Particle embolization of systemic-to-pulmonary collateral artery networks in congenital heart disease: Technique and special considerations

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ABSTRACT

Systemic-to-pulmonary artery collateral networks commonly develop in patients with single-ventricle physiology and chronic hypoxemia. Although these networks augment pulmonary blood flow, much of the flow is ineffective and contributes to cardiac volume loading. This volume loading can have detrimental effects, especially for single-ventricle patients. Some data suggest that occluding collaterals may improve outcomes after subsequent operations, especially when the volume of collateral flow is significant. Traditional practice has been to coil occlude the feeding vessel. We perform particle embolization of these collateral networks for two primary reasons. First, access to the feeding vessel is not blocked as collaterals may redevelop. Second, particles occlude the most distal connections. Thus, embolization with particles should be considered as an alternative to coil occluding the proximal feeding vessel.

Keywords: Coil/device/transcatheter, congenital heart disease, embolization, pediatric intervention

INTRODUCTION

Systemic-to-pulmonary collateral (SPC) arteries develop in patients with chronic hypoxemia, single-ventricle physiology, and other forms of congenital heart disease.[1,2] The precise pathophysiologic mechanisms leading to SPC development are incompletely understood, with hypoxemia-induced angiogenic factors and abnormal pulmonary blood distribution hypothesized to be involved.[3-5] Given their origins from the systemic circulation, much of the SPC flow is ineffective (i.e., recirculating oxygenated blood back to the lungs). In some patients, notably those with single-ventricle physiology, this ineffective flow can lead to significant volume loading. Data have demonstrated adverse effects associated with significant SPC flow in single-ventricle patients.[6-8]

Given this clinical picture, many interventional cardiologists opt to occlude SPCs, most often during routine preoperative cardiac catheterizations.[9,10] A commonly performed technique is to occlude the feeding vessel (e.g., internal mammary artery) proximally with a thrombotic coil. However, SPCs often recur from the same feeding vessel. Although coiling is acutely effective, this technique can be problematic because it significantly restricts – if not prohibits – further access of that vessel. Another issue is that embolization is ideally performed as distally as possible to ensure all tributaries are occluded. Coil embolization is suboptimal in this regard as it only occludes the proximal feeder.

We perform particle embolization of SPC networks for two primary reasons related to the issues above. First, particle embolization does not obstruct access to the feeding vessel. Second, particles occlude the most distal connections. This manuscript describes our procedural

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technique and demonstrates safety and efficacy of the procedure.

CASES AND TECHNIQUE

Cases

Sophisticated methods of quantifying SPC flow have been elegantly described.[11-13] Our impression is that cardiac magnetic resonance imaging (MRI) is the test of choice to quantify SPC flow, but MRI is not utilized as a universal standard of practice. Rather, we assess SPC flow during catheterization, first surveilling with an aortic root angiogram and then confirming with a selective angiogram of the feeding vessel. Determination of SPC burden was based on a modification of the Spicer method.[8] That method graded SPCs into four groups; however, the first two groups did not have opacification of the branch pulmonary arteries (PA). Similar to McElhinney *et al.*, we argue that PA opacification is necessary to be sure of connections to the PAs.[14] Hence, we defined SPC burden as mild if only the segmental PA branches opacified, moderate if the proximal PA (i.e., right pulmonary artery or left pulmonary artery) opacified, and severe if contrast refluxed back into the main pulmonary artery (MPA)/contralateral PA. To ensure reliable comparison before and after occlusion, SPC burden was based on angiographic assessment of a selective arteriogram, injecting 0.25 mL/kg of contrast over 1 s into the feeding vessel. The same criteria and angiographic technique were utilized to assess residual SPC burden after embolization.

We reviewed our institutional practice from August 2013 to June 2016. During this time, we performed particle embolization during 42 catheterizations on 34 patients. Table 1 outlines details of the cohort. The majority were performed on single-ventricle patients. Among the others, one patient had a "one-and-a-half ventricle repair" with a Yasui procedure and Glenn, one had repaired ventricular septal defect (VSD) and coarctation with MPA obstruction, and the last was a child born prematurely presenting for patent ductus arteriosus (PDA) occlusion and found to have significant SPCs during the procedure. The majority of catheterizations were routine preoperative evaluations. Among the others, a few were for hemoptysis, one patient had worsening ventricular dysfunction of unclear etiology, one had multiple postoperative effusions, and the other was to occlude a PDA as above. Among preoperative patients, particle embolization was performed within 7 weeks of surgery.

Once identified, we performed SPC occlusion during the same procedure. No cases had macrovascular SPCs or other concern that particles would embolize systemically. There was a statistically significant reduction in SPC burden, with complete occlusion in the majority of cases ($P = 0.01$); only three patients had residual SPCs – all mild; one had initially moderate and two had initially severe SPC flow [Table 1]. No patients had evidence of systemic embolization of particles immediately after or during follow-up. Patients were specifically screened for neurocognitive deficits, paresthesias, distal extremity pain/pallor/weakness, and vision changes every 4 h during the postcatheterization observation period; these issues were routinely assessed during subsequent cardiology encounters.

Table 1: Demographic and procedural characteristics of cohort

Catheterizations	42
Patients	34
Sex (%)	
Male	21 (62)
Female	13 (38)
Age (months)	35.5 (3.7-125)
Weight (kg)	10.1 (4.3-26.2)
Qp: Qs	0.9 (0.5-1.8)
$PVR_{indexed}$	1.3 (0.5-1.7)
Diagnoses (%)	
Single ventricle	39 (93)
Stage 1	14 (36)†
Glenn	20 (51)†
Fontan	5 (13)†
1½ and two ventricle	3 (7)
Catheterization indication (%)	
Preoperative	33 (79)
Hemoptysis	4 (10)
Other	5 (11)
Baseline SPC burden (%)	
Mild	21 (50)
Moderate	19 (45)
Severe	2 (5)
Residual SPC burden* (%)	
None	39 (93)
Mild	3 (7)
Collaterals embolized	1.5 (1-3)
Systemic saturations (%)	
Preembolization	83 (64-91)
Postembolization	81 (64-87)

Data presented as frequency (%) or median (range). †Reported percentages among the single-ventricle subset, *Reduction in SPC flow among the cohort was statistically significant (P=0.01). Qp: Qs: Pulmonary-to-systemic flow ratio, PVR: Pulmonary vascular resistance, SPC: Systemic-to-pulmonary collateral

Technique

Multiple agents are available to occlude SPCs [Table 2]. As mentioned, thrombotic coils are commonly used. Two common particle types are polyvinyl alcohol (PVA) and tris-acryl gelatin microspheres (TAGM). PVA particles are available in a range of sizes while TAGM are precisely calibrated spheres. We are unaware of any data to suggest one type of particle is superior to another in terms of safety or efficacy.[15] Our institution carries PVA embolization particles, which we deliver through a coaxial catheter system to control particle delivery and optimize safety.[16] A mapped image of the feeding vessel and SPC network is first saved as a

Table 2: Particle occlusion agents

Agent type	Characteristics	Embolization considerations
Particulate		
Polyvinyl alcohol microparticles	Irregular shape, packaged in a size range (e.g., 500-710 μ)	Require periodic "agitation" to remain in suspension
Tris-acryl gelatin microparticles	Precisely calibrated microspheres	Care taken if/when agitating; agitation may disrupt particle shape
Liquid		
N-butyl cyanoacrylate glue; ethylene vinyl alcohol	Liquid composition; do not depend on patients' coagulation system	Considered more difficult to control; may be more likely to reflux back - with unintentional embolization - given liquid properties

reference. All embolization equipment is prepared on a separate table, and the catheterization table is covered with additional sterile towels to lie under the delivery catheters, ensuring that all occluding equipment and particles can be easily contained and removed after embolization is complete. The feeding vessel is then engaged with a 4-French (Fr) catheter; we prefer the 4Fr Impress® Vertebral catheter (Merit Medical™, South Jordan, UT, USA) because of its large internal diameter (0.038"), soft radiopaque tip which allows for deep engagement into the feeding vessel, and torque characteristics. Depending on patient size, the tip is advanced 1–3 cm into the feeding vessel, based on the mapped reference image. A hemostatic y-adapter is placed on this "guiding" vertebral catheter, to limit blood loss. A floppy microcatheter is then advanced through the guiding vertebral catheter, placing its tip at the level of the deepest SPC origins. We prefer the 2.5Fr Cantata® microcatheter (Cook™, Bloomington, IN USA). A 3-way stopcock is attached to the microcatheter [Figure 1].

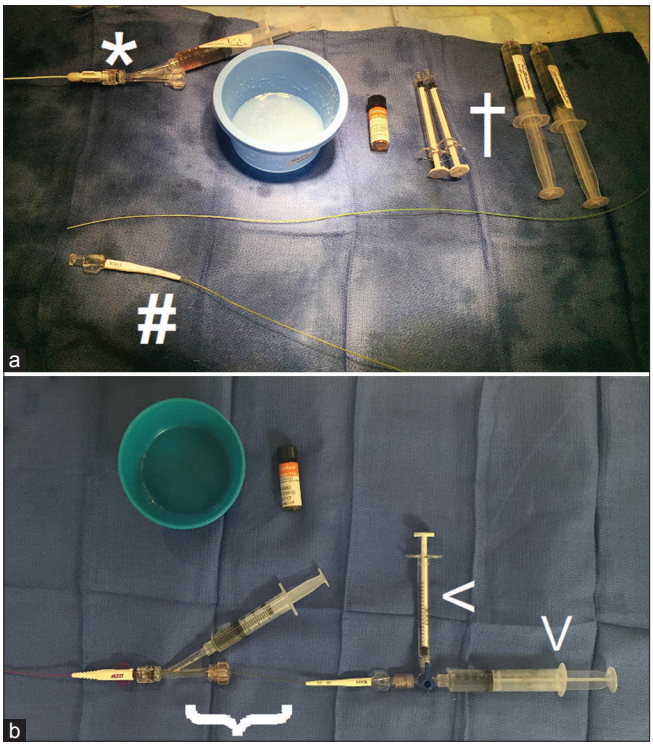

Figure 1: Particle occlusion equipment. (a) The equipment is separate. A hemostatic adapter has been attached to the 4Fr guiding catheter (*). The microcatheter (#) is ready to be inserted through the guiding catheter and into the distal feeding vessel. Ten-milliliter "reservoir" and 1 mL injector syringes are available and clearly marked (†). (b) The microcatheter is coaxially loaded into the guiding catheter ({). A 3-way stopcock is affixed to the microcatheter with the reservoir and injector syringes attached (arrowheads). Note the new sterile towels under the delivery system.

We next prepare the particle slurry using Contour® PVA particles (Boston Scientific™, Marlborough, MA USA). We utilize 500–710 micron particles based on the work of Srivastava *et al.*, who demonstrated mildly dilated terminal respiratory and bronchiolar arteries in histologic specimens of SPCs in single-ventricle patients s/p Fontan (median diameter 160 μm). The 500–710 micron particles allow distal occlusion while remaining confident they will not pass through into the systemic circulation.[17] The contrast:saline ratio of the injectate is important; the ideal injectate has a density to promote particle suspension, is adequately visualized under fluoroscopy, and is easily administered. An overly viscous injectate is easy to visualize but prone to particle clumping which clogs the delivery microcatheter. Conversely, an overly dilute injectate will be easier to deliver but is less visible and allows particles to float out of suspension. We mix one vial of particles with 15 mL of contrast and 2–3 mL of saline flush. We stock Omnipaque™ contrast (Novaplus®, GE Healthcare, Buckinghamshire, UK) which has worked well though we have no specific rationale for its use with embolization.

The injectate is mixed thoroughly and drawn into a 10 mL "reservoir" syringe. The reservoir syringe is inspected to ensure the particles are in suspension and not forming aggregates, sinking, or floating. The reservoir syringe is then secured to the right port of the 3-way stopcock, opposite the microcatheter. An empty 1 mL syringe is secured to the top-facing port. We use the 1 mL syringe included with the Cantata microcatheter as this syringe's plunger is well secured. The injectate is then vigorously mixed between the two syringes and during each reload of the delivery syringe to maintain particles in suspension.

The injectate is delivered cautiously and is continuously monitored through fluoroscopy. We periodically stop, approximately every minute, to visualize the injectate

through the transparent portions of the catheter system (e.g., 3-way stopcock, hemostatic adapter, etc.) to ensure particles are not clumping. During injection, flow through the SPC network will become sluggish and then stop. Particle delivery is halted when the injectate refluxes back to the tip of the guiding catheter. Further injection will potentially backflow into the source vessel (e.g., subclavian artery) and systemic vasculature with complications including tissue ischemia, infarction, and stroke.

Once flow ceases through the SPCs, the microcatheter is removed and covered with the additional sterile towels. A follow-up hand injection (0.25 mL/kg over 1 s) is performed through the guiding catheter to assess residual SPC burden. Both the operator and assistant change gloves if an additional SPC network is occluded to prevent inadvertent systemic injection of loose particles. Table 3 provides highlights of the technique.

DISCUSSION

SPCs commonly develop in single-ventricle patients, and data have demonstrated an association between significant SPC burden and prolonged effusions and hospital length of stay after congenital heart surgery.[18,19] Older studies, prior to new quantification techniques, failed to demonstrate an association between SPC flow and post-Fontan outcomes.[20,21] However, new MRI data demonstrate a strong association with improved post-Fontan outcomes when significant SPC burdens have been embolized.[22] Moreover, a strongly inverse relationship has been noted between cerebral blood flow and SPC flow, making effective occlusion of these collateral networks important.[23]

Thrombotic coil occlusion has been a common method to occlude SPCs.[24] SPCs tend to arise from normal feeding vessels (e.g., the internal mammary and intercostal arteries), and coil embolization occludes those feeding vessels proximally. However, SPCs often recur. Bradley *et al.* noted that patients who underwent SPC occlusion more than 2 months before surgery tended to have higher SPC flow at the time of surgery than patients who had not undergone preoperative SPC occlusion at all.[21] Similarly, Prakash *et al.* noted higher SPC flow in pre-Fontan patients who had undergone SPC occlusion compared to those who had not.[20] Therefore, coil occlusion can be problematic when SPCs reconstitute by impeding reaccess to the feeding vessel [Figure 2a]. Delivery of PVA particles through a coaxial system does not incur this issue with reaccess; in fact, the technique can allow for successful embolization of reconstituted SPCs when the feeder has been blocked by a coil [Figure 2b and c]. The coaxial delivery system also allows selective engagement of complex SPC networks, with multiple SPC branches arising from a single feeding vessel [Figure 3].

Table 3: Highlights of particle embolization

Timing	Considerations
Pre-procedure	
Equipment	Guiding catheter (e.g. 4 Fr vertebral), microcatheter for delivery, 3-way stop-cock to maintain particles in suspension (see Figures)
Particles	No data to suggest superiority; common choices are irregular vs. microspheres, PVA vs. TAGM (see Table 2).
Intra-procedure	Use 0.25 mL/kg over 1 second hand injections to define collateral burden
	Beware of vertebral and carotid arteries when occluding branches off the subclavian arteries
	Beware of the Artery of Adamkiewisc when occluding intercostal arteries
	Prepare particles on a back table. Cover the area of catheterization table under the embolization catheters-if possible-to prevent contamination of table with stray particles; consider changing gloves when occluding more than one collateral source
	Ensure the guiding catheter is at least 1-3 cm deep into the feeding artery
	Ensure the microcatheter is deep in the feeding vessel
	Inject particles slowly and stop when contrast refluxes to tip of guiding catheter; do not reflux particles into the central artery
Post-procedure	Monitor for signs of systemic embolization
	Monitor saturations

PVA: Polyvinyl alcohol, TAGM: Tris-acryl gelatin microspheres

A few additional safety issues warrant discussion. Given their size, PVA particles can potentially embolize systemically. Systemic embolization is never desirable and embolization into a vessel supplying central nervous tissue can be devastating. The vertebral and internal carotid arteries are obvious vessels to avoid. This is one reason we prefer the Impress vertebral catheter because its flexible tip allows for deep engagement of the feeding vessel. Another critical vessel is the great anterior radiculomedullary artery, also known as the "artery of Adamkiewicz."[25] It is the most important feeding artery of the thoracolumbar spinal cord; inadvertent embolization of this artery can result in spinal cord ischemia and paraplegia. The artery can arise from any intercostal artery, so preembolization angiograms surveilling for its source are especially important before embolization of intercostal arteries.

Limitations

The primary intent of our manuscript is to describe our technique of particle occlusion and demonstrate that the procedure is safe and effective. No true comparison with other methods was performed, so more detailed studies are needed to test hypotheses regarding the superiority of a technique. The data presented are also retrospective.

CONCLUSIONS

We describe our technique to embolize SPCs using PVA particles. Although further studies are needed, we believe

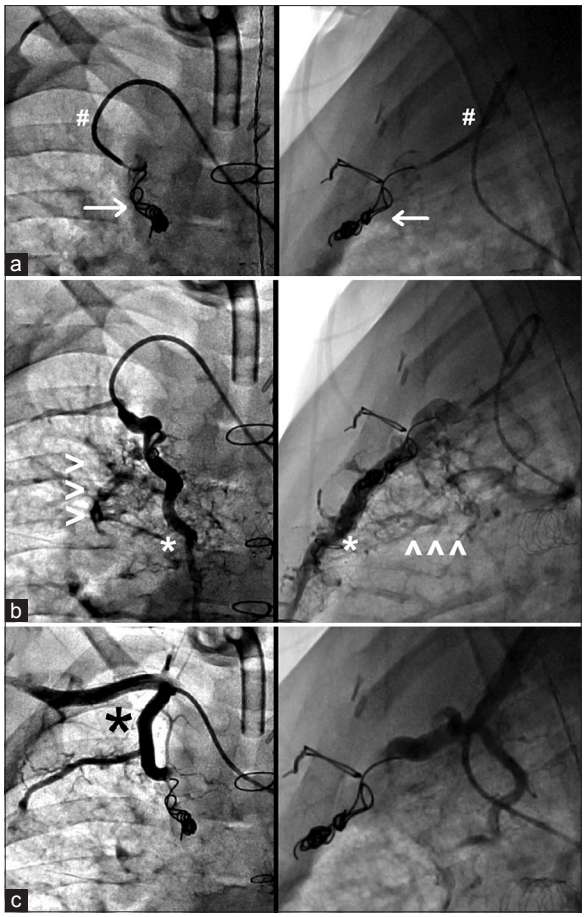

Figure 2: Angiograms, anteroposterior (left panels) and lateral (right panels) projections, depicting reconstituted systemic-to-pulmonary collaterals after coil embolization of the feeding vessel. (a) The guiding catheter tip is in the internal mammary artery (#), note the multiple coils (arrow) in the mid-internal mammary artery. (b) The internal mammary artery distal to the coils has reconstituted (*) and gives rise to multiple systemic-to-pulmonary collateral networks (arrowheads). (c) Postparticle injection demonstrates no residual systemic-to-pulmonary collateral flow with a patent internal mammary artery origin (*)

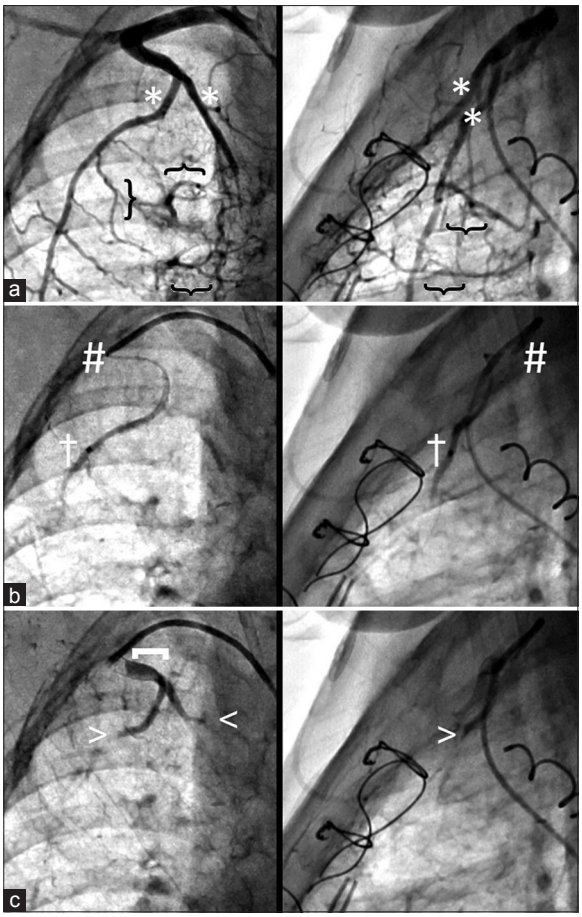

Figure 3: Angiograms, anteroposterior (left panels) and lateral (right panels) projections, depicting occlusion of "complex" systemic-to-pulmonary collaterals. (a) Injection through the 4Fr guiding catheter with its tip (obscured by contrast) in the proximal internal mammary artery, note the two large branches (*) of the internal mammary artery which give rise to multiple systemic-to-pulmonary collateral networks (}). (b) The two large feeding branches are selectively engaged with the microcatheter for precise particle delivery (†), the guiding catheter tip remains in the proximal internal mammary artery as a landmark (#). (c) Postparticle injection demonstrates no residual systemic-to-pulmonary collateral flow (arrowheads) with a patent internal mammary artery origin ([)

that particle embolization should be considered as an alternative to coil occluding proximal feeding vessels. Our data demonstrate that particle embolization is effective. And, the technique leaves the feeding vessel patent for subsequent embolization if SPCs recur, a unique benefit in select cases such as recurrent hemoptysis.

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Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Triedman JK, Bridges ND, Mayer JE Jr., Lock JE. Prevalence and risk factors for aortopulmonary collateral vessels after fontan and bidirectional Glenn procedures. J Am Coll Cardiol 1993;22:207-15.
2. Tadavarthy SM, Klugman J, Castaneda-Zuniga WR, Nath PH, Amplatz K. Systemic-to-pulmonary collaterals in pathological states: A review. Radiology 1982;144:55-9.
3. Starnes SL, Duncan BW, Kneebone JM, Rosenthal GL, Patterson K, Fraga CH, *et al.* Angiogenic proteins in the lungs of children after cavopulmonary anastomosis. J Thorac Cardiovasc Surg 2001;122:518-23.
4. Mori Y, Shoji M, Nakanishi T, Fujii T, Nakazawa M. Elevated vascular endothelial growth factor levels are associated with aortopulmonary collateral vessels in patients before and after the Fontan procedure. Am Heart J 2007;153:987-94.
5. Powell AJ. Aortopulmonary collaterals in single-ventricle congenital heart disease: How much do they count? Circ Cardiovasc Imaging 2009;2:171-3.

6. Lamberti JJ, Mainwaring RD, Spicer RL, Uzark KC, Moore JW. Factors influencing perioperative morbidity during palliation of the univentricular heart. Ann Thorac Surg 1995;60:S550-3.
7. Kanter KR, Vincent RN, Raviele AA. Importance of acquired systemic-to-pulmonary collaterals in the fontan operation. Ann Thorac Surg 1999;68:969-74.
8. Spicer RL, Uzark KC, Moore JW, Mainwaring RD, Lamberti JJ. Aortopulmonary collateral vessels and prolonged pleural effusions after modified Fontan procedures. Am Heart J 1996;131:1164-8.
9. Kanter KR, Vincent RN. Management of aortopulmonary collateral arteries in fontan patients: Occlusion improves clinical outcome. Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu 2002;5:48-54.
10. Stern HJ. Aggressive coiling of aortopulmonary collaterals in single-ventricle patients is warranted. Pediatr Cardiol 2010;31:449-53.
11. Downing TE, Whitehead KK, Dori Y, Gillespie MJ, Harris MA, Fogel MA, *et al.* Accuracy of conventional oximetry for flow estimation in patients with superior cavopulmonary connection: A comparison with phase-contrast cardiac MRI. Circ Cardiovasc Imaging 2013;6:943-9.
12. Whitehead KK, Sundareswaran KS, Parks WJ, Harris MA, Yoganathan AP, Fogel MA, *et al.* Blood flow distribution in a large series of patients having the Fontan operation: A cardiac magnetic resonance velocity mapping study. J Thorac Cardiovasc Surg 2009;138:96-102.
13. Prakash A. Significance of systemic to pulmonary artery collaterals in single ventricle physiology: New insights from CMR imaging. Heart 2012;98:897-9.
14. McElhinney DB, Reddy VM, Tworetzky W, Petrossian E, Hanley FL, Moore P, *et al.* Incidence and implications of systemic to pulmonary collaterals after bidirectional cavopulmonary anastomosis. Ann Thorac Surg 2000;69:1222-8.
15. Medsinge A, Zajko A, Orons P, Amesur N, Santos E. A case-based approach to common embolization agents used in vascular interventional radiology. AJR Am J Roentgenol 2014;203:699-708.
16. Brown SC, Boshoff DE, Eyskens B, Mertens L, Gewillig M. Use of a microcatheter in a telescopic system to reach difficult targets in complex congenital heart disease. Catheter Cardiovasc Interv 2009;73:676-81.
17. Srivastava D, Preminger T, Lock JE, Mandell V, Keane JF, Mayer JE Jr, *et al.* Hepatic venous blood and the development of pulmonary arteriovenous malformations in congenital heart disease. Circulation 1995;92:1217-22.
18. Grosse-Wortmann L, Drolet C, Dragulescu A, Kotani Y, Chaturvedi R, Lee KJ, *et al.* Aortopulmonary collateral flow volume affects early postoperative outcome after fontan completion: A multimodality study. J Thorac Cardiovasc Surg 2012;144:1329-36.
19. Odenwald T, Quail MA, Giardini A, Khambadkone S, Hughes M, Tann O, *et al.* Systemic to pulmonary collateral blood flow influences early outcomes following the total cavopulmonary connection. Heart 2012;98:934-40.
20. Prakash A, Rathod RH, Powell AJ, McElhinney DB, Banka P, Geva T, *et al.* Relation of systemic-to-pulmonary artery collateral flow in single ventricle physiology to palliative stage and clinical status. Am J Cardiol 2012;109:1038-45.
21. Bradley SM, McCall MM, Sistino JJ, Radtke WA. Aortopulmonary collateral flow in the fontan patient: Does it matter? Ann Thorac Surg 2001;72:408-15.
22. Glatz AC, Rome JJ, Small AJ, Gillespie MJ, Dori Y, Harris MA, *et al.* Systemic-to-pulmonary collateral flow, as measured by cardiac magnetic resonance imaging, is associated with acute post-fontan clinical outcomes. Circ Cardiovasc Imaging 2012;5:218-25.
23. Fogel MA, Li C, Wilson F, Pawlowski T, Nicolson SC, Montenegro LM, *et al.* Relationship of cerebral blood flow to aortic-to-pulmonary collateral/shunt flow in single ventricles. Heart 2015;101:1325-31.
24. Perry SB, Radtke W, Fellows KE, Keane JF, Lock JE. Coil embolization to occlude aortopulmonary collateral vessels and shunts in patients with congenital heart disease. J Am Coll Cardiol 1989;13:100-8.
25. Yoshioka K, Niinuma H, Ehara S, Nakajima T, Nakamura M, Kawazoe K, *et al.* MR angiography and CT angiography of the artery of Adamkiewicz: State of the art. Radiographics 2006;26 Suppl 1:S63-73.