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ORIGINAL ARTICLE

Collateral closure in congenital heart defects with Amplatzer vascular plugs: single-center experience and a simplified delivery technique for exceptional cases

Rouven Kubicki[1] · Brigitte Stiller[1] · Johanna Hummel[1] · Rene Höhn[1] · Thilo Fleck[1] · Jochen Grohmann[1]

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Abstract

The study describes our experience with Amplatzer Vascular Plugs (AVP2 and 4) and highlights a more refindes telescopic technique for AVP2 delivery. AVPs are well-established occlusion devices for vascular anomalies in congenital heart disease (CHD). The AVP2 is sometimes preferred to the AVP4 due to its shorter length, flat-profiled retention disks, and the availability of larger diameters, but its profile requires a larger inner lumen for safe delivery. The latter may actually hamper access to target lesions. This is a retrospective analysis of all CHD patients treated with the AVP2 and AVP4 between 12/2012 and 12/2015. Target vessels were characterized, measured, and the device-to-vessel diameter ratio calculated. A modified pigtail technique for AVP2 delivery was frequently used: a floppy wire was simply reinforced by the curved tip of a pigtail catheter (instead of the long sheath's dilator) to guide the required delivery sheath towards the desired landing zone. 59 patients with a median age and bodyweight of 3.0 years (range 0.1–75) and 13.8 kg (range 2.5–80) underwent the implantation of 106 plug-devices (30 AVP2, 76 AVP4) in 91 target vessels. Indications for their use were ductus arteriosus (19%), aortopulmonary (43%) as well as venovenous collaterals (34%) and other miscellaneous lesions (4%). The pigtail-supported AVP2 delivery in six patients proved very convenient. No complications occurred. AVPs are excellent devices for embolizing shunt vessels in CHD patients. Here, we describe a simplified telescoping technique for AVP2 delivery to enter curvy target lesions gently and efficiently.

Keywords Percutaneous intervention · Congenital heart disease · Embolization · Amplatzer vascular plug · Telescopic catheter technique

Introduction

Congenital heart disease (CHD) is associated with a wide variety of anomalous congenital or acquired superfluous vascular connections, resulting in shunting phenomena, often affecting patients with single ventricle physiology or multifocal pulmonary perfusion. When indicated, transcatheter closure of these vessels has become the leading approach [1]. Judicious use of these techniques requires understanding of the lesions' anatomy and pathophysiology beyond the numerous technical aspects. Since the first interventional closure of patent ductus arteriosus (PDA) by Porstmann [2] in 1967, occluding devices have been substantially improved. Nowadays, the interventionalists' armentarium is large, enabling the closure of major aortopulmonary collaterals (MAPCA), arteriovenous malformations (AVM), anomalous venovenous connections (VVC), artificial (surgical) shunts and other miscellaneous lesions. In this context, many clinicians prefer Amplatzer Vascular Plugs (AVP; AGA Medical, Golden Valley, MN)—especially the AVP2 and AVP4—used, however, still off-label for most CHD indications [3, 4]. Accessing the target lesion and delivering the optimal device can be difficult [5]. The AVP2 is sometimes the preferred device (over the AVP4) due to the former's shorter, unrestricted length, flat profiled retention

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✉ Jochen Grohmann
jochen.grohmann@universitaets-herzzentrum.de

[1] Department of Congenital Heart Disease and Pediatric Cardiology, Faculty of Medicine, Medical Center, University Heart Center Freiburg, Bad Krozingen, University of Freiburg, Mathildenstraße 1, 79106 Freiburg, Germany

disks, and availability of larger diameters. However, the AVP2's profile requires a larger inner lumen for delivery, a factor that could restrict its application. This report describes our experience with both AVP types, emphasizing a more refined telescopic technique using pigtail catheter support for AVP2 delivery in selected patients.

Materials and methods

We conducted a retrospective analysis of all CHD patients who underwent a vascular occlusion procedure with AVP2 or AVP4 at our institution between December 2012 and December 2015. The AVP2 and AVP4 were CE-mark approved for clinical use in 2007 and 2009, respectively. According to the manufacturer's specifications, AVPs are built with nitinol braids that have a self-expanding feature. Radiopaque platinum bands at both ends enhance visibility under fluoroscopy. The AVP4 is available in 4–8 mm diameters (1-mm increments), AVP2 in 3–22 mm (beyond the 4-mm device diameter, in 2-mm increments). The AVP4's profile is slim enough to enable delivery via the 0.038 inch inner diameter (ID) of various compatible diagnostic catheters (≥ 4Fr). In this respect, AVP2 plugs require at least 0.055 inch ID for sizes 3–8 mm (and up to 0.098 inch for the largest sizes 18–22 mm). On the other hand, the AVP2's unconstrained length is markedly shorter (e.g., 8 mm plug: length 12.5 mm for AVP4 versus 7 mm for AVP2).

All the interventions were performed with the patients under conscious sedation or general anesthesia. Patients usually received at least 100 IU kg^{-1} of heparin maintaining activated clotting time (ACT) ≥ 200 s throughout the procedure. Standard antibiotic prophylaxis was given before device deployment.

Target blood vessels were characterized by reviewing the original angiograms. Information on the vessels' diameter referred to the narrowest segments (except for PDAs where the (tubular) mid-segments' diameters were chosen as the reference). The size and number of implanted devices were recorded. We calculated the device size to the vessels' diameter ratio. The primary occlusion rate was checked for every implanted device. Any device-/procedure-related complaints or complications were documented.

Informed consent was obtained from each study participant's parents or legal guardian. All procedures conducted in this study involving human participants concurred with the ethical standards of our institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Telescopic technique for transcatheter AVP2 delivery

In general, we employed standard catheter techniques for AVP2 delivery, which was usually a braided kink-resistant long sheath with its dilator guided over a matching wire. If those attempts did not succeed, meaning the landing zone was inapproachable due to very curvy, tortuous, or sharp-angled vessel courses, we applied a modified telescopic (pigtail) technique: first, the required delivery sheath was positioned near or at the target vessel's entry, followed by removing the sheath's dilator, probing the target vessel with a suitable end-hole diagnostic catheter, and advancing a floppy wire (0.014 or 0.016 inch) far into the periphery; second, the diagnostic catheter was simply replaced by a standard pigtail catheter whose outer diameter matched exactly that of the inner lumen (ID) of the required delivery sheath; third, the pigtail catheter (instead of the sheath's original dilator) served as a curved reinforcement to guide the sheath to the desired landing zone.

Results

During the 3-year study period, we identified 59 patients (53% male) with a median age and body weight of 3 years (0.1–75) and 13.8 kg (2.5–80); 37% of those patients had a body weight ≤ 10 kg. Patients' characteristics and principal diagnoses are listed in Table 1. A total of 106 AVPs were successfully implanted in 91 blood vessels: 30 AVP2 (28%) of mean 7 mm (range 3–20 mm) and 76 AVP4 (72%) of mean 5 mm (range 4–8 mm). Two or more plugs were implanted in ten target vessels. The mean device-to-blood vessel ratio was for AVP2 1.46 (SD ± 0.28) and for AVP4 1.47 (SD ± 0.18). As illustrated in Table 2, we treated a wide variety of blood vessels. We had technical success handling all the target vessels, achieving complete primary occlusion in 82% (87/106). We observed no inadvertent device-related obstruction of neighboring vessels, nor any device embolization, vascular disruption or any other procedure-related complication. However, in 6 of the 59 patients (10.2%) AVP2 delivery was impeded until we used the modified pigtail-guided technique. The latter patients are summarized in Table 3, two of whom are exemplified in Figs. 1 and 2 (online resources 1–5). Those were 6 out of 15 patients (40%) with collaterals or atypical vascular connections who underwent AVP2 implantation. None of them had a PDA.

There was a significant difference in age and body weight between patients with biventricular and single ventricle physiology at the intervention time. In the single

Table 1 Patients' characteristics and diagnoses

Physiology	No. of patients	Primary diagnosis	Age (years)	BW (kg)
Biventricular	17	PDA	1.0 (0.0–66.0)	10.0 (6.4–84.0)
	5	PA, VSD, MAPCAs	0.48 (0.1–17.0)	6.3 (3.3–56.7)
	3	DORV, PS, MAPCAs	0.65 (0.12–7.0)	4.1 (2.5–21.0)
	4	Miscellaneous	1.5 (0.46–75.0)	10.1 (6.4–80.0)
Single ventricle	17	HLHS/C	3.0 (0.46–22.0)	13.8 (6.2–74.9)
	3	TA	12.0 (12.0–23.0)	49.4 (33.3–51.0)
	5	DILV	11.0 (4.0–15.0)	25.0 (15.5–54.0)
	5	Miscellaneous	6.0 (3.0–14.0)	18.0 (11.8–41.5)

Values as median (range)

PDA patent ductus arteriosus, *PA* pulmonary atresia, *VSD* ventricular septal defect, *MAPCAs* major aorto-pulmonary collaterals, *DORV* double outlet right ventricle, *PS* pulmonary stenosis, *DILV* double inlet left ventricle, *HLHS/C* hypoplastic left heart syndrome/complex, *TA* tricuspid atresia, *BW* body weight, *y* years, *kg* kilogram

Table 2 Plug choice in 59 patients

Site of intervention	No. of vessels	Type of device	No. of devices	Vessels diameter (mm)	Device-to-vessel ratio	Primary occlusion rate (%)
PDA	17 (19%)	AVP4	2	4 (2.5–7.1)	1.48 (1.17–1.94)	94
		AVP2	15			
AP Collateral	39 (43%)	AVP4	47	3.1 (1.8–6.8)	1.46 (1.18–2.22)	63
		AVP2	4			
Venous Collateral	31 (34%)	AVP4	26	4 (2.3–15.4)	1.43 (1.19–1.76)	70
		AVP2	7			
Miscellaneous	4 (4%)	AVP4	1	7.0 (2.2–14.7)	1.36 (1.16–1.56)	100
		AVP2	4			
Total	91		106	4	1.45	82

Values as median (range)

PDA patent ductus arteriosus, *AP* aorto-pulmonary, *AVP* Amplatzer™ vascular plug, *BW* body weight

Table 3 AVP2 implantation using pigtail technique

Case	Diagnosis	Site of intervention	Age (years)	BW (kg)	Size of AVP2 (mm)	Size of target vessel (mm)	Conventional attempt (min)	Pigtail attempt (min)
1	DILV, L-TGA, PS; s/p stage 3	SVC to atrial fistula	15	54	12	9.3	122	6
2	DORV, LV hypoplasia, PS; s/p stage 1	Azygos-to-portal vein fistula	0.6	6.5	8	6.7	98	12
3	PA, VSD, MAPCAs; s/p RV-PA-conduit	MAPCA DAO to RLLA	1	6.1	3	1.4	#	7
4	SV, PS; s/p stage 2	SCV to IVC collateral	14	43	12	8.3	#	14
5	DORV, LV hypoplasia, PS; s/p stage 3	Hepatico to atrial fistula	4	16.4	8	5.6	45	21
6	HLHS; s/p stage 2	SVC to IVC collateral	1	6.8	8	5.9	#	16

PA pulmonary atresia, *PS* pulmonary stenosis, *VSD* ventricular septal defect, *TGA* transposition of the great arteries, *MAPCAs* major aorto-pulmonary collaterals, *DORV* double outlet right ventricle, *DILV* double inlet left ventricle, *LV* left ventricle, *HLHS* hypoplastic left heart syndrome, *SVC* superior vena cava, *IVC* inferior vena cava, *DAO* aorta descendens, *RLLA* right lower lobe pulmonary artery, *BW* body weight, *y* years, *d* days, *s/p* status post, *min* minutes, # not available

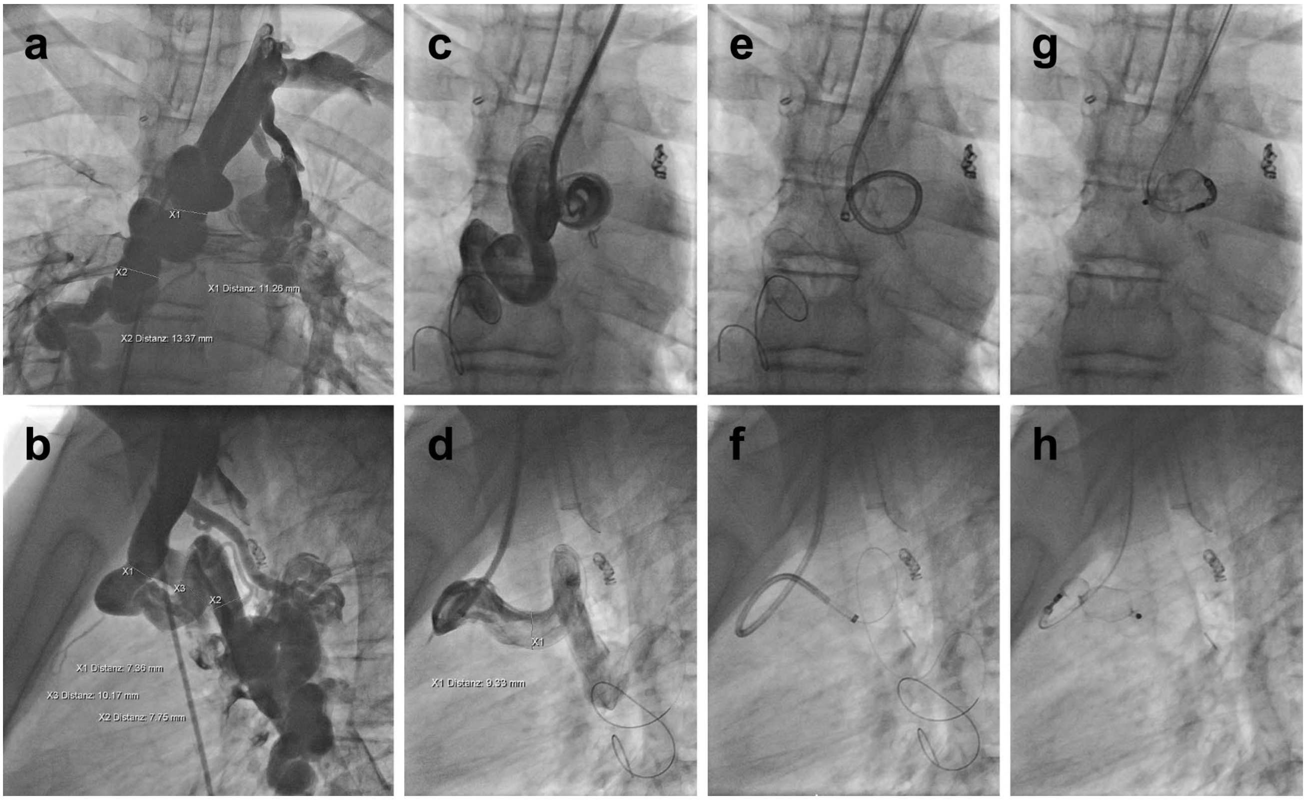

Fig. 1 (Upper panel p/a, bottom panel lateral view): Pigtail catheter support for AVP2 delivery in a patient aged 15 years (case 1, Table 3) with double inlet left ventricle (DILV), status post-stage III palliation. Angiography showing large decompressing veins arising from the innominate vein (**a/b**; online resource 1). Left jugular venous approach via a short 7 Fr sheath; selective injection into the largest collateral vein (diameter around 10 mm); floppy wire easily followed the very tortuous venous course (**c/d**; online resource 2). Initial attempts to advance a 5 Fr long sheath with its dilator on different 0.035 inch wires failed. Finally, the proximal vessel's sharp 270-to-360° loop was successfully probed with the 5 Fr long sheath simply supported by a 5 Fr pigtail catheter (ID 0.038 inch) serving as a curved reinforcement on the 0.016 inch floppy wire (**e/f**; online resource 3). Deployment of a 12-mm AVP2 (**g/h**; online resource 4 and 5)

ventricle group (58%), five patients presented status post-stage I, six post-stage II and the remaining 22 children had undergone stage III palliation. In those patients, the majority of occlusion procedures were indicated in venous collaterals with low-flow velocities. Most patients with biventricular physiology suffered from a PDA or aorto-pulmonary collaterals. Miscellaneous structures included an azygos vein aneurysm (AVA), an azygos-to-portal vein fistula, a pulmonary AVM and a systemico-to-pulmonary artery shunt. 17 patients underwent PDA occlusion (off-label use). On angiography, PDAs were classified as Krischenko type A in 5 (29%), type C in 4 (24%) and type E in 7 (41%) [6]. PDA occlusion was performed with the AVP2 in 15 of the 17 patients (88%) and only two atypical tubular PDAs were closed with the AVP4 (12%).

Discussion

The Amplatzer Vascular Plugs AVP2 and AVP4 are well-established for transcatheter closure of abnormal vessels in congenital heart disease (CHD). Both plugs are versatile, easy to use and effective in a variety of settings [3, 7–11]. The AVP2 is sometimes preferable to the AVP4 due to its shorter length, flat-profiled retention disks, and the availability of larger diameters (range 3–22 mm), but its profile demands a larger catheter lumen (ID) for delivery. The latter may actually hamper the occlusion of difficult-to-reach target lesions. In fact, AVP2 delivery was an issue in 10% of the patients in our series, strictly speaking, in 40% of those with curvy collaterals or atypical vascular

Heart and Vessels (2019) 34:134–140

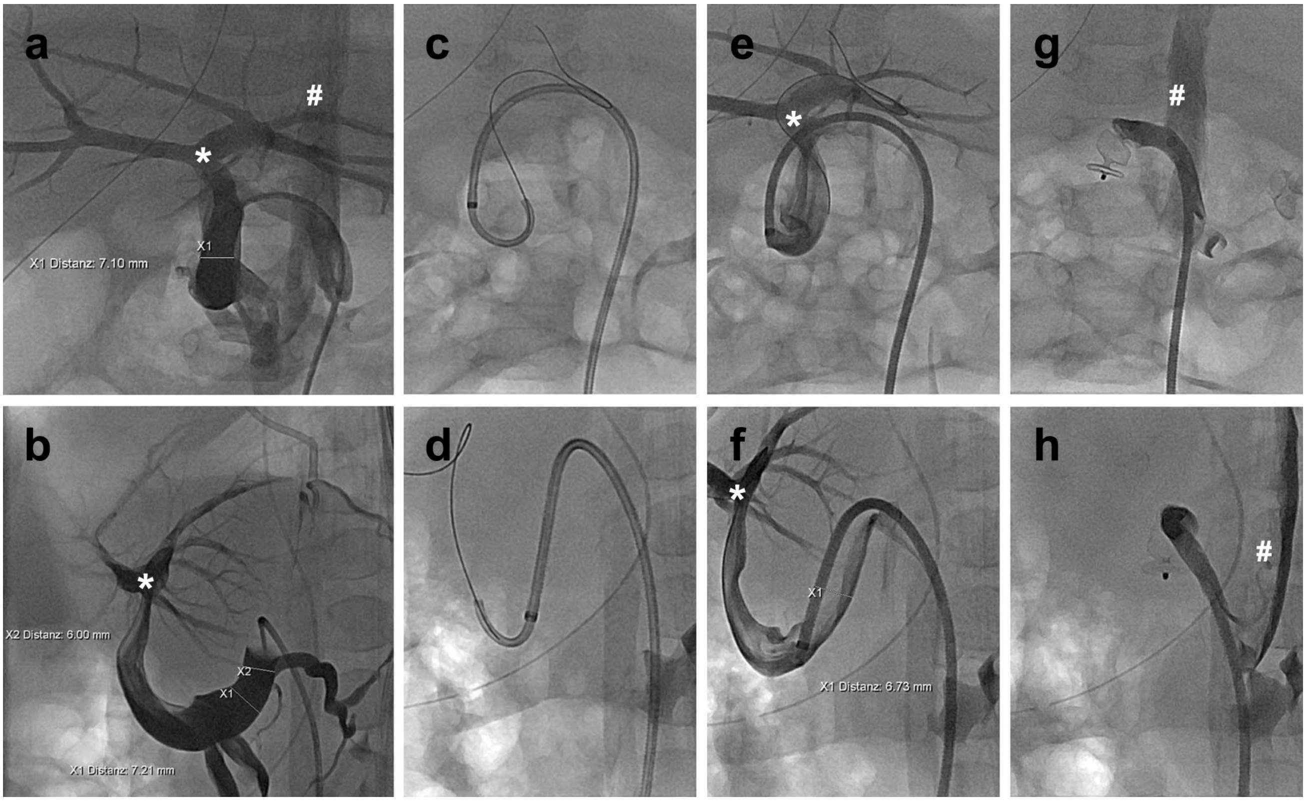

Fig. 2 (Upper panel p/a, bottom panel lateral view, *portal vein, #hemiazygos vein): Pigtail catheter support for AVP2 delivery in a patient aged 6 months (case 2, Table 3) with DORV with LV hypoplasia and PS, hemiazygos continuity to the left-sided superior vena cava and agenesis of the inferior vena cava; status post-stage I and failing stage II palliation (due to hypoxemia). Left femoral venous approach. Selective angiography showing a complex S-shaped venous connection (diameter around 6.7 mm) between the left-sided vena hemiazygos and the portal vein system (**a**/**b**). A 5 Fr pigtail catheter served as a curved reinforcement to guide a 5 Fr delivery sheath on a 0.016 inch floppy wire (**c**/**d**). Hand injections of contrast via the sheath's side port to identify a proper landing-zone (**e**/**f**). Final result after deployment of an 8 mm AVP2 (**g**/**h**)

connections. Conventional techniques had failed in those patients, yet our simplified pigtail approach always succeeded, which is why we consider it a promising alternative tool whenever a long sheath is required for device delivery.

The great advantage of our technique could be that only three components must work together (a floppy wire, a pigtail catheter, and a matching long sheath), making the procedure technically easier than other telescopic systems [12–14]. Brown et al. recommended a very effective

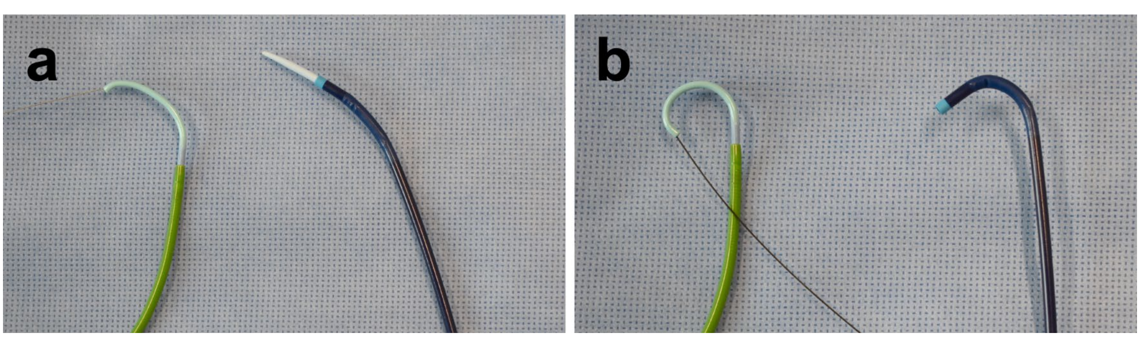

Fig. 3 Simplified telescope system on 0.016 floppy wire versus steerable guiding sheath. Of note, pigtail catheter's varying configuration depending on the floppy wire's location or probing depth. Tip deflections with the steerable sheath are not achievable until its (non-deflectable) dilator has been removed (**a**/**b**)

technique consisting of a floppy wire, a microcatheter, a diagnostic catheter, a cut-off guiding catheter and an introducer sheath, thus employing at least five to six components requiring close interaction [5]. Steerable guiding sheaths may also facilitate such a procedure. One of the latest generation is the Destino Twist (Oscor, Palm Harbor, FL), which is available in child-suitable sizes from 6.5 Fr onward [15]. However, tip deflections up to 180° can only be achieved once its (non-deflectable) dilator has been removed (Fig. 3).

Other potential alternatives are large-volume detachable coils with effective anchor properties and the highest possible packing density to form a plugging nest (options via http://www.angiocalc.com). Many of these coil systems are easily steerable through tortuous vessels via standard microcatheters (ID 0.021–0.027 inch) that slip through any diagnostic catheter (ID 0.035–0.038 inch) [16–18]. Coils are often ideal for sealing small to medium-sized collaterals; however, some of them also offer very large (secondary) diameters measuring up to 20 mm or even more. In turn, completely occluding larger vessels may require the deployment of multiple coils, and may subsequently result in longer fluoroscopy time, the increased use of contrast agents, and higher costs. The MVP microvascular plug system (Covidien, Medtronic, Minneapolis, MN) also passes microcatheters. This is a detachable nitinol skeleton plug partially covered by a polytetrafluoroethylene (PTFE) membrane. However, MVP's unconstrained length of 12 mm and diameter not exceeding 6.5 mm has limited its use so far [19–21].

In this series, more than 60% of the target vessels were high-flow lesions. We documented no device embolization, vascular disruption, or procedure-related complication. In our experience, the AVP4 is an ideal device for closing high-flow vascular (tubular) malformations due to its flexible grip not requiring much oversizing. Its properties render the AVP4 for use especially in pediatric patients. The AVP4 was thus the most commonly used (72% of all patients in our series). This observation is supported by previous reports [4, 22, 23]. However, the AVP4's use is limited to embolizing small- to moderate-sized vessels measuring 3–6 mm. Finally, its relatively long unconstrained length should be considered as a potential drawback in targets with a short landing zone.

To minimize the risk of residual shunting and AVP embolization, it is important to use 30–50% larger plugs with respect to the target vessel (as already recommended) [4, 7]. Our device-to-vessel ratio was a median 1.47 for AVP4 and 1.46 for AVP2, resulting in a primary occlusion rate of 64% for AVP4 and 97% for AVP2. This remarkable difference may be explained by the AVP's architecture: the AVP4 has a multi-layered, double-lobed design, whereas the AVP2 is multi-layered and multi-segmented, which enables faster vessel occlusion due to more wire mesh. Variable occlusion time remains a major shortcoming, especially large vessel size, full anticoagulation during catheterization, and high-flow-situations are factors that can prolong the occlusion time [7].

AVP2 off-label use for PDA closure has proved to be a valuable tool, even in preterm infants [24–28]. The AVP2 was used in our study in PDA types A, C, and E. Probing these PDAs and advancing the long sheaths needed for delivery were straightforward in all patients. We also confirm that AVP4 can be considered an efficient alternative for tubular (atypical) ducts closure in selected patients [26, 29]. Primary occlusion rates range from 87% [3] to 94% [11]. We achieved a primary occlusion rate of 93% for PDAs in our study.

Limitations

This is a small series with the limitations typical of a retrospective study, and our results should be judged with caution. For a statistically sound matching procedure, we had very few patients.

Conclusion

The AVP2 and AVP4 are flexible devices enabling the reliable occlusion of a large variety of different vascular malformations in CHD. Both devices proved to be effective and safe. A novel and simple technique using pigtail catheter support for long sheath delivery is presented to occlude even difficult-to-reach lesions in a very gentle and efficient manner.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest and do not have to disclose any agreements.

References

1. Feltes Timothy F, Bacha Emile, Beekman Robert H, Cheatham John P, Feinstein Jeffrey A, Gomes Antoinette S, Hijazi Ziyad M, Ing Frank F, Michael de Moor W, Morrow Robert, Mullins Charles E, Taubert Kathryn A, Zahn Evan M (2011) Indications for cardiac catheterization and intervention in pediatric cardiac disease: a scientific statement from the American Heart Association. Circulation 123(22):2607–2652
2. Porstmann W, Wierny L, Warnke H (1967) Closure of persistent ductus arteriosus without thoracotomy. Ger Med Mon 12(6):259–261
3. Schwartz M, Glatz AC, Rome JJ, Gillespie MJ (2010) The Amplatzer vascular plug and Amplatzer vascular plug II for

vascular occlusion procedures in 50 patients with congenital cardiovascular disease. Catheter Cardiovasc Interv 76(3):411–417
4. Wiegand G, Sieverding L, Bocksch W, Hofbeck M (2013) Transcatheter closure of abnormal vessels and arteriovenous fistulas with the Amplatzer vascular plug 4 in patients with congenital heart disease. Pediatr Cardiol 34(7):1668–1673
5. Brown SC, Boshoff DE, Eyskens B, Mertens L, Gewillig M (2009) Use of a microcatheter in a telescopic system to reach difficult targets in complex congenital heart disease. Catheter Cardiovasc Interv 73(5):676–681
6. Krichenko A, Benson LN, Burrows P, Moes CA, McLaughlin P, Freedom RM (1989) Angiographic classification of the isolated, persistently patent ductus arteriosus and implications for percutaneous catheter occlusion. Am J Cardiol 63(12):877–880
7. Wang W, Li H, Tam MD, Zhou D, Wang DX, Spain J (2012) The Amplatzer vascular plug: a review of the device and its clinical applications. Cardiovasc Interv Radiol 35(4):725–740
8. Ramakrishnan S (2015) Vascular plugs—a key companion to interventionists—'Just Plug it'. Indian Heart J 67(4):399–405
9. Barwad P, Ramakrishnan S, Kothari SS, Saxena A, Gupta SK, Juneja R, Gulati GS, Jagia P, Sharma S (2013) Amplatzer vascular plugs in congenital cardiovascular malformations. Ann Pediatr Cardiol 6(2):132–140
10. Fischer G, Apostolopoulou SC, Rammos S, Kiaffas M, Kramer HH (2007) Transcatheter closure of coronary arterial fistulas using the new Amplatzer vascular plug. Cardiol Young 17(3):283–287
11. Hill SL, Hijazi ZM, Hellenbrand WE, Cheatham JP (2006) Evaluation of the Amplatzer vascular plug for embolization of peripheral vascular malformations associated with congenital heart disease. Catheter Cardiovasc Interv 67(1):113–119
12. Butera G, Hassan E, MacDonald ST (2012) Telescopic catheter-in-long sheath and parallel to a stiff guide wire technique for complex pulmonary artery anatomy. Catheter Cardiovasc Interv 80(4):673–677
13. Zhu X, Tam MD, Pierce G, McLennan G, Sands MJ, Lieber MS, Wang W (2011) Utility of the Amplatzer vascular plug in splenic artery embolization: a comparison study with conventional coil technique. Cardiovasc Interv Radiol 34(3):522–531
14. De Santis A, Cifarelli A, Violini R (2010) Transcatheter closure of coronary artery fistula using the new Amplatzer vascular plug and a telescoping catheter technique. J Cardiovasc Med (Hagerstown) 11(8):605–609
15. Lange M, Bultel H, Weglage H, Loffeld P, Wichter T (2016) Using a steerable guiding sheath to implant an AMPLATZERAmulet Left Atrial Appendage Occluder for prevention of thromboembolic stroke. Int J Cardiol 221:466–467
16. Jambon E, Petitpierre F, Brizzi V, Dubuisson V, Le Bras Y, Grenier N, Cornelis F (2017) Proximal occlusion of medium-sized vessels with the penumbra occlusion device: a study of safety and efficacy. Cardiovasc Interv Radiol 40(2):210–215
17. Yu PS, Yu SC, Ng CT, Kwok MW, Chow SC, Ho JY, Underwood MJ, Wong RH (2016) Coil embolization of diverticulum of Kommerell: a targeted hybrid endovascular technique. Ann Thorac Surg 101(5):e139–e141
18. Fanning NF, Berentei Z, Brennan PR, Thornton J (2007) HydroCoil as an adjuvant to bare platinum coil treatment of 100 cerebral aneurysms. Neuroradiology 49(2):139–148
19. Conrad MB, Ishaque BM, Surman AM, Kerlan RK Jr, Hope MD, Dickey MA, Hetts SW, Wilson MW (2015) Intraprocedural safety and technical success of the MVP micro vascular plug for embolization of pulmonary arteriovenous malformations. J Vasc Interv Radiol 26(11):1735–1739
20. Boudjemline Y (2017) Covidien micro vascular plug in congenital heart diseases and vascular anomalies: a new kid on the block for premature babies and older patients. Catheter Cardiovasc Interv 89(1):114–119
21. Sathanandam S, Justino H, Waller BR 3rd, Gowda ST, Radtke W, Qureshi AM (2017) The medtronic micro vascular plug for vascular embolization in children with congenital heart diseases. J Interv Cardiol 30(2):177–184
22. MacDonald ST, Carminati M, Butera G (2011) Initial experience with the Amplatzer vascular plug IV in congenital heart disease: coronary artery fistula and aortopulmonary collateral artery embolization. J Invasive Cardiol 23(3):120–124
23. Adelmann R, Windfuhr A, Bennink G, Emmel M, Sreeram N (2011) Extended applications of the Amplatzer vascular plug IV in infants. Cardiol Young 21(2):178–181
24. Delaney JW, Fletcher SE (2013) Patent ductus arteriosus closure using the Amplatzer(R) vascular plug II for all anatomic variants. Catheter Cardiovasc Interv 81(5):820–824
25. Zahn EM, Nevin P, Simmons C, Garg R (2015) A novel technique for transcatheter patent ductus arteriosus closure in extremely preterm infants using commercially available technology. Catheter Cardiovasc Interv 85(2):240–248
26. Baruteau AE, Hascoet S, Baruteau J, Boudjemline Y, Lambert V, Angel CY, Belli E, Petit J, Pass R (2014) Transcatheter closure of patent ductus arteriosus: past, present and future. Arch Cardiovasc Dis 107(2):122–132
27. Philip R, Waller BR 3rd, Agrawal V, Wright D, Arevalo A, Zurakowski D, Sathanandam S (2016) Morphologic characterization of the patent ductus arteriosus in the premature infant and the choice of transcatheter occlusion device. Catheter Cardiovasc Interv 87(2):310–317
28. Garay FJ, Aguirre D, Cardenas L, Springmuller D, Heusser F (2015) Use of the amplatzer vascular plug II device to occlude different types of patent ductus arteriosus in pediatric patients. J Interv Cardiol 28(2):198–204
29. Baruteau AE, Lambert V, Riou JY, Angel CY, Belli E, Petit J (2015) Closure of tubular patent ductus arteriosus with the Amplatzer vascular plug IV: feasibility and safety. World J Pediatr Congenit Heart Surg 6(1):39–45