JACC Vol. 31, No. 2
February 1998:444–50

Reopening After Successful Coil Occlusion for Patent Ductus Arteriosus

CURT J. DANIELS, MD, STEVEN C. CASSIDY, MD, FACC, DOUGLAS W. TESKE, MD, FACC, JOHN J. WHELLER, MD, FACC, HUGH D. ALLEN, MD, FACC

Columbus, Ohio

Objectives. **This study was performed to determine the frequency of patent ductus arteriosus (PDA) reopening and the factors that may predict reopening after successful coil occlusion.**

Background. **Transcatheter coil occlusion is a widely used and accepted method to close a PDA. After documented successful coil occlusion, we found PDAs that reopened. We hypothesized that specific factors are involved in those that reopened.**

Methods. **All patients who underwent percutaneous transarterial PDA coil occlusion were studied. Successful coil occlusion was documented. PDA reopening was determined when Doppler-echocardiography (DE) performed after the procedure was negative for PDA flow but at follow-up demonstrated PDA shunting. Patients with a reopened PDA were compared with all other patients in evaluating independent variables.**

Results. **Coil occlusion for PDA was attempted in 22 patients. Clinical success was achieved in 20 patients (91%), and DE was negative for PDA shunting in 19 patients (90%). At follow-up, five patients demonstrated reopening. The PDA minimal diameter was 1.4 ± 0.5 mm (mean ± SD) for the reopened group and 1.2 ± 0.7 mm for the other patients. The PDA length was 2.9 ± 1.9 mm for the reopened group and 7.1 ± 3.2 mm for all other patients. All those with type B PDA were in the reopened group. When independent variables were compared between groups, only PDA length and type B PDA predicted reopening ($p < 0.05$).**

Conclusions. **PDA reopening may occur after successful coil occlusion. Short PDA length and type B PDA are associated with reopening. The data suggest that in such anatomy, alternative strategies to the current coil occlusion technique should be considered.**

(J Am Coll Cardiol 1998;31:444–50)

Transcatheter occlusion for patent ductus arteriosus (PDA) has been successfully performed with a number of devices (1–5). Gianturco coil occlusion for PDA has become the preferred method because of the smaller delivery system (3F to 5F), lower expense and previous experience with coils compared with other transcatheter devices.

The PDA minimal diameter has been a consistent morphologic feature guiding PDA coil selection, number of coils deployed and, in some studies, overall success of the procedure (6–10). Early experience demonstrated that PDAs with a large minimal diameter were susceptible to coil embolization and residual shunting (7,8). More recently, PDAs with a minimal diameter >3.5 to 4.0 mm have been successfully occluded by means of a multiple coil technique (9–11). Morphologic features other than PDA diameter, such as length and shape, have not been factors considered to correlate with success.

We have performed successful coil occlusion for PDA, with results comparable to other institutions (6–9). Despite procedural, clinical and angiographic success, we found PDAs that reopened after documented coil occlusion. In all patients with a reopened PDA, the PDA minimal diameter was <3.5 mm. Therefore, we hypothesized that factors other than minimal diameter, such as PDA length and shape, are involved in those that reopened. This study was performed to determine the frequency of PDA reopening and the factors that may predict reopening after successful coil occlusion.

Methods

Patients. Between May 1995 and June 1996, all patients who underwent PDA coil occlusion at Columbus Children's Hospital were included in the study. Before being referred for PDA coil occlusion, all patients had clinical and echocardiographic findings of a PDA. Patients were excluded from coil occlusion if they had other cardiovascular abnormalities requiring operation. Written informed consent was obtained from the parents of patients before PDA coil occlusion. The protocol was approved by the Human Subjects Research Committee of Columbus Children's Hospital.

Procedure. Percutaneous transarterial PDA coil occlusion was performed in all patients by means of the previously described protocol (6). The femoral artery was accessed, and either a 4F or 5F sheath was placed. The use of intravenous heparin (50 to 75 U/kg) was based on the preference of the interventional cardiologist. The PDA minimal diameter and

From the Division/Section of Pediatric Cardiology, Columbus Children's Hospital and Ohio State University College of Medicine, Columbus, Ohio.

Manuscript received April 30, 1997; revised manuscript received September 22, 1997, accepted October 23, 1997.

Address for correspondence: Dr. Hugh D. Allen, Division/Section of Pediatric Cardiology, Columbus Children's Hospital, 700 Children's Drive, Columbus, Ohio 43205. E-mail: Hallen@chi.osu.edu.

Published by Elsevier Science Inc.

0735-1097/98/$19.00
PII S0735-1097(97)00491-9

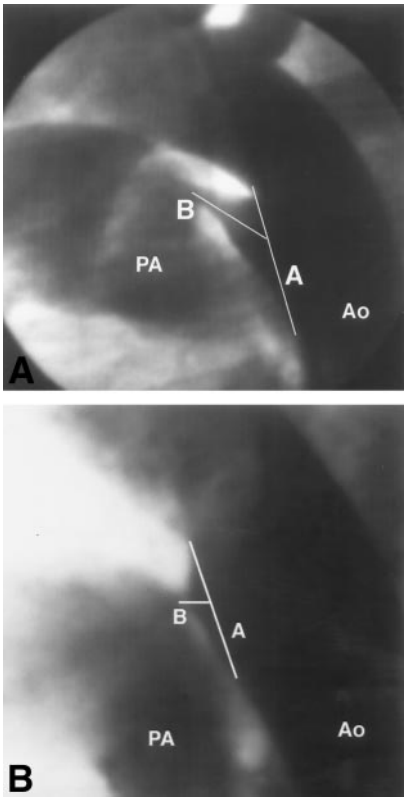
Abbreviations and Acronyms

DE = Doppler-echocardiography
MPA = main pulmonary artery
PDA = patent ductus arteriosus

PDA length were determined from a cineangiogram of the descending aorta. The method for determining PDA length is shown in Figure 1. Cephalothin was administered intravenously at 25 mg/kg body weight before coil occlusion. For all procedures, Gianturco coils of 0.38-in. wire diameter (Cook Inc.) were used. The coil length and width were determined using previously described criteria (6).

A descending aorta cineangiogram was performed ~10 min after coil deployment to grade any residual shunt. A second coil was placed if greater than a trace left to right shunt was present. Protamine sulfate was not administered. Cardiac auscultation was performed to document loss of the continuous murmur. Cephalexin was orally administered for the next two days at a dose of 10 mg/kg every 6 h.

Figure 1. PDA length was measured from the straight lateral view of the aorta cineangiogram. Length calibration used postangiogram grids. The lateral view of the aorta cineangiogram was reviewed, and a systolic frame that maximized the length of the ductus was chosen for the measurement. The aortic end of the PDA was defined by a line running parallel to the anterior surface of the descending aorta at the level of the PDA **(line A).** A second line was made along the long axis of the PDA connecting line A to the PDA–pulmonary artery junction **(point B).** The length between line A and point B along the PDA long axis was the PDA length: 5.8 mm **(A);** 2.3 mm **(B).** Ao = aorta; PA = pulmonary artery.



Post-coil occlusion data. The success of PDA coil occlusion may be defined as previously described by Lloyd et al. (6). *Procedural success* was defined as coil implantation within the PDA on the chest radiograph the morning after the procedure. *Clinical success* described the loss of a continuous murmur. *Angiographic success* was the absence of contrast entering the main pulmonary artery (MPA) on the post-coil occlusion aorta cineangiogram. Doppler-echocardiography (DE) was performed in all patients within 24 h of PDA coil occlusion, with success defined as the absence of a shunt into the MPA.

Follow-up data. Within 12 months of PDA coil occlusion, study patients had an evaluation that included cardiac auscultation, chest radiograph and DE. Cardiac auscultation defined the presence of a systolic ejection murmur, a continuous murmur or no murmur. The chest radiograph visually confirmed placement of the PDA coil. DE determined the presence or absence of a PDA shunt.

PDA reopening. PDA reopening was diagnosed when postprocedural DE was negative for PDA flow but demonstrated shunting at follow-up. If a new continuous murmur was present at follow-up, we considered this to be clinical PDA reopening; if only the Doppler study was positive at follow-up, this was considered silent PDA reopening.

Statistical analysis. Patients with a reopened PDA after successful coil occlusion were compared with all other patients by logistic regression analysis evaluating age, patient weight, mean pulmonary artery pressure, mean aortic pressure, PDA minimal diameter, the ratio of coil diameter to PDA minimal diameter, PDA length and the ratio of PDA minimal diameter to PDA length. Results are expressed as mean value ± SD. The Fisher exact test was used to compare catheterization date, heparin use and PDA type.

Results

Patients. The clinical data and results are summarized in Table 1. Coil occlusion for PDA was attempted in 22 patients. The patients ranged in age from 1.4 to 15.3 years (median 4.9) and in weight from 10.5 to 66.7 kg (median 19.8).

Local anesthesia and conscious sedation were used for 19 procedures, and 3 were performed under general anesthesia. Intravenous heparin was administered in 16 of 22 patients. The mean pulmonary artery pressure ranged from 6 to 26 mm Hg (mean 16), and the mean descending aorta pressure ranged from 43 to 113 mm Hg (mean 77). The angiographic classification of the ductus arteriosus (12) included 12 patients with type A (conical with an ampulla of sufficient length), 3 with type B (conical with a short ductal ampulla), none with type C (tubular), 2 with type D (multiple areas of constriction within the ductus) and 5 with type E (long conical with the narrowest part remote from the trachea).

The PDA minimal diameter ranged from 0.5 to 2.8 mm (mean 1.3). The coil diameter implanted was more than two times the minimal diameter of the PDA in all cases. The PDA

Table 1. Clinical Data and Results for 22 Patients Who Underwent Patent Ductus Arteriosus Coil Occlusion

Pt No./Age (yr)	Wt (kg)	No. of Coils Implanted (length [cm] × width [mm])	PDA Type	PDA Diam (mm)	PDA Length (mm)	Murmur			DE	
						Pre	Post	F/U	24°	F/U
1/5.6	16.8	1 (5 × 5)	A	1.0	5.7	C	N	N	−	−
2/4.9	19.6	2 (5 × 5, 4 × 3)	A	2.1	5.1	C	N	N	−	−
3/10.6	37.4	1 (3 × 4)	E	0.5	12.9	C	N	N	−	−
4/1.4	10.5	1 (4 × 3)	A	1.5	5.8	C	N	S	−	−
5/7.2	22.0	1 (8 × 5)	A	1.5	3.7	C	N	N	−	−
6/13.5	52.3	1 (5 × 5)	A	0.5	6.2	C	N	N	−	−
7/3.8	20.0	1 (8 × 5)	A	1.5	4.7	C	N	S	−	−
8/3.2	34.1	1 (5 × 5)	D	1.9	5.4	C	N	N	−	−
9/2.8	13.8	1 (5 × 5)	A	1.0	4.0	C	N	S	−	−
10/4.4	16.5	1 (5 × 5)	A	0.5	4.6	C	N	S	−	−
11/11.3	66.7	1 (4 × 3)	E	0.5	10.6	C	N	S	−	−
12/15.3	45.4	1 (5 × 3)	E	0.5	8.4	C	N	S	−	−
13/3.8	15.2	1 (5 × 5)	A	1.4	4.8	C	N	N	−	−
14/5.3	19.8	1 (4 × 3)	E	0.5	12.7	C	N	S	−	−
15/13.7	45.2	0*	A	2.8	6.6	C	C	†	†	†
16/4.7	17.3	1 (5 × 5)	A	1.9	7.7	C	C	C	+	+
17/2.6	13.8	1 (8 × 8)	E	1.5	12.6	C	N	‡	+	‡
Reopened PDA										
18/4.7	18.1	1 (5 × 5)	D	1.3	6.0	C	N	N	−	+
19/4.5	22.3	1 (5 × 5)	B	1.0	1.0	C	N	N	−	+
20/8.6	28.8	1 (5 × 5)	B	1.7	3.6	C	N	C	−	+
21/5.10	18.2	1 (5 × 5)	A	1.0	1.8	C	N	C	−	+
22/13.9	60.6	1 (5 × 5)	B	2.2	2.3	C	N	C	−	+

*Three coils attempted (8 cm × 8 mm) and embolized to the pulmonary artery; a coil was not successfully deployed. †Patient underwent surgical ligation. ‡Patient was lost to follow-up and did not complete the follow-up studies. C = continuous murmur; Diam = diameter; F/U = follow-up; N = no murmur; Post = after coil occlusion; Pre = before coil occlusion; Pt = patient; S = systolic murmur; Wt = weight; + = Doppler-echocardiographic (DE) evidence of patent ductus arteriosus (PDA) shunt; − = no evidence of PDA shunt by DE.

length ranged from 1.0 to 12.9 mm (mean 6.2). The PDA minimal diameter/length ratio ranged from 0.04 (long and thin) to 1.0 (short and wide).

Occlusion results. Procedural success was achieved in 21 (95%) of 22 patients. In four patients, one coil embolized, and in one patient three coils embolized (Patient 15). A coil was not successfully deployed in Patient 15, and therefore discharge and follow-up studies were not performed. All embolized coils were retrieved by transcatheter techniques. No shunt was detected angiographically in 14 patients (67%) and only a trace in 7 (33%). Within 24 h of the procedure, there was absence of a continuous murmur (clinical success) in 20 patients (95%).

DE performed before hospital discharge demonstrated no PDA shunt in 19 of 21 patients in which a coil was successfully deployed (90% success at hospital discharge).

Follow-up data. Follow-up evaluation for 20 patients (Patients 15 and 17 not included) averaged 6 months (range 2 to 12). Cardiac auscultation revealed a continuous murmur in four patients. In one patient the continuous murmur represented a persistent shunt (Patient 16), whereas in the other three, the murmur defined clinical PDA reopening. Of those patients with follow-up chest radiographs (n = 20), coil position was unchanged in 19. The chest radiograph for Patient 22 documented a change in coil position (Fig. 2). DE at follow-up demonstrated PDA shunting in six patients. In one patient, positive Doppler study results represented a persistent PDA shunt (Patient 16), whereas in five, shunting defined PDA reopening.

Therefore, five patients demonstrated PDA reopening after successful coil occlusion (three with clinical reopening, two with silent reopening). PDA reopening was demonstrated angiographically in patient 21 (Fig. 3).

Patients with reopened PDA versus all other patients. The patients with PDA reopening after successful coil occlusion (n = 5) were compared with all other patients (n = 17). The data are summarized in Table 2. For the reopened PDA group, the PDA minimal diameter ranged from 1.0 to 2.2 mm (mean 1.4 ± 0.5) and the PDA length from 1.0 to 6.0 mm (mean 2.9 ± 1.9). For all other patients, the PDA minimal diameter ranged from 0.5 to 2.8 mm (mean 1.2 ± 0.7) and the PDA length from 3.7 to 12.9 mm (mean 7.1 ± 3.2). Figure 4 compares the PDA minimal diameter with the PDA length for the two groups.

Logistic regression analysis of independent variables and the Fisher exact test demonstrated that only PDA length significantly predicted PDA reopening ($p < 0.05$). For PDA length <3.7 mm, the positive and negative predictive values for reopening were 100% and 95%, respectively.

Type B PDA was significantly associated with the reopened

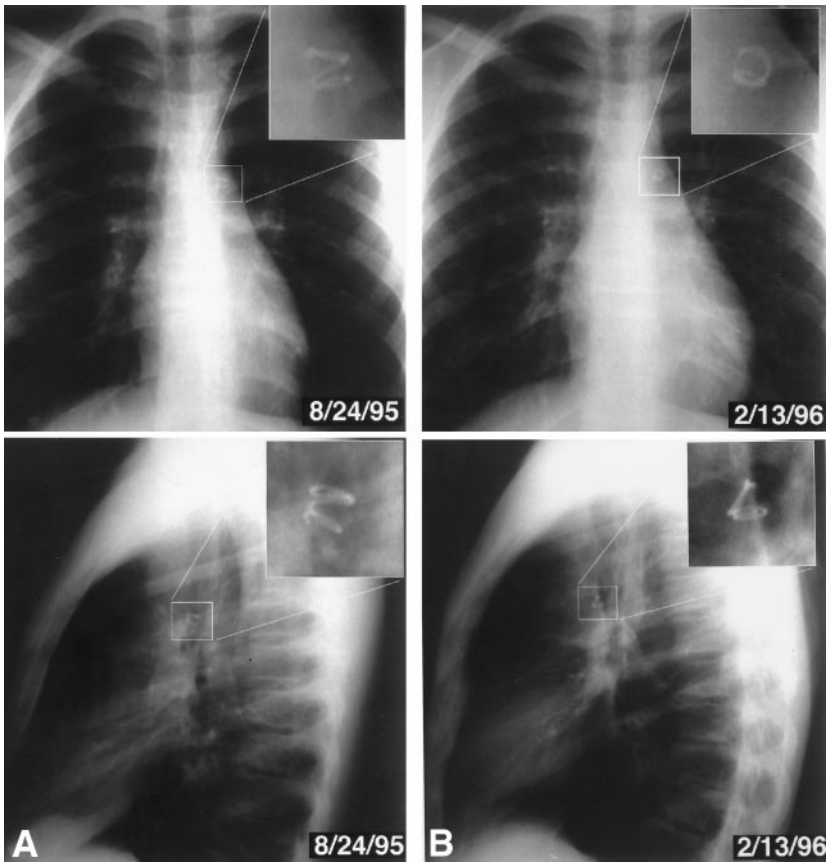


Figure 2. Chest radiographs demonstrating late PDA coil movement (Patient 22). **A,** Posteroanterior **(top)** and lateral **(bottom)** chest radiographs from 2 months after PDA coil occlusion. **B,** Posteroanterior **(top)** and left lateral **(bottom)** chest radiographs 8 months after the procedure. The chest radiographs demonstrate a change in the position of the coil within the PDA.

PDA group when compared with all other PDA types ($p < 0.01$).

Discussion

Our data demonstrate that despite successful coil occlusion for PDA, many reopened. The early experience with PDA coil occlusion found that large diameter PDAs were associated with a higher incidence of coil embolization and a lower overall success (7,8). More recently, large diameter PDAs have been successfully coil occluded with a multiple-coil technique (9–11). Our patient with the largest PDA diameter (2.8 mm) was the only patient in which a coil could not be deployed. The larger minimal diameter was the only factor identified as contributing to procedural failure in this case. Despite this, in comparing the patients with a reopened PDA with the rest of the study group, the PDA minimal diameter was not a statistically significant variable predictive for PDA reopening. In our study, only short PDA length and angiographic type B PDA were associated with reopening.

PDA reopening. In three of five patients whose PDA reopened, a characteristic morphologic feature was found. The aortic ampulla and the length of the PDA containing the minimal diameter (the "occludable length") was short (Fig. 1B). The type B PDA is described by many as a wide-diameter/short-length PDA. Because the type B PDA is dependent on short length, we expected and found that all those with type B PDA were in the reopened PDA group. When analyzing our data for large minimal diameter, no difference was found. However, the PDA minimal diameter/PDA length ratio approached significance with the wide/short PDA ($p = 0.06$). Therefore, short length appears to be an independent factor associated with reopening; however, if the PDA is wide and short, this may add additional risk of reopening.

Others have also reported difficulty in coil occluding short, type B PDA. Moore et al. (8) noted that residual PDA shunts after coil occlusion were more common in type B PDA. Hijazi and Geggel (9) were unable to coil occlude only 2 of 33 PDAs, both of which were short.

We were able to successfully close short PDAs but only temporarily. The minimal diameter of our patients with short-length PDAs was considerably smaller than that reported by either Hijazi and Geggel (9) or Moore et al. (8) and may have been favorable for our initial success.

Shim et al. (13) reviewed 75 patients who underwent coil occlusion and specifically evaluated the incidence of "recanalization" after coil occlusion. Because of the potential changes in coil position, thrombus formation, clot retraction and thrombolysis that may occur early after coil occlusion, they did not consider DE performed immediately after the procedure accurate for complete closure. Recanalization, in their study, was considered to have occurred if PDA shunting was detected in a patient with previous complete occlusion documented by follow-up DE. Recanalization was not identified in the study by

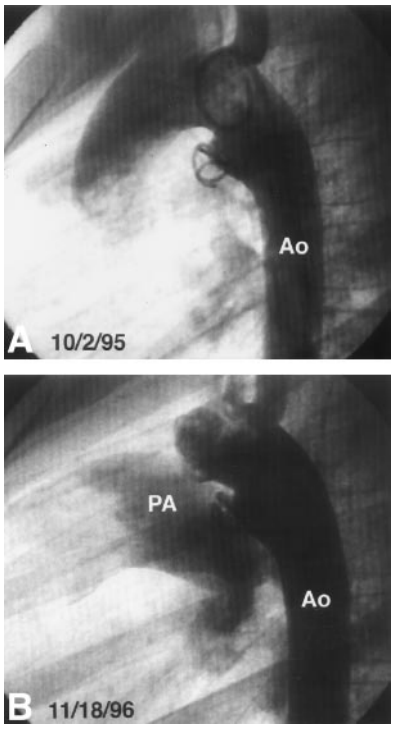


Figure 3. PDA reopening demonstrated angiographically when Patient 21 underwent a second coil occlusion procedure for PDA reopening. Aorta cineangiograms in a straight lateral view. **A,** After the initial coil procedure, coil position was not optimal, but no angiographic shunt was detected. **B,** PDA reopening with contrast filling the main and branch pulmonary arteries. Ao = aorta, PA = pulmonary artery.

Table 2. Comparison Between Reopened Patent Ductus Arteriosus Group and All Other Patients

Variable	Reopened PDA (n = 5)	All Others (n = 17)	p Value*
Age (yr)	7.4 ± 4.0	6.7 ± 4.4	NS
Weight (kg)	29.6 ± 17.8	24.6 ± 15.8	NS
Cath date (early)†	3	8	NS
Heparin use	4	12	NS
MAoP (mm Hg)	70.2 ± 2.2	63.5 ± 6.7	NS
MPAP (mm Hg)	13.0 ± 1.0	16.6 ± 4.9	NS
PDA type			< 0.01‡
A	1	11	
B	3	0	
D	1	1	
E	0	5	
PDA min diam (mm)	1.4 ± 0.5	1.2 ± 0.7	NS
PDA length (mm)	2.9 ± 1.9	7.1 ± 3.2	< 0.05§
Coil diam/PDA min diam ratio	4.2 ± 1.2	5.1 ± 2.5	NS
PDA min diam/PDA length ratio	0.64 ± 0.35	0.21 ± 0.14	NS‖

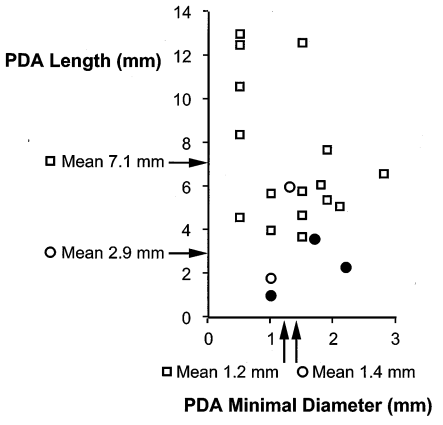
*Logistic regression analysis was used to compare age, patient weight, mean aortic pressure (MAoP), mean pulmonary artery pressure (MPAP), patent ductus arteriosus (PDA) minimal diameter (min diam), PDA length, PDA coil diameter/PDA minimal diameter ratio and PDA minimal diameter/PDA length ratio; the Fisher exact test was used to compare catheterization (Cath) date, heparin use and PDA type. †First 11 procedures for PDA coil occlusion. ‡PDA type B was statistically significant between the two groups, with type B associated with PDA reopening. §PDA length was statistically significant between the two groups; short PDA length was associated with reopening. ‖PDA diameter/length ratio approached significance (p = 0.06); wide and short PDA was associated with reopening. Data presented are mean value ± SD or number of patients. NS = p > 0.05.

Shim et al. (13) nor in a study by Hijazi and Geggel (14) of 100 patients undergoing PDA coil occlusion.

We considered the PDA to be completely closed if DE was negative for PDA shunting before hospital discharge. In most patients, DE was performed the morning after the procedure. Patient 22 was the only patient in whom follow-up DE was negative 2 months after coil occlusion and positive for PDA shunting at 8 months. In this particular patient, we documented a late change in coil position that accounted for the reopening. This patient would have been identified as having PDA recanalization by Shim et al. (13). Applying our definition of reopening, Shim et al. (13) would have identified two patients with PDA reopening. By either definition, the finding of a previously coil occluded PDA with subsequent reopening may occur and appears by our data to be related to the PDA length.

As Shim et al. (13) discussed, early dynamic changes in thrombus formation may be involved in the process of early successful closure but late PDA shunting. With a short PDA and a short occludable length, there is a smaller and possibly thinner thrombus formed within the PDA. Additionally, the thrombus would have less surface area in contact with the PDA, thereby creating an environment conducive for reopening. For Patient 22, the coil moved within the PDA sometime between the 2- and 8-month follow-up evaluations and defines the cause for reopening. For Patient 21, the coil moved toward the pulmonary artery after deployment, and the final coil position was not optimal. We suspect that reopening may have occurred secondary to a lack of occludable PDA surface area

Figure 4. Scattergram comparing the PDA length with PDA minimal diameter between the reopened group and all other patients. The patients with reopened PDAs are represented by **open circles** (n = 5), and those with clinical reopening and a continuous murmur by **solid circles.** All other patients are represented by **squares** (n = 17). The reopened group is segregated toward short PDA length but distributed throughout the range of minimal diameter. Mean values for PDA length and minimal diameter are shown for each group. Between the two groups only the PDA length was statistically significant (p < 0.05).



in contact with the coil, allowing for coil movement. In the other three patients whose PDA reopened, coil movement was not detected, final coil position was satisfactory with at least two loops of coil at the aortic end of the ductus, and the process for reopening was not clear.

Silent PDA reopening. Of the five patients with PDA reopening, three (Patients 20, 21 and 22) had a continuous murmur indicating clinical PDA reopening. The other two patients had silent reopening. Based on the preference of the parents and the primary cardiologist, Patient 21 underwent a second coil occlusion procedure, and Patients 20 and 22 had surgical ligation performed. The treatment for silent PDAs is less well defined. Silent PDAs are reported to occur in 0.5% of children with innocent murmurs (15). To date, there has been only one case of endarteritis reported from a silent PDA (16). Latson et al. (17) used an animal model with a PDA umbrella device and found no additional risk of endocarditis after occlusion when no shunt (n = 8) or only a trivial shunt (n = 2) was present. They concluded that those patients with silent PDAs after device closure require endocarditis prophylaxis, but the risk does not warrant additional device closure or surgical ligation. With PDA coil occlusion, animal models have demonstrated ductal endothelialization around the coil, and therefore, the risk for endarteritis is minimized (18).

We recommend endocarditis prophylaxis when there is a silent PDA after coil occlusion. The current data on silent but "coiled" PDAs are not sufficient to determine whether these patients should undergo additional closure procedures or be maintained on endocarditis prophylaxis indefinitely. Patient 19 refused a second coil procedure and underwent surgical ligation, and Patient 18 is currently receiving endocarditis prophylaxis, with no plans for an additional procedure.

Short PDA length. In our study, PDAs reopened with a length <3.7 mm (n = 4). The PDA length at which successful coil occlusion becomes favorable is not known, but our data would suggest that the shorter the PDA length, the less likely the PDA will remained closed. Therefore, in patients with short PDA length, alternative strategies to the current coil occlusion technique should be considered.

The Gianturco coil and the Gianturco-Grifka vascular occlusion device (GGVOD) (19) are the only transcatheter PDA occlusion devices that are approved by the Food and Drug Administration for widespread use. The Gianturco-Grifka device has been successfully used with a wide range of PDA diameters, but the device is not suitable for short-length PDAs (19,20). The Rashkind PDA occluder has been used to occlude short-length PDAs (21,22). However, their deployment requires a large delivery system (8F or 11F) unsuitable for many patients, and there is a high incidence of residual shunts. Using an adjustable buttoned device, Rao et al. (4) have successfully closed short-length PDAs. The adjustable buttoned device requires a 7F sheath and is not available for general clinical use.

We are currently determining whether two-dimensional echocardiography can accurately define the size and shape of the PDA before closure. When a short-length or type B PDA is encountered at catheterization, whether to proceed with coil occlusion is not clearly known. If coil occlusion is attempted, our study demonstrates that meticulous placement of the coil within the ductus with at least two loops at the aortic end and sizing the coil to be two times the minimal diameter of the ductus is necessary but may not prevent reopening.

With short-length PDAs, adaptations to the current coil technique should be considered. The preemptive placement of more than one coil has not been studied for short PDAs but has been successful for large-diameter PDAs (14). Lloyd et al. (6) suggested that thrombin pretreatment of coils may reduce residual shunting. The multiple-coil technique and thrombin pretreatment of coils need further investigation with short length PDAs.

Limitations of the study. The measurement of PDA length requires that two separate lines are drawn and as such increases the chance for variability in the final point–PDA length (Fig. 1). Depending on where the long-axis line is started on line A, the length may vary within 0.5 mm. This was most apparent with a wide ampulla and an irregularly shaped ductus. In every case, the line along the PDA long axis was made in an attempt to maximize PDA length while staying within the PDA long axis.

Conclusions. Transcatheter coil occlusion is an effective method for closing a PDA. Previous reports have demonstrated that success is associated with the minimal diameter of the PDA. Despite all our patients having small minimal diameter PDAs, we found PDA reopening in five patients. Short PDA length was the only independent variable that significantly predicted PDA reopening. Type B PDA, which is dependent on short length, was associated with PDA reopening. Our data would suggest that in the presence of a short PDA length and type B PDA, alternative strategies to the current coil occlusion technique should be considered.

References

1. Portsmann W, Wierny L, Warnke H. Der Verschluss des ductus arteriosus persistens ohne thorakotomie (1, Miffeilung). Thoraxchirurgie 1967;15:109–203.
2. Rashkind WJ, Mullins CE, Hellenbrand WE, Tait MA. Nonsurgical closure of patent ductus arteriosus: clinical application of the Rashkind PDA occluder system. Circulation 1987;75:583–92.
3. Hosking MCK, Benson LN, Musewe N, Dyck JD, Freedom RM. Transcatheter occlusion of the persistently patent ductus arteriosus: forty-month follow-up and prevalence of residual shunting. Circulation 1991;84:2313–7.
4. Rao PS, Sideris EB, Haddad J, et al. Transcatheter occlusion of patent ductus arteriosus with adjustable buttoned device: initial clinical experience. Circulation 1993;88:1119–26.
5. Verin VE, Saveliev SV, Kolody SM, Prokubovski VI. Results of transcatheter closure of patent ductus arteriosus with the Batallooccluder. J Am Coll Cardiol 1993;22:1509–14.
6. Lloyd TR, Fedderly R, Mendelsohn AM, Sandhu SK, Beckman RH III. Transcatheter occlusion of patent ductus arteriosus with Gianturco coils. Circulation 1993;88:1412–20.
7. Cambier PA, Kirby WC, Wortham DC, Moore JW. Percutaneous closure of small (<2.5 mm) patent ductus arteriosus using coil embolization. Am J Cardiol 1992;69:815–6.
8. Moore JW, George L, Kirkpatrick SE, et al. Percutaneous closure of the small patent ductus arteriosus using occluding spring coils. J Am Coll Cardiol 1994;23:759–65.

9. Hijazi ZM, Geggel RL. Results of antegrade transcatheter closure of patent ductus arteriosus using single or multiple Gianturco coils. Am J Cardiol 1994;74:925–9.
10. Hijazi Z, Lloyd TR, Beekman RH III, Geggel RL. Transcatheter closure with single or multiple Gianturco coils of patent ductus arteriosus in infants weighing ≤8 kg: retrograde versus antegrade approach. Am Heart J 1996;132:827–35.
11. Hijazi ZM, Geggel RL. Transcatheter closure of large patent ductus arteriosus (> or =4 mm) with multiple Gianturco coils: immediate and mid-term results. Heart 1996;76:536–40.
12. Krichenko A, Benson LN, Burrows P, Moes CAF, McLaughlin P, Freedom RM. Angiographic classification of the isolated, persistently patent ductus arteriosus and implications for percutaneous catheter occlusion. Am J Cardiol 1989;67:877–80.
13. Shim D, Fedderly RT, Beekman RH III, et al. Follow-up of coil occlusion of patent ductus arteriosus. J Am Coll Cardiol 1996;28:207–11.
14. Hijazi ZM, Geggel RL. Transcatheter closure of patent ductus arteriosus using coils. Am J Cardiol 1997;79:1279–80.
15. Houston AB, Gnanapragasm JP, Lim MK, Doig WB, Coleman EN. Doppler ultrasound and the silent ductus. Br Heart J 1991;65:97–9.
16. Balzer DT, Spray TL, McMullin D, Cottingham W, Canter CE. Endarteritis associated with a clinically silent patent ductus arteriosus. Am Heart J 1993;125:1192–3.
17. Latson LA, McManus BM, Doer C, Kilzer K, Cheatham JP. Endocarditis risk of the USCI PDA Umbrella for transcatheter closure of patent ductus arteriosus. Circulation 1994;90:2525–8.
18. Grabitz RG, Neuss MB, Coe JY, Handt S, Redel DA, von Bernuth G. A small interventional device to occlude persistently patent ductus arteriosus in neonates: evaluation in piglets. J Am Coll Cardiol 1996;28:1024–30.
19. Grifka RG, Vincent JA, Nihill MR, Ing FF, Mullins CE. Transcatheter patent ductus arteriosus closure in an infant using the Gianturco-Grifka vascular occlusion device. Am J Cardiol 1996;78:721–3.
20. Grifka RG, Ing FF, McMahon WS, et al. Transcatheter occlusion of patent ductus arteriosus and aorto-pulmonary collaterals using the Gianturco-Grifka vascular occlusion device [abstract]. J Am Coll Cardiol 1997;29 Suppl A:172A.
21. Wessel DL, Keane JF, Parness I, Lock JE. Outpatient closure of the patent ductus arteriosus. Circulation 1988;77:1068–71.
22. Dyck JD, Benson LN, Smallhorn JF, McLaughlin PR, Freedom RM, Rowe RD. Catheter occlusion of the persistently patent ductus arteriosus. Am J Cardiol 1988;62:1089–92.