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Coil Occlusion of the Large Patent Ductus Arteriosus

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Abstract

While coil occlusion is well accepted for the small patent ductus arteriosus (PDA), occlusive devices are preferred for the larger (> 3 mm) ducts by most institutions. Because of costs concerns, occlusive devices are not always realistic in many countries. The technique of simultaneous delivery of multiple coils with biopptome assistance works well for relatively larger ducts. This technique requires careful case selection through echocardiography. The duct anatomy plays a crucial part in determining the suitability for coil occlusion. Coil occlusion has a specific advantage for relatively larger ducts in selected small children and in preterm infants because it is possible to accomplish delivery of multiple coils through relatively small introducer sheaths. In addition, aortic narrowing is less likely because coils compact in the ampulla. This review describes case selection strategies and techniques of coil occlusion of the large PDA. Relevant illustrative images are shown.

Initial reports of the use of Gianturco coils for the patent ductus arteriosus were published in early 1990s.¹ Coil occlusion is now almost universally established as a simple, safe and effective technique for occlusion of the small patent ductus arteriosus (PDA) that measures less than 3 mm in diameter at its narrowest point (usually at the site of insertion of the duct in the pulmonary artery).^{2,3} Coil occlusion of larger ducts is technically challenging because of a greater tendency for coil embolization.⁴ Various modifications in technique have been suggested to reduce the risk of embolization. They include the use of detachable coils,⁵ deployment of thicker (0.052 inch) coils,⁶ simultaneous deployment of two or more coils,⁷ snare-assisted delivery,⁸ and biopptome assisted-delivery.^{9–11} Occlusive devices such as the Amplatzer Duct

Occluder (ADO) overcome many limitations of coils for closure of large PDAs and allow for better control and safety. Most institutions now prefer occlusive devices for PDAs that are >3 mm. Devices are however considerably more expensive than coils, and in many developing countries device closure costs substantially more than surgical closure. The biptome-assisted coil occlusion technique has emerged as a less-expensive alternative to the ADO.^{10–13} With careful attention to case selection and technique it is possible to coil occlude the majority of ducts. Further, in specific instances, such as in selected small infants, coil occlusion may have an advantage over the Amplatzer duct occluder. This review will describe case selection strategies and the coil occlusion technique for ducts that are relatively large (< 3mm at the narrowest point).

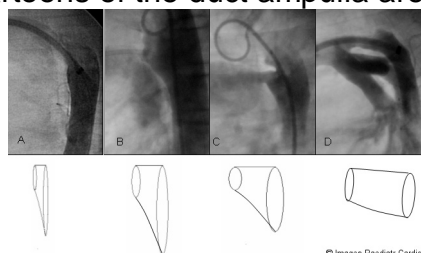
Anatomic and physiologic considerations

The PDA is typically an asymmetric, truncated cone with considerable variations in its size, shape and attachment to the aorta (Fig. 1). The narrowest part of the duct is typically close to the pulmonary arterial end of the duct. This is perhaps because of the tendency of the duct to close from its pulmonary artery (PA) end early after birth. Variations in the size of the ampulla often determine suitability for coil occlusion.¹⁴

The ampulla in the majority of ducts is generous enough to accommodate coils of appropriate size for occluding the PA end. In some instances, however, the ampulla is shallow. Rarely, it is absent altogether. The broader aortic end of the ampulla typically originates from the leftward aspect of the aorta. It is therefore often necessary to undertake the aortogram in the right anterior view as well as the conventional lateral view.

Unless the pulmonary vascular resistance is considerably elevated, the PDA shunts continuously from aorta to PA. The duct size and relative resistances of the systemic and pulmonary artery circuits determine the extent of flow reversal that occurs in the proximal descending aorta. From the standpoint of coil occlusion, flow reversal is a useful phenomenon because it can be used to for angiographic definition (see below) and for deposition of coils. The hemodynamic significance of the duct is determined by size, length (longer ducts are likely to offer greater resistance to flows) and age at presentation.

Figure 1 Angiograms obtained from four patients are shown to illustrate the wide variety encountered with anatomy of the ampulla of the PDA. The angiograms are arranged according to the size of the ampulla from the most shallow (A) to the relatively generous (C). 'D' is an example of a tubular duct. Equivalent cartoons of the duct ampulla are shown below.



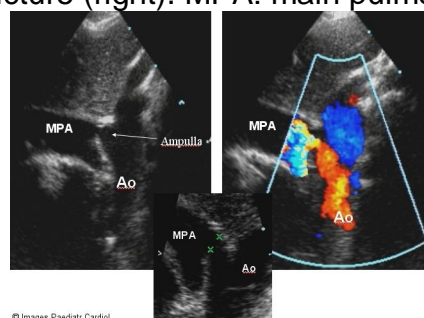
Clinical evaluation, chest X-ray and ECG

A good clinical evaluation provides valuable clues on the likely size of the duct and pulmonary blood flow. Increased precordial activity, bounding pulses and a murmur that is grade III or louder all suggest that the duct is likely to be large with a significant left to right shunt. The chest X-ray in these patients typically reveals increased pulmonary blood flow and cardiac enlargement with a prominent aorta and ECG reveals prominent left ventricular forces with prominent q waves in lateral chest leads. Clinical, X-ray and ECG features of elevated pulmonary vascular resistance may preclude the possibility of coil occlusion.

Echocardiography

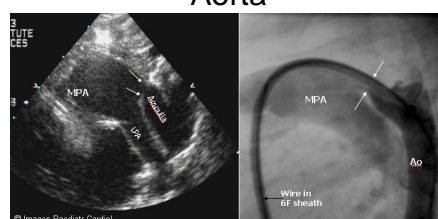
A detailed echocardiographic evaluation of the duct anatomy and physiology is a must for all patients undergoing coil occlusion. Excellent definition of anatomy is feasible in almost all infants and children and in many adults.^{15,16} The duct diameter should be measured in a high parasternal long-axial view at the point where it opens into the pulmonary artery (Fig. 2,3). The measurement must be made using the zoomed two-dimensional echocardiographic image (Fig. 2) and not the width of the color Doppler jet. Subtle adjustments in the transducer position and angulations are required for precise definition of the PDA at its pulmonary artery insertion.

Figure 2 Echo definition of the patent ductus arteriosus. This is a high left parasternal view (ductal view) obtained in an infant. The duct insertion as well as the ampulla is clearly defined. Measurement of the duct insertion site is made in the magnified view (bottom insert). Note the retrograde flow of blood in the color Doppler picture (right). MPA: main pulmonary artery, Ao: Aorta.



Since this measurement varies with different phases of cardiac cycle, the maximum measured diameter at pulmonary artery insertion should be reported. Repeated measurements may have to be made and the most concordant measurement should be reported. The ductal ampulla is often defined in the high parasternal long-axial or in the supra-sternal long-axis view (Fig. 3).

Figure 3 The frame on the left shows a 2D echocardiography frame (high parasternal view). An angiographic frame from the same patient in the lateral view (rights frame) has been obtained by hand injection through the long sheath placed across the duct. White arrows show the pulmonary artery end of the duct. LPA: left pulmonary artery, MPA: Main pulmonary artery, Ao: Aorta



The ductal ampulla is considered adequate if its maximal dimension along the long axis is greater than twice the measured ductal diameter. (Fig. 4)

Essentially, one needs to visualize whether a coil that is large enough to occlude the duct can occupy the ampulla without protrusion into the aorta. It is a good idea to draw a picture of the echo anatomy (Fig. 4) in the report and plan the strategy for coil occlusion based on the echocardiographic anatomy. Echocardiography provides many clues about the physiologic significance of the duct. A large duct with increased pulmonary blood flow is suggested by a left atrial and left ventricular enlargement and flow reversal in the descending thoracic and abdominal aorta. The Doppler gradients across such a duct at end diastole are typically low (< 30 mm Hg). In our experience, peak systolic Doppler gradients do not correlate well with duct size. Major elevation of pulmonary vascular resistance is suggested by low velocities in both directions across the PDA together with absence of flow reversal in the descending aorta. These ducts are typically very large and coil occlusion is often not an acceptable option.

In addition to evaluation of the PDA, the origins of the main branch pulmonary arteries should be carefully inspected for stenosis at their origins. Any internal inconsistencies between duct size estimation and hemodynamic correlates (above) should prompt reassessment of size through repeat measurements. For example if the duct is measured as 2 mm in a child who has a large shunt that is clinically obvious with echocardiographic features of a large shunt, there is a distinct possibility of an error in the measurement.

Figure 4 Suprasternal view of the duct ampulla. The frame on the left is an echo frame showing the duct ampulla. The pulmonary artery end of the duct may not be profiled in this view. The frame on the right is a cartoon from the same echo image. The line with arrows at its ends shows the long axis of the ampulla. Ao: Aorta, PA: pulmonary artery



Case Selection

The decision on the closure strategy for PDA is determined by the following considerations:

1. Duct Size at its narrowest point (usually at PA insertion)
2. Size of the Ampulla
3. Shape of the ampulla
4. Age and weight of the patient

For coil occlusion to be successful the coil diameters typically have to be greater than or equal to twice the smallest diameter of the duct and the ampulla on the aortic aspect of the duct should be large enough to accommodate the coil(s) (maximum dimension ? twice the smallest duct diameter). A conical or funnel shaped ampulla is best suited for coil occlusion

because it allows the coil loops to pack themselves without protrusion into the aorta. Fortunately the vast majority of ducts have this shape. The patient's age and weight determines the diameter of descending aorta. The descending aortic diameter needs to be large enough for the coils to form without straightening up. The maximum size of the delivery system is also determined by the patient's age and weight. Based on these considerations, the following “rules of thumb” can be used as approximate guides:

1. **Adults and older children (> 15 Kg):** It is possible to coil occlude most ducts < 5 mm in adults and older children and the size of the ampulla is seldom a major consideration here. The Duct occluder is a better option for ducts > 5 mm in diameter but coil occlusion can be attempted in institutions where cost differences matter. Ducts greater than 8 mm in diameter are generally unsuited for coil occlusion and should undergo closure using the Amplatzer duct occluder irrespective of the size of the ampulla.
2. **Infants and young children (5-15 Kg):** Ducts that are greater than 5 mm in diameter are often difficult to coil occlude irrespective of size of the ampulla. Ducts that are 3 mm or smaller can be coil occluded even in instances where the ampulla is small. For ducts that are 3-5 mm in diameter, the size of the ampulla matters. The maximum diameter of the ampulla should be ? twice the smallest duct diameter. The duct occluder usually works well as an alternative to coils for this category of patients except in the occasional child with a very large duct (> 8 mm).
3. **Small infants < 5 Kg:** This is a challenging subset. However, in this category, coils are often a better alternative to the conventional Amplatzer duct occluder since they do not protrude into the aorta. An important additional consideration here is the size of the descending aorta. In general it is very difficult to deploy coils larger than 8 mm in diameter. Therefore, ducts larger than 4 mm diameter are usually not suited for coil occlusion irrespective of size of the ampulla. For ducts smaller than 4 mm, the same rules (above) apply.
4. **Very small infants and preterm newborns (< 2 Kg):** Here the size of the delivery system is an additional concern. Typically only 4 French delivery systems can be used. Such systems allow a single 0.052 inch coils or two 0.038 coils. Coil diameters of 6 mm or more often cannot be used because of descending aortic size. In this subset, ducts > 3 mm in diameter should perhaps undergo surgery.

Access

For infants and young children with good echocardiographic windows arterial access may not be required at all. A venous access with a 5 or 6 French introducer is usually adequate initially and arterial access need not be obtained. After coil occlusion it is usually possible to evaluate the results through echocardiography in the catheterization lab. The advantages of avoiding arterial access include avoiding heparin and thereby potentially accelerating occlusion of the duct, and elimination of inherent risks of arterial

puncture such as bleeding and femoral artery thrombosis. If additional coils have to be delivered, it is necessary to obtain arterial access. For this purpose a 4F introducer sheath is sufficient.

Hemodynamic evaluations

Standard hemodynamic measures should be obtained. In the event that the pulmonary vascular resistance is elevated and there are doubts on whether the PDA closure would reverse the pulmonary artery hypertension, it may be wise to balloon occlude the duct and measure the pulmonary artery pressures. Balloon occlusion can be accomplished by a balloon end-hole catheter (7F Swan Ganz catheter is well suited for this purpose) passed from the venous route into the aorta. The inflated balloon is then pulled back into the duct. This may necessitate an additional venous access. Alternatively the balloon catheter may be passed via a larger long sheath and the PA pressure can be measured from the side arm of the sheath. The systemic arterial pressure should be measured simultaneously and arterial access is therefore needed. It is also useful to obtain blood gas samples from ascending and descending aorta. Large ducts (> 10 mm) may require occlusion balloon catheters. Such ducts are seldom suited for coil occlusion. Little data is currently available on how balloon occlusion data can be interpreted in hypertensive ducts. From our preliminary experience with 20 patients who had hypertensive ducts, it appears that a decline in PA mean and PA diastolic pressures to less than 25% of the baseline appears to predict a good long-term outcome after duct closure.

Angiography

Aortography for profiling the PDA: In the event arterial access is obtained a conventional aortogram in the left lateral view and 45° RAO views with the pig-tail catheter in the proximal descending aorta positioned just distal to the ampulla usually allows reasonable definition of the PDA. The use of a marker pigtail allows for accurate measurements of the PA end of the duct. Large volumes (1-2 ml/Kg) of contrast medium at the maximum possible flow rates recommended for the catheter (\cong 18 ml/sec) should be used.

Angiography when arterial access is not obtained

In our institution we do not routinely obtain arterial access for coil occlusion of PDA in infants and small children.¹² It is still possible to obtain satisfactory an angiographic profile of the PDA without arterial access using techniques outlined below.

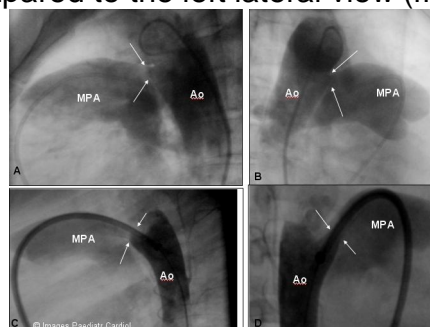
After obtaining baseline hemodynamic information a long sheath passed via the femoral vein is positioned across the PDA in the descending aorta over a 0.038-inch guide-wire. The 45 cm Balkin contralateral introducer sheath (Cook Inc., Bloomington, IN) can be used for the PDA in infants and small children. This sheath has been originally designed for access to the contralateral femoral artery. This sheath has a shape that is well suited for the PDA and comes in sizes from 5.5F -7F. For small infants (< 3 Kg) with ducts < 3.5 mm a 4 F long sheath (> 25 cm long, Cook) can be used . When two or more 0.052-inch coils are to be simultaneously delivered, 7F contralateral or 8-9F

Mullin's sheath (Cook Inc.) is used. Once the Sheath is in the descending aorta, the dilator of the long sheath is removed. With the guide-wire in place, the sheath is withdrawn into the aortic end of the duct ampulla. A hand injection of 5 -10 ml of contrast into the sheath in the lateral and 45° right anterior oblique views usually allows excellent definition of the duct ampulla and measurement of duct diameter at pulmonary insertion. With guide wire across the sheath small adjustments in sheath position can be made for the best angiographic definition.

Measurements

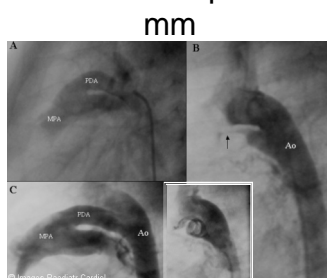
The maximum diameter of the pulmonary artery (PA) end of the PDA should be measured. The lateral view is usually better suited for this purpose (Fig. 5).

Figure 5 Angiograms from selected ducts. Frames A and B are from an older patient with a relatively shallow duct. Frames C and D are from an infant. Frame A shows a left lateral view of an aortogram. The Ampulla is better profiled in this view as compared to Frame B. In the second example, the ampulla appears larger in the right anterior oblique (RAO) view (Frame D) as compared to the left lateral view (frame C).



The diameter of the pulmonary arterial end of the duct varies with the cardiac cycle and the largest diameter should be identified through careful frame-by-frame evaluation. Often the largest diameter is in a frame where the duct is less well opacified. Ductal spasm is not infrequent in infants and is provoked by attempts to cross it. (Fig. 6) In our institution we prefer to use the echocardiographic measurement of the duct size to guide the choice of coil diameter unless the angiographic measurement is larger.

Figure 6 These images show an example of transient but dramatic spasm of a large patent arterial duct in an 8-month-old infant. Frame A is a lateral angiogram showing the large tubular patent arterial duct (PDA) opacifying main pulmonary artery (MPA) and its branches. B. Aortogram showing the duct to be severely constricted in the middle (black arrow) and non-opacification of MPA. C. Repeat angiogram showing completely opened up arterial duct. The duct was coil occluded (insert). Coil combination and sheath sizes for biptome-assisted occlusion of patent arterial ducts larger than 2.5



Technique of Biptome Assisted Coil Delivery

Coil selection

Gianturco coils with diameters at least twice the measured duct diameters at PA end are chosen. We prefer to use the echocardiographic measurement to guide coil selection unless the duct diameter by angiography is larger than the echo measurement. This is done to avoid being misguided by duct spasm. It is preferable to use simultaneously delivered multiple coils for ducts that measure more than > 3 mm in diameter. This usually results in a higher immediate occlusion rates. For ducts > 3.5 mm in diameter one or more coils should be 0.052-inch coils. For ducts > 4.5 mm in diameter it may be necessary to deliver 3 coils simultaneously and for ducts > 6 mm in diameter four coils may have to be simultaneously delivered. Ducts > 8 mm in diameter are best closed by the Amplatzer duct occluder. (Table 1).

Table 1

Duct size	Suggested coil combination*	Minimum size of the long sheath
2.5-3 mm	Two 0.038-inch 6 mm-6 cm coils or a single 0.052-inch 6 mm-6cm coil	4F**
3-3.5 mm	Two 0.038-inch 8 mm-8 cm coils or a single 0.052-inch 8 mm-8 cm coil	4F**
3.5-4 mm	A combination of one 0.052-inch 8 mm, 8 cm coil with one 0.038-inch 8 mm-8 cm coil	5.5F
4-4.5 mm	Two 0.052-inch 8 mm-8 cm coils	7F
4.5-5 mm	Three 0.052-inch 8 mm-8 cm coils or one 10mm, 10 cm with two 8 mm-8 cm coils	8F
5-6 mm	Four coils: Two 0.052-inch, 12mm -15 cm coils and, Two 0.052 inch 10 mm-10 cm coils	9F
6-8 mm	Five coils: Two 0.052-inch, 15mm -15 cm coils, Two 0.052-inch, 12mm -15 cm coils, one 0.052 inch 10 mm-10 cm coil	9F
> 8 mm	Usually not suited for coil occlusion	

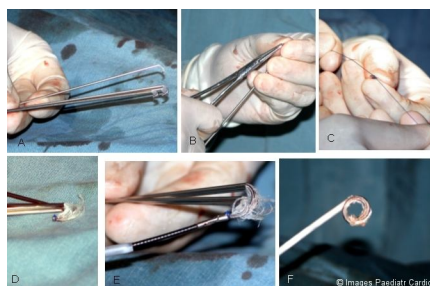
F: French, * Coil lengths have not been specified, usually coil lengths (in cm) that are same as the coil diameters (in mm) are adequate. For PDA with a shallow ampulla in infants and small children, however coil turns have to be cut to ensure that the coils turns fit into the ampulla. **3F bioptome will need to be used if a 4 F sheath is to be used. For all other situations a 5 F bioptome is adequate.

Coil preparation (Fig. 7)

Coils are housed in steel tubing with a black sleeve at one of its ends. The coil is pushed out by a wire introduced from the end with the black sleeve. The round ball at tip of the coil that emerges from the tube is stretched out by a few millimeters using a hemostat. If multiple coils are used, the stretched-out

ends are secured together using 3-0 prolene suture. A 5.2 F-120 cm long bioptome (Cook Inc.) passed via a short introducer sheath (one size smaller than the long sheath used for deployment of the coils in the PDA). The secured end of the coils is grasped by the bioptome. It is important to ensure that the coil is firmly held by the jaws of the bioptome. The coils are then pulled into the short sheath by the bioptome. The short sheath essentially serves as an introducer for delivering the coils into the long sheath that is previously positioned across the duct. If it is anticipated that coil turns would not fit into the ampulla, between ½ to 2 coil turns should be cut with a scissor. The cut end of the coil should be inspected for sharp edges and a few more millimeters of the coil can be cut to ensure smoothness. Cutting off the end of the coil is often necessary in infants. When the 4 F sheath is used in very small infants, a 3F bioptome is used.

Figure 7 Coil preparation for bioptome assisted coil occlusion. This sequence shows the preparation of four coils for simultaneous deployment in a 6 mm duct. The deployment sequence is shown in Figure 10. A small segment of each coil is brought out of the steel tubing (A). The ends of the coil are stretched out using a hemostat (B). The stretched out ends are secured together using a 3-0-prolene suture (C and D). A 5 F bioptome is passed through a short (8F) introducer (E), the secured end of the coil is held by the jaws of the bioptome and pulled into the introducer (F).



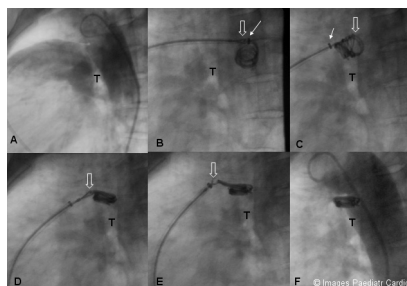
Deployment of coils (Fig. 8)

The coils are then delivered via the long sheath all the way and one to two loops are extruded out of the tip of the sheath in the descending thoracic aorta. The side arm of the sheath should be connected to the pressure transducer. The entire assembly is then pulled back towards the pulmonary artery until the sheath tip is just beyond the duct ampulla. Here coils are almost entirely brought out of the sheath. Typically the retrograde flow across the duct pushes the entire coil mass into the ampulla. There is an abrupt cessation of oscillatory movements (as a result of pulsatile forward flow in the descending aorta) together with compaction of the coils as they enter the duct ampulla. All coil turns should compact in the ampulla. This is sometimes difficult to ensure when coil diameters are very large or when more than 4 coils are simultaneously delivered. The tracheal air shadow can serve as an additional landmark to guide the coil placement. The relationship of the

tracheal air shadow to the duct ampulla and the pulmonary arterial end of the duct is previously identified in the ductal angiogram. Once the coils compact in the ampulla the sheath is slowly pulled back until the pressure recorded from the side arm of the sheath declines indicating that the tip of the sheath is now on the pulmonary artery. At this point the bioptome is slowly pulled back until a small part of the coil protrudes into the pulmonary artery. Some resistance is felt at this stage. There is further compaction of the coil turns in the ampulla. Efforts should be made, as far as possible, to leave less than half a turn to protrude into the pulmonary artery. Contrast injection through the side arm can be made to ensure that the coils are correctly positioned with free flow into the branch pulmonary arteries. The jaw of the bioptome should be released soon after a satisfactory position is obtained. Attempts to hold the coils for longer periods should be avoided because this often results in one or more coil-turns being inadvertently pulled into the pulmonary artery. In the event that the coils chosen are too small for the duct, one or more turns or the entire the coil mass can be pulled into the pulmonary artery by the bioptome. The coils can be withdrawn into the sheath and redeployed after addition of another larger coil to the coil mass. An echocardiogram or aortogram (if arterial access was obtained) should be performed after 3 minutes. Additional 0.038-inch coils are delivered if a well-defined jet of residual flow was demonstrable by either color Doppler or angiography (see below). Small diffuse whiffs of flow often disappear over the next 12-24 hours.

Figure 8 Bioptome-assisted simultaneous deployment of multiple coils.

Frame A shows an aortogram in the left lateral view. The duct measured 6 mm. Four coils (two 12mm 0.052-inch coils and two 8 mm 0.038-inch coils) are simultaneously held by a 5 F bioptome and brought out of a 9F long sheath placed across the duct in the descending aorta (B). The block arrow points at the jaws of the bioptome and the smaller arrow indicates the tip of the sheath. The assembly is pulled back until the tip of the sheath is in the MPA. This is recognized by a decline in pressure in the side arm of the long sheath. This event coincides with the coils moving into the ampulla. The coils start to compact at this stage (C). The bioptome is then gently pulled into the MPA (D) and the jaws of the bioptome are opened after a small length (< half a turn) of coil protrudes into the MPA (E). Frame F shows an angiogram obtained 3 minutes after release. The tracheal air shadow (T) serves as an additional guide for the coil positioning.

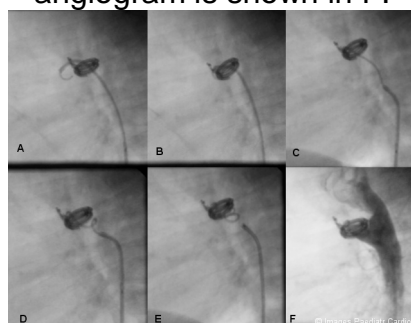


Delivery of additional coils (Fig. 9)

Additional coils are contemplated whenever there is an unacceptable amount of residual flow (clearly defined color jet on Doppler, filling of the entire MPA on angiography). It is advisable to obtain arterial access in the event the duct needs to be re-crossed. A 4 French introducer sheath can be used for this purpose. Heparinization is needed at this stage. The duct is crossed from the arterial end using a 0.035-inch glide wire (Terumo or Roadrunner, Cook) and a 4 French right coronary catheter. Dacron fibers of the previously deployed coils can get entangled if a regular Teflon wire is used. Once the wire is across the duct the catheter should be gently advanced over the wire. In general, 5 mm diameter, 5cm long coils work well as additional coils in these situations.

Half a turn of the coil is brought out of the tip of the 4 F catheter positioned in the MPA across the duct. The catheter is slowly pulled back until the protruding half turn reaches the PA end of the duct. The coil is then delivered by slowly withdrawing the catheter while keeping the guidewire in the catheter in close contact with the coil. Catheter withdrawal tends to pull the protruding coil out of the MPA and guidewire advancement may result in excessive coil protrusion. Coil delivery has to be accomplished in small steps ensuring at all times that the coil length protruding out into the MPA is kept constant at half a turn until a substantial length of coil is exposed out of the catheter (Fig. 9). Advancing the catheter towards the ampulla usually results in formation of coil turns that should be positioned in the ampulla. Hand injections of contrast 3 minutes after coil delivery should be made to assess residual flows.

Figure 9 Deployment sequence for additional coil via the arterial route. Half a turn of the coil is brought out of the catheter in the pulmonary artery (A). The catheter is pulled back until it is flush with the rest of the coils (B). The catheter is then slowly withdrawn keeping a constant length of the coil loop in the pulmonary arterial end of the duct (C). Once a sufficient length of the coil is exposed (enough to form one or more loops), the assembly is advanced into the ampulla (D) and the rest of the coil is delivered (E). The final angiogram is shown in F.

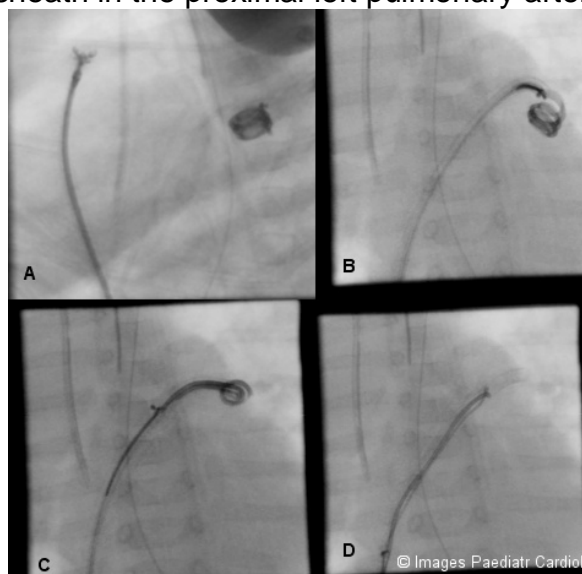


Complications

Embolization to the Branch Pulmonary Arteries (Fig. 10)

This can happen soon after coil release or rarely within 24 hours or exceptionally after that. The dislodged coils usually embolize to the proximal right or left pulmonary arteries if they are large and if multiple coils are used. Single coils usually embolize distally to smaller branches. Sufficient time is available for planned retrieval because instability is rare. The long sheath should be retained in the MPA. A 4 French multipurpose catheter or the 4F snare catheter should be passed via the long sheath and positioned near the embolized coil mass with the help of a glide wire guided by the movement of the coil when it comes in contact with the wire. An Amplatz gooseneck snare (5 mm for children and small vessel embolization, 10 mm for other situations) should be used to grasp the coil tip. When multiple coils have been used for PDA closure it is important to hold the coils at the sutured end. The coils must be captured into the long sheath in the pulmonary artery because it is important to prevent the coil mass to be entangled in the tricuspid valve tensor apparatus (Fig. 10).

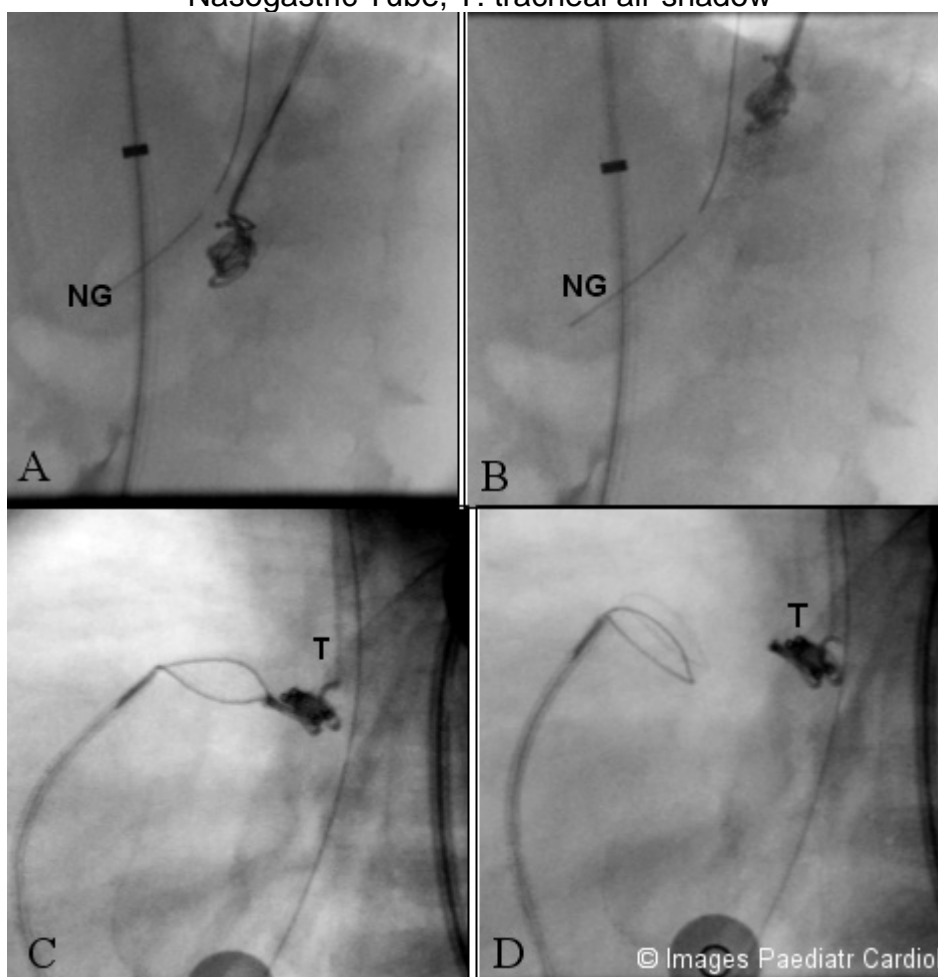
Figure 10 Retrieval sequence after embolization into the left pulmonary artery. Two coils were used to close a large duct an infant. These coils embolized as soon as the jaws of the bioprobe were opened into the LPA (A). The sutured end of the coils have been grasped by a snare (B) and withdrawn into a long sheath in the proximal left pulmonary artery (C and D).



Embolization to the descending thoracic aorta (Fig. 11)

When coil(s) embolize into the aorta, the duct should be immediately re-crossed with a 5F multipurpose catheter or snare catheter. A 10 mm Amplatz gooseneck snare (Microvena, MN, USA) should be used to hold the end of the coil(s) and the same coil(s) can be deployed in the duct once again as the catheter is pulled back towards the MPA.

Figure 11 Retrieval sequence after embolization into the descending aorta. The snare catheter is introduced via the femoral vein and advanced into the descending aorta via the duct. The sutured end of the coil is grasped by the snare (A) and withdrawn (B) until the coil mass is firmly anchored in the duct ampulla (C). The snare is released after ensuring a secure position (D). NG: Nasogastric Tube, T: tracheal air shadow



Loss of grip on the coil mass

The jaws of the biptome may sometimes lose their grip on the coil mass when coils are being pulled back into the long sheath after an initial unsatisfactory deployment. A variable part of the coil remains in the sheath. Attempts to recapture the coils with the biptome or a snare are unlikely to succeed and the coils may get pushed out of the sheath. A 3 F vascular retrieval forceps (Cook) works well in this situation. The tip of the vascular retrieval forceps has a short (3 cm), soft guidewire that can be positioned adjacent to the coil tip in the sheath. The jaws of the forceps open adequately enough to grasp the coil tip and retrieve the coil mass.

Inability to release the coil after biptome jaws are opened

Occasionally coil tip remains in the jaws after they are opened. The coils can be released by slow rotation the biptome with the jaws open. Alternatively,

advancing the long sheath to the jaws of the biopptome helps in the release of the coil.

Hemolysis from residual flows

Hemolysis is a rare but a serious complication of coil occlusion.^{17–19} For hemolysis to occur there often has to be clearly defined residual flow at the end of the procedure together with an audible murmur. Of 1299 patients who underwent PDA coil occlusion at our institution between August 1998 and June 2007, 7 patients (age, 6 weeks – 64 years) developed overt hemolysis. All had large ducts and residual flows after the procedure. The occurrence of hemolysis correlated significantly with both age as well as duct size. Hemolysis was associated with a fall in hemoglobin of 3–6 g/100 ml (3 patients), jaundice (3), and renal failure (1). Hemolysis subsided spontaneously in two patients and additional coils had to be deployed in 3 patients. Once hemolysis is established it is often difficult to eliminate flows and many additional coils may be required. It is therefore important to be aggressive and early intervention should be considered if residual flows are significant. In our series, one 6-week-old infant continued to have significant flows and ongoing hemolysis after three additional coils were deployed in two settings. The hemolysis (and residual flows) in this infant only resolved after exchange transfusion.

Post-procedure management

The patient can be sent home 6-8 hours after the procedure once recovery from sedation or anesthesia is complete especially if arterial access has not been used.¹⁵ For children in whom arterial access was obtained we choose to keep them overnight. We consider it mandatory to obtain an echocardiogram just prior to discharge for residual flows across the PDA, LPA turbulence and aortic flows and ventricular function. A small fraction of patients develop varying degrees of left ventricular dysfunction immediately after duct closure. We suggest antibiotic prophylaxis for endocarditis be maintained for 6 months after the procedure. We recommend follow-up echocardiography, 3 months after the procedure and yearly thereafter for 3 years after the procedure unless there are residual issues.

Long Term Concerns

Compatibility with magnetic resonance (MR) imaging

The conventional stainless steel coils are not MR compatible and likely to produce artifacts during imaging. Most manufacturers have started to make coils using materials that are MR compatible (MR –eye coils, Cook inc.). The 0.052-inch coils are still made of stainless steel. This is an important limitation that needs to be overcome by manufacturers in the future.

Stenosis of the left pulmonary artery origin

It is important particularly in infants to avoid excess coil loop protrusion into the left pulmonary artery. Both after initial deployment and during follow-up the LPA flows should be carefully evaluated by color Doppler.

Residual flows and re-canalization

Residual flows at 24 hours tend to persist. In addition, in a small proportion of completely occluded ducts (0.3% in our experience) may re-canalize. The indication for repeat coil occlusion is not clear. We recommend coil occlusion if a murmur is audible.

Results of coil occlusion – a single institution experience

At our institution, coil occlusion is the preferred mode for treatment of PDA primarily because it is the least expensive of all methods available. From August 1998 to June 2007, 1299 PDA coil occlusions have been attempted at our institution. The biptome assisted technique of multiple coils was used in 455 patients. The median duct size was 3 mm (range 1.7-10 mm). Coil occlusion was feasible in a wide range of age groups 6 days –65 years. A substantial proportion of these patients were infants; 53% weighed \geq 10 Kg and 8.3 % (108 patients) weighed \geq 5 Kg. Four preterm infants (900 gms – 1.5 Kgs) underwent successful coil occlusion. The procedure was unsuccessful in 12 patients (0.9%). Immediate residual flows were seen in 11.6% of the entire series. At 3 months follow up, 4.7% of the patients recorded residual flows and 2% acquired stenosis of the left pulmonary artery origin as defined by new color Doppler flow turbulence at the origin of the left pulmonary artery. Coil embolization occurred in 98 patients (7.5%); 44 of which occurred to the aorta and 54 to the branch pulmonary arteries. The incidence of coil embolization declined to 4% in the last 200 cases. Six infants underwent coil occlusion while on a ventilator for heart failure and / or pneumonia. In the entire series there was one procedure related mortality. In this infant the coil mass embolized to the right pulmonary artery and could not be retrieved. Cardiac surgery was performed to retrieve the coil but the infant succumbed to refractory pulmonary hypertension and right lung injury.

Cost comparisons revealed a substantial advantage of coil occlusion over device occlusion. The average cost of coil occlusion in our institution was 29% that of the device. It is possible that re-sterilization and reuse of the biptome would contribute to this advantage. However, like in many institutions world over, we also re-sterilize and reuse the delivery cable and the sheaths of the occlusive device. The cost of the biptome and the delivery system for the occlusive device are quite similar.

Conclusions

Coil occlusion of ducts $>$ 3 mm is technically feasible and this is a substantially less expensive alternative to occlusive devices. It is especially advantageous in selected small infants and preterm newborns (with suitable anatomy) because it can be accomplished through a smaller introducer

sheath. It is necessary to pay attention to specific anatomic and technical details to ensure success.

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