZER Retrieval

One of the chief benefits of **AMPLATZER** devices of essentially all types is that they are easily "resheathable" until released. After they are released, things again become a bit trickier. However, often the device can be snared or captured with a bioptome at the point where the delivery cable attaches and then can be fully retrieved into the delivery sheath (or more easily through a slightly larger sheath). Attempting to reattach the delivery cable to a released device by trying to screw them back together in situ is usually a waste of time because the cable is seldom in perfect alignment. Do not waste time snare the device and get it out of the body.

Vascular Occlusion

Coils

Cesare Gianturco, an Italian radiologist, first described the use of coiled spring "wooly tails" in 1975. Since that time, Gianturco-type coils have become commonplace in catheterization labs for occlusion of a variety of vascular (and other) structures. Coils come in a variety of shapes, sizes, and constituents, but share the common characteristic of a spring-like shaped metal coil, usually embedded with synthetic filaments that promote thrombosis Fig. 36. The most common coils in pediatric catheterization labs are made of steel or platinum. Steel coils are "MRI safe," but produce greater artifact than platinum coils. Steel coils also maintain greater radial force then platinum coils, but are somewhat more difficult to visualize on fluoroscopy. Recently, new non-ferromagnetic metal alloy coils were made available with similar characteristics to the steel coils. Ideal coil characteristics depend on the indication. Coil occlusion of PDAs is discussed in Section II. Most coils are delivered through shaped or end-hole catheters by carefully delivering the coil out of the catheter with a straight wire, or pulling back the catheter while holding the wire and coil in place. Detachable coils also exist and numerous technical modifications are possible including multiple coil and bioptome assisted delivery.

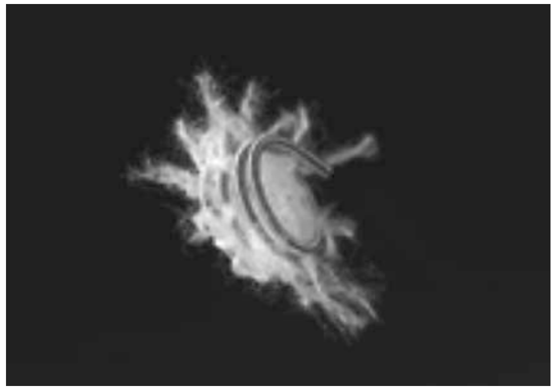

Fig. 36 A coil