

Original Studies

Trans-Catheter Closure of Patent Ductus Arteriosus—What Is the Best Device?

Abdolrahim Ghasemi,¹ MD, Swati Pandya,² MD, Surendranath Veeram Reddy,² MD, Daniel R. Turner,² MD, Wei Du,² PhD, Mohamad Ali Navabi,³ MD, Mohammad Reza Mirzaaghayan,³ MD, Abdolrazagh Kiani,³ MD, Katherine Sloan,² DO, and Thomas J. Forbes,^{2*} MD

Background: Over the past three decades, transcatheter occlusion of patent ductus arteriosus (PDA) has evolved to be the procedure of choice. Gianturco and Flipper coils are the most commonly used coils in the United States for closure of small and moderate size PDAs. For larger PDAs, interventionalists in the United States commonly use the Amplatzer Duct Occluder (ADO) and those in Europe use the ADO or the Nit-Occlud Coils (NOC). A comparison between Gianturco coils, Flipper coils, ADO, and NOC has never been made. **Objective:** To compare the success and complication rate associated with the four different devices used for transcatheter closure of PDA. Success was defined as complete closure of PDA with absence of a residual shunt (R.S.) at six months follow-up. **Methods:** Two institutions collaborated in combining their data to evaluate the results of transcatheter closure of PDA. **Results:** Totally, 546 patients underwent successful PDA occlusion at both institutions. Gianturco and Flipper coils were used in 120 (22%) and 119 (22%) patients respectively. A total of 152 (28%) patients received ADO and 155 (28%) patients received NOC. Immediate R.S. were noted in 226 (41.4%) patients in the entire study group with the NOC group having the highest percentage of R.S. (80/155, 51.6%, $P = 0.004$). Of the 484 patients with follow-up echocardiograms at 6 months, 35 (7.2%) patients had persistent R.S. The NOC (3/143, 2.1%) and ADO (5/150, 3.3%) groups had the least R.S. at six months follow-up. **Conclusion:** Per our definition of success, the Nit-Occlud coils and the Amplatzer duct-occluder devices had significantly higher success rate for PDA occlusion versus the coils. © 2009 Wiley-Liss, Inc.

Key words: gianturco coil; flipper coil; amplatzer duct occluder; nit-occlud coil

INTRODUCTION

Over the past two decades, trans-catheter occlusion of patent ductus arteriosus (PDA) has evolved to be the procedure of choice. The transcatheter closure of PDA was first described by Porstmann et al. [1] in 1967. Since then, a number of methods have been developed for transcatheter closure of PDA. Rashkind's umbrella device [2] was used for almost a decade before Cambier et al. [3] and Moore et al. [4] described the first use of Gianturco coils for transcatheter coil of PDA in 1992. A number of other coils and devices with various delivery techniques were developed in the past decade for successful closure of PDA. Gianturco (Cook Inc., IN) and Flipper coils (Cook Inc., IN) are the most commonly used coils in the United States for closure of small and moderate size PDAs

¹Department of Pediatric Cardiology and Cardiac Surgery, Shaheed Behshiti University of Medical Science, Modarres Hospital, Tehran, Islamic Republic of Iran

²Division of Pediatric Cardiology, Children's Hospital of Michigan, Detroit Medical Center, Detroit, Michigan

³Department of Pediatric Cardiology and Cardiac Surgery, Imam Hospital, Tehran University of Medical Sciences, Tehran, Iran

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*Correspondence to: Thomas J. Forbes, MD, Cardiac Catheterization Laboratory, Division of Cardiology, Children's Hospital of Michigan, USA. E-mail: tforbes@dmc.org

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even though these coils were not originally designed for PDA occlusion.

For transcatheter closure of larger PDAs, interventionalists in the United States commonly use the Amplatzer Duct Occluder (ADO, AGA Med Corp, MN) and those in Europe use the ADO or the Nit-Occlud Coils (NOC, PFM Medical, Germany). Currently, the ADO is the only FDA approved device in the United States while the NOC is in clinical trials for FDA approval. A comparison between Gianturco coils, Flipper coils, ADO, and NOC has never been made. Our objective was to compare the success and complication rates associated with the four different devices used for trans-catheter closure of PDA. Success was defined as complete closure of PDA with absence of a residual shunt demonstrated by echocardiography at the six-month follow-up visit, post coil, or device closure of PDA.

MATERIALS AND METHODS

Two institutions collaborated in combining their data to evaluate the results of trans-catheter closure of PDA. A retrospective chart review was performed on all patients undergoing transcatheter closure of PDA at Children's Hospital of Michigan (CHM) from March 1994 to November 2007. Internal Review Board approval was obtained for the study. Similar retrospective chart review was performed at Behesti Medical University (BMU), Tehran, Iran from May 2003 to June 2007.

Procedural Technique

Informed consent was obtained prior to the procedure. Procedures were done under moderate sedation or general anesthesia. Aortography was performed to delineate ductal anatomy and size. All Gianturco, Flipper and flexible NOC embolizations were performed via the retrograde approach. All Amplatzer devices and NOCs except for the flexible type were deployed using the ante-grade approach. Heparin was administered to maintain activated clotting time more than 250 sec.

Gianturco and Flipper Coils

The Gianturco and Flipper coils were used exclusively at CHM, Detroit. The coils were deployed by placing half to three-fourth's of a loop of the coils on the pulmonary end and the remaining coils placed on the aortic end. The Gianturco and Flipper coil size was approximately twice the size of the narrowest ductal diameter.

For patients who underwent PDA coil closure with a Gianturco or Flipper coils, an angiogram was taken

10–15 min following coil deployment. Trivial residual shunt was defined as a small puff of contrast seen crossing the ductus that did not extend to the pulmonary valve. If a jet of contrast was observed across the embolized ductus or the main pulmonary arterial segment filled with contrast, extending to the pulmonary valve, the shunt was considered greater than trivial requiring either a second angiogram or additional coil deployment. If greater than a trivial shunt was observed, a second angiogram was taken 25–30 min following initial coil deployment. If, after the second angiogram, more than a trivial shunt was observed, a second or third Gianturco coil was placed.

ADO and NOCs

At CHM, the ADOs were chosen for patients whose narrowest diameter was more than 2 mm. At BMU, the ADOs were preferentially used for patients weighing >6 kg, with narrowest PDA diameter of ≥ 5 mm and for moderate to large PDA type B and C groups. The NOCs were used exclusively at BMU, Tehran. The NOCs were preferentially used for small infants: less than six months old or weighing <6 kg, PDA types D and E groups and for those patients who had a relatively narrow descending aorta. Three different types of coils were used: Nit-Occlud Flex (flexible) for closure of small PDAs, Nit-Occlud Medium (reinforced coil) for closure of medium-sized PDAs, and Nit-Occlud Stiff (reinforced coil) for closure of medium to large size PDAs.

Patients in whom a NOC was attempted for PDA closure having more than a trivial shunt with the appropriate size coil, the coil was withdrawn into the delivery system and the PDA was closed with an appropriate size ADO. A trivial shunt at the end of the procedure in patients who underwent NOC or ADO closure was accepted and did not receive a second coil or device. Patients were discharged home on the same day or the next day following the procedure and prophylaxis against bacterial endocarditis was continued till the six-month follow-up.

Pre and Post Coil/Device Data

Digitally stored angiograms were examined retrospectively. Measurements were made of the narrowest PDA diameter, length, and the ductal ampulla. The PDA type was evaluated by utilizing the Krichenko classification [5]. The type of coil or device and their size were noted. Post coil/device delivery angiograms were reviewed to assess immediate residual shunt and final coil/device position. Complications including coarctation of aorta (CoA), left pulmonary artery stenosis

TABLE I. Comparison of Four PDA Closure Devices

Type of Device <i>n</i> (percent)	Gianturco 120 (22%)	Flipper 119 (22%)	Amplatzer 152 (28%)	Nit-Occlud 155 (28%)	<i>P</i> -value
Age (yrs)	4.7 ± 5.1	4.3 ± 5.1	6.8 ± 10.1 ^a	6.5 ± 8.6 ^b	0.01
≤1 yr 140 (%)	27 (19.3)	38 (27.1)	36 (25.7)	39 (27.9)	
>1–≤5 yrs 233 (%)	59 (25.3)	50 (21.5)	66 (28.3)	58 (24.9)	NS
>5 yrs 169 (%)	34 (20.1)	31 (18.3)	47 (27.9)	57 (33.7)	
Male: Female	33: 87	44: 75	53: 99	49: 106	NS
Weight (kg)	20.4 ± 21.2	18.8 ± 6.4	20.5 ± 19.2	19.8 ± 16.6	NS
Narrowest PDA diameter (mm)	2.2 ± 0.8	2.2 ± 1.0	3.2 ± 1.5	2.3 ± 1.4	<0.001
PDA type					
A 355 (%)	91 (25.6)	88 (24.8)	94 (26.5)	82 (23.1)	<0.001
B 40 (%)	8 (20)	2 (5)	17 (42.5)	13 (32.5)	
C 45 (%)	7 (15.6)	14 (31.1)	14 (31.1)	10 (22.2)	
D 11 (%)	2 (18.2)	4 (36.4)	3 (27.2)	2 (18.2)	
E 84 (%)	12 (14.3)	11 (13.1)	13 (15.5)	48 (57.1)	
Unknown 11 (%)	–	–	11 (100)	–	
No. of coils/device					
1	87	89	152	143 ^c	
2	21	22	–	3 ^d	<0.001
≥3	12	8	–	–	

^aSignificant compared with Gianturco and Flipper group.

^bSignificant compared with Flipper group.

^cNine patients in whom a Nit-Occlud coil was initially tried eventually received an Amplatzer duct occluder for PDA closure—not included in the table.

^dAmplatzer duct occluder was the second device used in three patients with residual shunts after PDA closure with Nit-Occlud coils.

All data expressed as sample number (*n*) and percentage (%) or mean and standard deviation (SD); Yrs, years, kg, kilograms; mm, millimeter; NS, not significant; No, number; PDA type - based on Krichenko's classification.

(LPA), and coil or device embolization were documented.

Follow-Up

Transthoracic echocardiograms done at least six months after the initial procedure were reviewed for a residual shunt. They were also reviewed to detect any complications such as coil/device embolization, LPA stenosis, or CoA.

Statistical Methods

Statistical analysis was performed using SAS 9.1 software. The patients were divided into four groups: Gianturco coil, Flipper coil, ADO, and NOC groups. Patients who had more than one coil were assigned to the first coil group. The four groups were compared with respect to patient demographic characteristics (age, weight, and gender) and PDA characteristics (ductus type) by one way analysis of variance or chi-square tests. We then evaluated final coil/device position, coil number, immediate post embolization residual shunt as determined angiographically, and six-month follow-up echocardiographic residual shunt in all the four groups. Complications occurring during the procedure, immediately after, or at their follow-up visit were noted. Treatment outcomes such as immediate and six-month follow-up residual shunts were compared across the four groups using chi-square tests.

RESULTS

Demographic Characteristics

A total of 546 patients underwent successful PDA occlusion at both institutions. Females constituted for more than two-thirds of the study population (*n* = 367). In 120 (22%) patients, the first coil deployed was a Gianturco coil and in 119 (22%) patients the Flipper coil was initially used. The ADO device was used in 152 (28%) patients and the NOC was initially used in 155 (28%) patients. Baseline demographics, PDA characteristics, and number of coils or devices for all four groups are shown in Table I. Mean age was significantly different between four groups with a higher mean age in the ADO group (6.8 ± 10.1 years, *P* = 0.01) when compared with the Gianturco (4.7 ± 5.1 years) and flipper (4.3 ± 5.1 years) groups. The mean age in the NOC group was significantly higher (6.5 ± 8.6 years, *P* = 0.01) when compared with the Flipper group. The weight and gender were similar among all four groups.

PDA Characteristics

There was a significant difference in the narrowest PDA diameter between the four groups. The narrowest PDA diameter was significantly larger in the Amplatzer group (3.2 ± 1.5 mm) when compared with other three groups. The most common type of PDA in all four groups was the Krichenko's PDA type A. Of note, 48/

TABLE II. Comparison of Residual Shunts and Complications of Four PDA Closure Devices

Type of Device <i>n</i> (percent)	Gianturco 120 (22%)	Flipper 119 (22%)	Amplatzer 152 (28%)	Nit-Occlud 155 (28%)	<i>P</i> -value
Immediate R.S.	42 (35)	38 (32)	66 (43.4)	80 (51.6)	0.004
R.S. at 6 months	15/96 ^a (15.6)	12/95 ^a (12.6)	5/150 ^a (3.3)	3/143 ^a (2.1)	<0.0001
Embolization	11 (9.2)	3 (2.5)	0	3 (2)	0.002
Coarctation	0	0	0	1 (0.7) ^b	NS
LPA stenosis	2 (1.7)	0	1 (0.7)	0	NS

^aSix-month follow-up echocardiographic data available only in these patients.

^bNo interventions required to date.

All data expressed as sample number (*n*) and percentage (%) in parenthesis; R.S, residual shunt; LPA, left pulmonary artery; NS, not significant.

TABLE III. Comparison of Residual Shunts and Complications in the Three Age Groups for the Four PDA Closure Devices

	≤1 year 140	>1–≤5 years 233	>5 years 170	<i>P</i> value
Immediate R.S. 226/543 ^a	59 (26.1)	89 (39.4)	78 (34.5)	NS
Gianturco 42	14 (33.3)	20 (47.6)	8 (19.1)	NS
Flipper 38	13 (34.2)	16 (42.1)	9 (23.7)	NS
Amplatzer 66	15 (22.7)	28 (42.4)	23 (34.9)	NS
Nit-Occlud 80	17 (21.2)	25 (31.3)	38 (47.5)	0.03
R.S. at 6 months 35/484 ^b	13 (37.2)	11 (31.4)	11 (31.4)	NS
Gianturco 15	5 (33.3)	5 (33.3)	5 (33.3)	NS
Flipper 12	5 (41.7)	4 (33.3)	3 (25)	NS
Amplatzer 5	1 (20)	2 (40)	2 (40)	NS
Nit-Occlud 3	2 (66.7)	0 (0)	1 (33.3)	NS
Embolization 17	5	6	6	NS
Gianturco 11	2	4	5	NS
Flipper 3	2	1	0	NS
Amplatzer 0	0	0	0	NS
Nit-Occlud 3	1	1	1	NS
Coarctation 1	1	0	–	NS
Gianturco 0	0	0	0	NS
Flipper 0	0	0	0	NS
Amplatzer 0	0	0	0	NS
Nit-Occlud 1	1	0	0	NS
LPA Stenosis 3	2	1	0	NS
Gianturco 2	1	1	0	NS
Flipper 0	0	0	0	NS
Amplatzer 1	1	0	0	NS
Nit-Occlud 0	0	0	0	NS

^aThe age of three patients in the Amplatzer group was unknown.

^bSix-month follow-up echocardiographic data available only in these patients.

All data expressed as sample number (*n*) and percentage (%) in parenthesis; R.S, residual shunt; LPA, left pulmonary artery; NS, not significant.

84 (57%) patients in the study group with Krichenko's PDA type E received a NOC for PDA closure.

Number of Coils/Devices

In all four groups, the majority of patients required only one coil or device. In Gianturco group, the additional coils were always Gianturco coils. Of the 31 patients in Flipper group who required additional coils, 21 had a Gianturco coil used as the second coil or third coil. No patients in the ADO group needed a second coil or device. Three patients in the NOC group had significant residual shunts at three-month follow-up visit and needed an Amplatzer device for complete closure of PDA.

Treatment Outcomes

Immediate residual shunts. Immediate residual shunts were noted in 226/546 (41.4%) patients in our study population. As shown in Table II, residual shunts immediately after trans-catheter closure of PDA were significantly different between the four patient groups ($P = 0.004$). The immediate residual shunts were highest in the NOC group (51.6%) followed by the ADO (43.4%), Gianturco (35%), and Flipper (32%) groups. Table III compares the residual shunts and complications for four PDA devices and the three age subgroups. The immediate residual shunts were not significantly different between the three age subgroups (Table III). There was no significant difference in immediate

TABLE IV. Comparison of Residual Shunts With PDA Type

Krichenko's PDA Types	A	B	C	D	E	Unknown	<i>P</i>
Immediate R.S. <i>n</i> = 226/546	150/355 (42.3)	17/40 (42.5)	28/45 (62.2)	3/11 (27.3)	23/84 (27.4)	5/11 (45.5)	0.003
R.S. at 6 months <i>n</i> = 35/473 ^a	20/307 ^a (6.5)	4/37 ^a (10.8)	7/42 ^a (16.7)	1/9 ^a (11.1)	3/78 [†] (3.6)	–	NS

^aFollow-up echocardiograms at six months in patients whom a PDA type was identified were available for a total of 473 patients only. All data expressed as sample number (*n*) and percentage (%) in parenthesis; R.S., residual shunt; NS, not significant.

TABLE V. Comparison of Residual Shunts With Narrowest PDA Diameter

	Mean ± SD	Small ≤1 mm	Medium >1 to ≤3 mm	Large >3 mm	Unknown	<i>P</i>
Immediate R.S. 226/546 (%)	3.1 ± 1.4	9/71 (12.7)	147/351 (41.9)	65/114 (57)	5/10 (50)	<0.0001
R.S. at 6 months 35/473 [†] (%)	3.2 ± 1.5	0/65 ^a	20/304 ^a (6.6)	15/105 ^a (14.3)	0/40 ^a	<0.001

^aFollow-up echocardiograms at six months in patients whom a PDA size was documented were available for a total of 474 patients only. All data expressed as sample number (*n*) and percentage (%) in parenthesis; R.S., residual shunt; mm, millimeter; S.D., standard deviation.

residual shunts between the three age subgroups within each of the Gianturco, Flipper, and ADO groups. In NOC group, patients who were more than five years of age had a significantly higher immediate residual shunts (38, 47.5% *P* = 0.03) when compared with patients ≤ 5 years of age.

Six-month Follow up

Of the 484 patients in our study population who had follow up echocardiograms at six months, 35 (7.2%) patients were noted to have a persistent residual shunt. The NOC group had the lowest percent of patients with residual shunts (3/143, 2.1%) at six-month follow up (*P* < 0.0001). In ADO group, the residual shunts were seen in 3.3% patients at six-month follow up. The Gianturco (15.6%) and Flipper (12.6%) groups had the highest percent of patients with residual shunts at six-month follow up. Furthermore, the residual shunts at six-months were not significantly different between the three age sub groups for all four PDA device groups.

Residual Shunts and PDA type

Table IV compares immediate and six-month follow up residual shunts with the Krichenko's types of PDA. Irrespective of the type of coil/device used, the Krichenko's type "C" PDA was the commonest type of PDA associated with residuals shunts immediately (28/45, 62.2%, *P* = 0.003) after the procedure and also at six-month follow up (7/42, 16.7%). Immediate residual shunts were comparable in types "A" and "B" at 42.3% and 42.5% respectively. Krichenko's PDA type "D" and "E" had the least number of immediate residual shunts at 27.3% and 27.4% respectively. At six-month follow up, the Krichenko's PDA type "E" had the least number of residual shunts (3/78, 3.6%).

Residual Shunts and PDA size

As expected and shown in Table V, irrespective of the coil/device used, the immediate residual shunts were significantly higher in patients with medium (147/351, 41.9%) and large sized (65/114, 57%, *P* = < 0.0001) PDAs when compared with patients with small-sized PDAs (9/71, 12.7%). The highest number of residual shunts at six-month follow up was seen in patients with a large sized PDA (15/105, 14.3%). The residual shunts at six-months follow up were seen in 20/304 (6.6%) patients with a medium-sized PDA. No patients with a small PDA had a residual shunt at six-month follow up.

Irrespective of the type of coil/device used, the mean narrowest PDA diameter in patients with an immediate residual shunt was significantly higher (3.1 ± 1.4 ml, *P* = < 0.0001) when compared with those patients who did not have immediate residual shunts (2.2 ± 1.2 ml). Similarly, the mean narrowest PDA diameter in patients with a residual shunt at six-month follow up was significantly higher (3.2 ± 1.5 ml, *P* = 0.001) when compared with those patients who had complete occlusion of the PDA at six-month follow up (2.5 ± 1.3 ml).

Complications

There was no mortality in all four groups. Major complications including coil or device embolization (*n* = 17), coarctation of aorta (*n* = 1), and LPA stenosis (*n* = 3) are compared in Table II for all four groups. Major complications for the three age subgroups are compared in Table III. There was no statistically significant difference in major complications between the three age subgroups for the four devices used in this study.

Coil/device embolization. There was no significant difference in the number of patients who had coil/device embolization between the three age subgroups.

The Gianturco coils embolized in 11/120 (9.2%) patients when compared with 3/119 (2.5%) patients with Flipper coils. No patients in the ADO group had device embolization. Three patients in the NOC group had coil embolization and eventually needed closure with Amplatzer device.

Coarctation. Only one (0.7%) of 155 patients in the NOC group developed coarctation of aorta as a direct complication of the procedure. This was noted in a three-month-old patient who developed a peak gradient of 10 mm Hg across the aortic isthmus, immediately post coil closure with a NOC. A follow-up echocardiogram at one month revealed complete closure of the PDA. At 16 months of age, the peak gradient across the aortic isthmus had increased to 23 mm Hg and the patient underwent balloon angioplasty of the coarctation site. At last follow-up, the infant was 5.5-year-old and had no residual coarctation.

LPA stenosis. There was no significant difference in the number of patients who developed LPA stenosis between the three age subgroups. Two (1.7%) patients in Gianturco group and 1 (0.7%) patient in ADO group were noted to have LPA stenosis on six months follow up echocardiograms, with both being conservatively followed at this time. In the ADO group, LPA stenosis was observed in an 11-month-old infant who received an oversized ADO device. An echocardiogram performed the next day after the procedure documented a peak gradient of 25 mm Hg across proximal LPA. This patient later underwent balloon angioplasty at three-month follow-up visit and is currently three years old with a peak gradient of 20 mm Hg across proximal LPA.

Other complications. We encountered two patients with hemolysis immediately following coil embolization of their PDA. Both were infants, one having three coils placed, the other nine coils placed, respectively. The patient with nine coils required surgical removal of the coils and ligation/division of the PDA. The other patient was conservatively followed, with hemolysis resolving three days later. Groin hematoma at the access site was seen in 13 (11%) patients each in the Gianturco and Flipper group. One (2.7%) of the 37 patients who underwent ADO device closure at CHM, developed groin hematoma. Three (2.5%) patients in Flipper group and four (3.3%) patients in Gianturco group had transient loss of pulse after cardiac catheterization needing no treatment or intervention. None of the 37 patients who underwent ADO device closure at CHM had loss of pulse as a complication of the procedure. One (0.9%) patient in Flipper group developed transient bradycardia prior to coil delivery which resolved spontaneously. In Gianturco group, two patients (1.7%) developed transient heart block with

junctional escape rhythm that resolved with catheter manipulation. One (2.7%) of the 37 patients who underwent ADO device closure at CHM developed supraventricular tachycardia during right heart catheterization that spontaneously resolved within a minute with catheter manipulation. Information regarding minor complications involving access site and arrhythmias were not readily available for patients who underwent transcatheter closure of PDA at BMU, Tehran.

Nit-Occlud Coil Group

All PDA closures with NOCs were performed at BMU, Tehran. It should be noted that the precise size coil or device needed for closure of a certain sized PDA was not always available at this institution. Eleven patients in whom a NOC was initially used for trans-catheter closure of PDA eventually received an ADO device for PDA closure. In 2/11 patients who eventually received an ADO device, a significant residual shunt prior to device delivery was noted with use of an appropriately sized NOC, necessitating its removal and use of an ADO device. This was probably related to the distensibility of the PDA and under sizing of the narrowest PDA diameter. Undersized coils were used in three patients that were replaced with appropriate size ADO devices. Immediate coil embolization was noted in two patients who eventually underwent ADO device closure during the same cardiac catheterization. In another patient, coil embolization was noted at three-month follow-up visit and underwent a second cardiac catheterization with ADO device closure. A significant residual shunt was noted in three patients at three-month follow-up visit and an appropriate size ADO device was added to the coils for complete closure of the residual shunts.

DISCUSSION

Over the past three decades, a number of coils/devices with different delivery techniques have been used for transcatheter closure of PDA. To date, no consensus opinion exists with regard to what type of closure device is most efficacious and cost effective. In fact, because of the varied morphology of the PDA, perhaps there is no single closure device of choice. To that end, we compared four commonly used closure devices, namely the Gianturco coil, Flipper coil, ADO device and NOC to compare efficacy and safety profiles in a large retrospective analysis.

We have discontinued performing 24 hr echocardiogram post PDA closure due to its poor reliance in predicting overall outcome, which was better assessed at

six-month follow-up echo [6]. In that study, Turner et al. noted that recanalization did not occur if complete occlusion was noted at the six-month follow-up echo. Conversely, if recanalization had occurred, or a residual shunt persisted at the six-month follow-up, no spontaneous closure was noted without performing any further intervention. Therefore, we used six-month follow-up echo to assess residual shunts and success rate for the outcome of the procedure. In our study, the highest echocardiographic PDA occlusion rate at six-month follow up was seen in the NOC group (98%) followed by the ADO group at 97%. The lowest six-month echocardiographic PDA occlusion rate was seen in the Gianturco group at 84%.

PDA Occlusion Efficacy

Immediate PDA occlusion rates using Gianturco or detachable coils varied from 62% to 89% [4,7,9-12]. Moore [4] and Lloyd [7] reported immediate angiographic closure rate of 62% and 68% respectively with the use of Gianturco coils. Magee et al. reported the European PDA coil registry data and noted an immediate closure rate of 59% and 95% at one-year follow up [8]. Hijazi and Geggel reported their antegrade technique using multiple Gianturco coils to close PDAs \geq 4 mm in diameter and noted a significantly higher complete occlusion rate of 89% immediately after the procedure and 94.4% at six-week follow-up. (9). The higher complete occlusion rate reported by Hijazi and Geggel is probably related to their philosophy of achieving complete closure of PDA, confirmed both angiographically and by a color flow Doppler echocardiography before the procedure is terminated. In 1997, Hizaji and Geggel reported the immediate and mid-term results of the first 100 patients who underwent transcatheter PDA closure at their institution. They noted an immediate complete occlusion rate of 93% with the use of single or multiple coil technique (10). Uzun et al. reported their experience with the use of Cook detachable coils and noted closure rates of 66% immediately after the procedure and 91% at six-month follow up [11]. Grifka opined that the suboptimal results with the Flipper detachable coils were due to the lower profile of the Flipper coils [12]. We noted comparable immediate closure rates with both Gianturco (65%) and Flipper (68%) coils. The six-month occlusion rate was slightly higher with the use of Flipper coils (87%) when compared with the Gianturco coils (84%) however it did not reach statistical significance. On the basis of our experience, we believe that the clinical thrombogenicity with Gianturco and Flipper coils is similar in spite of structural differences between the two coils. We speculate that our immedi-

ate and six-month follow up complete occlusion rates are lower to that reported in literature due, partly, to not being aggressive in using multiple coils to achieve complete PDA occlusion before the procedure was terminated and also to the inherent differences between the operators as to what is considered a successful result. We have brought eight patients back for a repeat coil embolization procedure, seven of which were successfully closed, one was not able to be traversed. Four patients each in the Gianturco and Flipper group who received more than one coil for PDA closure had a residual shunt at six-month follow-up. Our institutional policy of aggressive anticoagulation with heparin to maintain the ACTs $>$ 250 seconds may have contributed to a lower immediate PDA occlusion rate.

Our study showed that approximately half of all patients undergoing PDA closure with ADO (43%) and NOCs (52%) had residual shunts noted on angiograms performed 10 min after the procedure. However, a significant proportion of the residual shunts disappeared by six-month follow up. Pass et al. reported the multicenter ADO device trial results and noted immediate angiographic and one-year closure rates of 76% and 99.7%, respectively [13]. Masura et al. reported their immediate and short-term results with the use of ADO in 23 patients and noted a complete occlusion rate of 30.4% on angiograms performed 10 min after device deployment and 100% complete occlusion rate by 24 hr after the procedure, confirmed by color flow Doppler echocardiography [14]. Even though our immediate angiographic occlusion rate was lower (57%) than that reported by Pass et al., we noted that a significant proportion of the residual shunts disappeared by six months with a six-month echocardiographic occlusion rate of 96.7%. We speculate that operator's preference of aggressive heparinization to maintain higher ACTs may be contributing, at least in part, the lower percentage of immediate angiographic occlusion rate in our study population.

Tometzki et al. reported an early occlusion rate of 91% at 24 hr with the use of Duct-occlud coils for PDA closure [15]. Celiker et al. used NOCs for PDA closure and reported an early occlusion rate of 71% at 24 hr and 93% by six months [16]. Moore et al. reported the results of the phase I FDA clinical trial of Duct-Occlud device occlusion of PDA and noted echocardiographic occlusion rates of 55% at discharge, 88% at two-months follow up and 94% at 12-month follow up [17]. Our immediate (48.4%) and six-month (98%) angiographic closure rates with the NOCs, which are modified versions of the duct-occlud coils, are comparable with that reported by Moore et al.

Our study showed that irrespective of the coil/device used, the Krichenko's type C is associated with the

highest incidence of residual shunts both immediately and at six-month follow up. We also noted that, irrespective of the coil/device used, the mean narrowest PDA diameter of more than 3 mm is associated with residual shunts both immediately and six-months after the procedure.

Complications

In our experience, there was no mortality or late recanalizations with any of the coils/devices. The Gianturco coils are associated with highest rate of embolization, up to 23% as reported by Shrivastava et al. [18]. ADO devices have the lowest risk (0.4%) of embolization [13]. Our embolization rates are comparable with that described previously. We noted highest rate (9.2%) of coil embolization with the Gianturco coils and attribute it to its uncontrolled release mechanism. Coil embolization was noted in three patients each in Flipper (2.5%) and NOC (2%) groups. Most of the coil embolizations were noted in the learning phase and could have been prevented, at least in part, with use of appropriate size coils. No device embolization was noted in the ADO group. Coarctation of aorta and LPA stenosis are the other major complications that have been previously described with transcatheter closure of PDA. In the multicenter ADO device trial, Pass et al. noted 2/435 (0.5%) patients with partial LPA stenosis and did not encounter any patient with significant aortic obstruction post ADO device closure of PDA [13]. In the phase I FDA clinical trial of duct-occlud device, Moore et al. did not encounter any patients with LPA stenosis or coarctation [17]. We encountered one patient with coarctation of aorta (NOC group, 0.7%) and three patients with LPA stenosis (2/120, 1.7% in Gianturco group and 1/152, 0.7% in ADO group) as complications of the procedure. We believe that the incidence of coarctation of aorta and LPA stenosis has significantly decreased with increasing use of retrievable coils/devices for PDA closure.

Gianturco and Flipper coils

Both the Gianturco and Flipper coils that are widely used in the United States were not specifically designed for PDA closure. Gianturco coils are made of stainless steel wire of 0.038 inch diameter and have multiple dacron fibers embedded within the coil loops to enhance thrombogenicity. The free-release technique used for delivery of Gianturco coils is a disadvantage that is associated with risk of coil embolization. Flipper coils are of slightly smaller profile with a wire diameter of 0.035 inch and with less thrombogenic material when compared with Gianturco coils but come with an advantage of controlled release technology.

Gianturco and Flipper coils are extensively used for PDA occlusion in United States for patients with minimum PDA diameter of <2 ml. At our institution (CHM), Gianturco coils were used almost exclusively till 1999 after which Flipper coils were introduced in an effort to have a more controlled delivery.

Amplatzer Duct Occluder

ADO was the first device that was specifically designed for transcatheter closure of PDA. It is also the first device that has been approved by the Food and Drug administration (FDA, 2003) for PDA occlusion in United States. ADO device is a wire mesh made of nickel and titanium alloy (Nitinol) that is filled with polyester fabric to enhance thrombogenicity and the device comes with a delivery sheath with controlled release mechanism. ADO devices have been used for PDA closure for patients with a minimum PDA diameter of ≥ 2 ml in size. Contraindications for use of ADO devices are patients less than 6 kg and younger than six months of age. At CHM, ADO devices are routinely used for transcatheter closure of PDAs with a minimum diameter of ≥ 2 ml in size.

Nit-Occlud Coils

The NOCs, extensively used in Europe since 2001, are improved versions of the Duct-Occlud PDA occlusion device that was specifically designed for PDA occlusion and in use since 1992. In the United States, clinical trials with NOCs have concluded and the data has been submitted for review by the FDA. NOC is made of nickel and titanium alloy (Nitinol) and is wound in a secondary helix type loop which when released conforms to a double-opposing cone shape. The coils have a graduated stiffness from aortic to proximal windings for optimal adaptation to ductal anatomy. NOCs have no dacron fibers and come pre-mounted on a flexible delivery system which allows full retrieval or repositioning prior to release. There are three different designs of NOCs for PDA occlusion: Nit-Occlud Flex is a flexible coil for closure of small PDAs, Nit-Occlud Medium is a reinforced coil for closure of medium size PDAs and the Nit-Occlud Stiff which is a reinforced coil for closure of medium to large PDAs. The NOCs or ADO devices were exclusively used for PDA occlusion at BMU, Tehran. NOCs are suitable for all types of PDA and sizes up to 5 mm. Since NOCs can be delivered through a 4 or 5 French catheter, we believe that NOCs can be used for closure of large PDAs (up to 5 mm) in smaller infants, who are less than six months and weigh less than 6 kg, where use of ADO may be associated with higher incidence of complications.

Limitations. This study is limited by its retrospective nature. We also believe that some of the results in our study may be slightly different if the appropriate sized coil or device was available at BMU, Tehran. The learning curve at both institutions for all the devices was not accounted for in this study. The Krichenko's PDA type and narrowest PDA diameter were evaluated by an experienced cardiologist and we did not check for any interobserver variability. We used trans-thoracic echocardiography to evaluate for LPA stenosis and believe that lung perfusion scan is a better tool to quantify the degree of LPA stenosis.

CONCLUSIONS

Per our definition of success, with complete closure at 6 month follow-up, Nit-Occlud coils and Amplatzer duct occluder devices are superior to Gianturco and Flipper coils in terms of the PDA occlusion efficacy with comparable or superior complication rates. Transcatheter occlusion has become the procedure of choice for treating patients of all ages with PDA. There are at least four different devices available in the United States for transcatheter closure of PDA. To date, there is no single device that would fit all the different types and sizes of PDA and the search for the perfect or ideal device continues. We believe that an ideal device for PDA closure is one that will meet all of the following criteria: made of a material that is MRI compatible, conforms to the various PDA shapes and sizes, can be easily and safely delivered through a 4 or 5 French catheter with the help of retrievable delivery systems, and leaves the duct permanently closed soon after deployment. Until such an ideal device is available, cardiac catheterization laboratories will need to carry a variety of PDA closure coils and devices to best cater to their patient population.

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