Review Article

Catheter interventional closure of veno-venous collaterals in cyanotic patients after partial cavopulmonary shunts in pediatric patients: clinical practice review

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Abstract: The development of veno-venous collaterals is an important and treatable cause of cyanosis in patients who had undergone partial cavo-pulmonary connection (PCPC) operations. Nevertheless, the literature on this complicated therapeutic option is sparse. Patients can present cyanosis either immediately after the operation (<30 days), which delays or hinders discharge from the intensive care unit or cyanosis may occur late: (>30 days and/or in another hospital admission), after the operation. Hence, transcatheter closure of veno-venous collaterals is the treatment of choice. Four patients were selected who showed cyanosis at variable durations after PCPC; the morphology of the collaterals and their hemodynamic effect was described and the strategy for closure of such abnormal vessels is suggested. Veno-venous collaterals described in our series were seen originating mainly or mostly from innominate vein angles. The drainage sites were either above the diaphragm into a cardiac structure: the coronary sinus (CS) and/or atria; or below the diaphragm into the inferior vena cava (IVC) or hepatic veins through the paravertebral venous system and/or the azygous system. It is stated in the literature that several types of devices and coils can be used to close the collaterals such as the Amplatzer vascular plugs (AVPs), Amplatzer duct occluder II (ADOII), non-detachable and detachable coils. In this clinical review, the technical details that determine device type and size are explained. The recent generations of hydrogel-coated coils were also used in this series of patients to close the difficult types of collaterals with better results. All described vessels were closed successfully, without any complications. The patients had a significant rise in their transcutaneous oxygen saturations and hence, a clear clinical benefit.

Keywords: Veno-venous collaterals; cyanosis; partial cavo-pulmonary connection (PCPC); Amplatzer vascular plug (AVP); hydrogel-coated coils

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Introduction

Background

Veno-venous collaterals frequently occur after partial cavopulmonary connection (PCPC) for surgical palliation of patients with functionally univentricular hearts (UVH) (1), with a reported incidence that varies from 17% to as high as 31% (2). Veno-venous collaterals decrease the arterial oxygen saturation in such patients and may worsen the outcome (3). Hence, early treatment is mandatory (4). Transcatheter closure of veno-venous collaterals and fistulas is the treatment of choice, especially since nowadays a wide variety of devices and other closure materials are available to safely and effectively close those abnormal vessels (5). Moreover, there are also institutional preferences for certain devices and techniques based on individual center's experience.

Rationale and knowledge gap

Although it is mentioned in the literature that several devices and coils can be used safely and effectively to close such venous collaterals, there are several technical details that determine the type and size of the closure material that need to be addressed. In recent years, hydrogel coils are used more widely in such interventions, but reports about their safety and efficacy in comparison to traditional coils are still lacking. Furthermore, cavopulmonary shunts mirror a frail hemodynamic state. Every other procedure to improve hemodynamics [pulmonary artery (PA)-stenting, coarctation of the aorta (CoA)-stenting, closure of aortopulmonary (AP) collaterals] should be considered and if indicated preformed at the same catheterization.

Objectives

We aimed to discuss a series of patients who had closure of veno-venous collaterals found after PCPC operation in our center. This is to show the anatomical variations, hemodynamic effects of veno-venous collaterals and their impact on the clinical outcome of patients after PCPC operation. Furthermore, to explain in details the indications and techniques of closure based on the institutional strategy as well as the broad guidelines of management.

Cases presentation

Single-ventricle physiology includes all patients with congenital heart disease in whom a biventricular surgical repair is not possible and in whom stepwise palliation surgeries end in separation of the systemic and pulmonary circulation after the Fontan principle (total cavopulmonary connection; TCPC) (6). PCPC represents an intermediate step that in our center is performed at the age of 3 to 6 months, aiming for TCPC completion at the age of 18–24 months. After a successful PCPC operation, an arterial oxygen saturation of 85% is considered to be optimal. However, a considerable number of patients may present severe cyanosis (1), which mandates diagnostic/therapeutic catheterization (4). In the early post operative period after PCPC, these patients cannot be weaned off oxygen inhalation and, hence, cannot be discharged from the hospital. The diagnosis of veno-venous collaterals is suspected when the oxygen saturation is impaired (7), and can be confirmed by an ultrasound bubble test (8). Transcatheter closure of veno-venous collaterals, which develops in post-PCPC patients, is the treatment of choice and may be considered as a life-saving maneuver in cases presenting severe cyanosis. Accordingly, four patients were selected based on the timing of cardiac catheterization to explain our strategy for management of veno-venous collaterals that develop after variable durations after PCPC operation. The first patient was catheterized for cyanosis, early after PCPC, and could not be discharged from the hospital. The second patient had cyanosis after one month, while the last two patients were catheterized at several occasions after PCPC because of persistent and/or recurrent cyanosis. All our described patients were treated successfully without complications using a wide range of different occlusive devices. Oxygen saturation increased significantly and the clinical fate of the patients was improved.

Patient 1*: *Early post operative treatment (<30 d post PCPC)

A 5-month-old male patient (6.5 kg) needed treatment for persistent cyanosis and oxygen dependency two weeks following a PCPC operation. His post operative course was also complicated by infarction of the right middle cerebral artery. Originally, he had double inlet left ventricle, discordant ventriculoarterial connection, CoA, hypoplastic aortic arch and an open ductus under prostaglandin E infusion (PGE). At the second week of life a Norwood operation with right-sided modified Blalock Taussig (mBT) shunt 3.5 mm had been performed and the shunt was stented with a coronary stent one month later. At the age of 3 months, a re-CoA was treated with a percutaneous stent. At catheterization the superior vena cava (SVC) pressure was

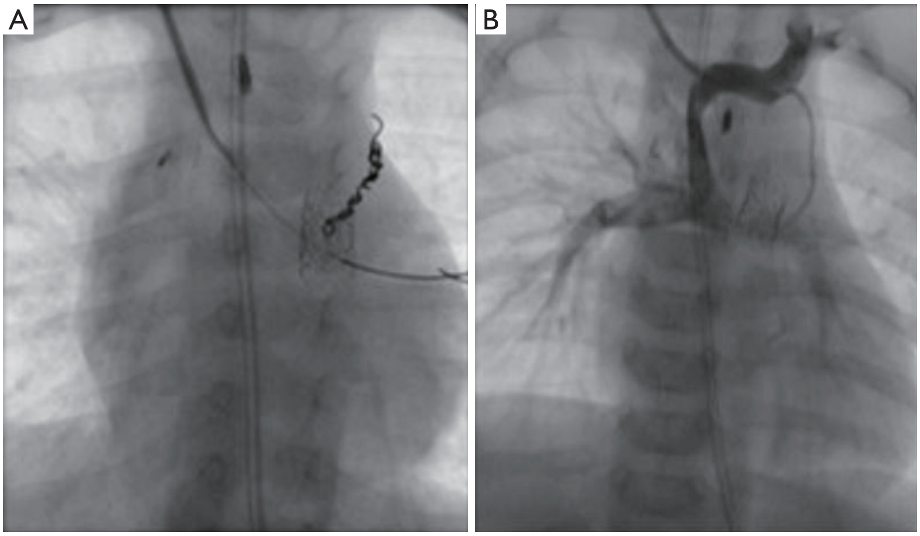

Figure 1 Angiograms showing successful closure of a hemodynamically significant veno-venous fistula draining into cardiac structures. (A) Antero-posterior view showing the morphology of the fistula (recanalized LPSVC) draining into the right atrium and coronary sinus. (B) Antero-posterior view after closure of the fistula using a detachable Azur CX micro-coil. LPSVC, left persistent superior vena cava.

11 mmHg mean, with a trans-pulmonary gradient (TPG) of 4 mmHg. The saturation of the pulmonary venous blood was 100%, aortic blood saturation under oxygen was 84%, and 60% without oxygen. At contrast injection into the innominate vein a re-canalized left persistent superior vena cava (LPSVC) with a diameter of 1–2 mm was seen draining into the coronary sinus and the right atrium (*Figure 1A*). Additionally, a severe left pulmonary artery (LPA) stenosis was present which was later stented with a bare metal stent. Through the 4-F sheath in the right jugular vein (RJV), a 4-F catheter was placed into the innominate vein and the LPSVC was entered with a micro-catheter (Progreat, Terumo, Tokyo, Japan). The vessel was then closed with one detachable Azur 0.018 CX microcoil 3 mm × 8 cm (Terumo) (*Figure 1B*). Four days later the patient was discharged home with a trans-cutaneous SaO_2 of 88% in room air.

Patient 2: *Late post-operative treatment (>30 d post PCPC)*

A male patient (4 months, 4.9 kg) one month after PCPC could not be weaned of oxygen treatment. His diagnosis was: atrioventricular (AV) and ventriculoatrial (VA) discordance (congenitally corrected transposition of the great arteries; cc-TGA), hypoplastic left ventricular (LV) (severe mitral stenosis), pulmonary atresia. The first operation was a right sided (mBT) shunt performed on the 8th day of life together with atrioseptectomy. A PCPC and LPA patch was performed one month ago. Now the transcutaneous arterial oxygen saturation was 77% under oxygen. At catheterization pressures were as follow: SVC pressure was 12, TPG was 3, and left ventricular end diastolic pressure (LVEDP) was 9 mmHg. Injection into the SVC revealed a veno-venous fistula measuring around 2–3 mm arising from the innominate vein angel going to the paravertebral venous system (*Figure 2A*). After venous access at the RJV (4-F) was achieved a 4-F catheter was advanced into the innominate vein. From there the collateral was entered with a 2.4-F Progreat microcatheter. Three non-detachable microcoils (Tornado 4×3 mm; Cook Europe, Limerick, Ireland) were deployed and the collateral was closed completely (*Figure 2B*). The transcutaneous oxygen saturation rose to 85% without oxygen and the patient was discharged home 2 days after the catheter intervention.

Patient 3: *Complex cyanotic patient with persistent (>2 months) cyanosis post PCPC*

A male patient was born with dextrocardia, lung sequester (lower part of the right lung), tricuspid atresia Ic [large ventricular septal defect (VSD)], and atrial septal defect (ASD) II. At one month of age a right mBT shunt 3.5 mm was performed with dissection of the main PA. One month later the sequester feeding artery to the right lung was closed with several coils. At the age of 4 months, a PCPC

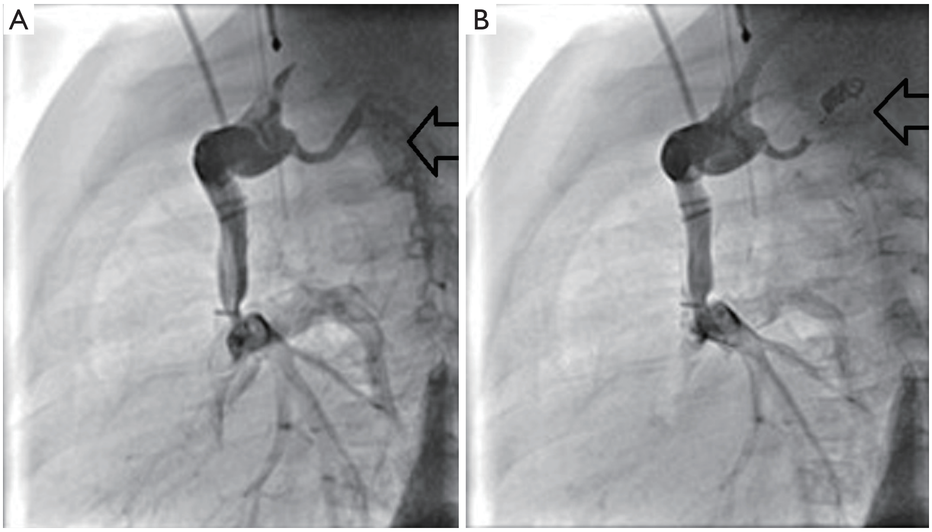

Figure 2 Angiograms showing successful closure of a hemodynamically significant veno-venous fistula from the innominate vein angel to the paravertebral venous system draining to the lower body half. (A) Lateral view showing the exact morphology of the fistula (arrow). (B) Lateral view after closure of the fistula by three non-detachable Tornado micro-coils (arrow).

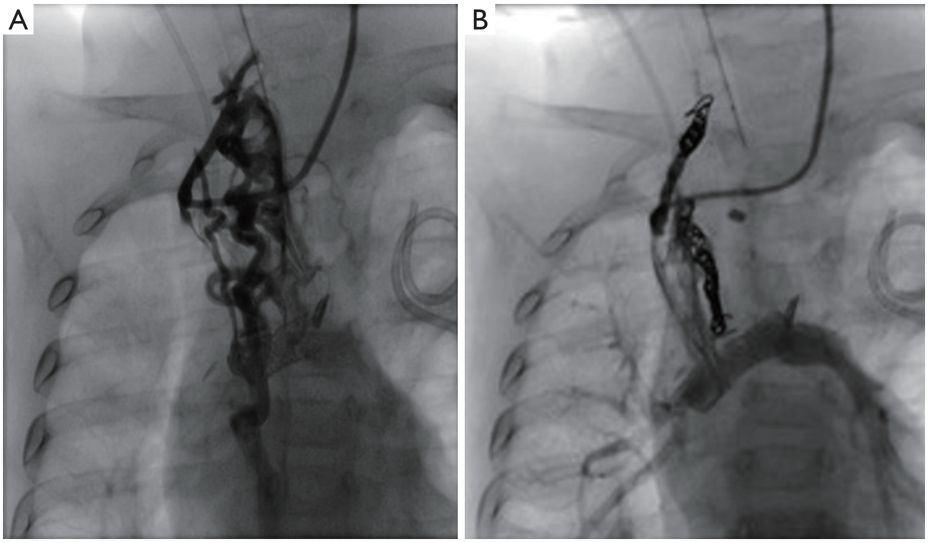

Figure 3 Angiograms showing successful closure of multiple veno-venous fistulas from the SVC to the paravertebral system. (A) Antero-posterior view showing the morphology of the fistulas. (B) Antero-posterior view after closure of the fistulas with a microplug and Azur CX coils. SVC, superior vena cava.

was performed followed by a stent implantation into the LPA. The patient was on long-term ventilation with very low arterial oxygen saturation (<66%) and repeated pneumothoraces despite high oxygen levels in the inspired air. Two months after PCPC, being still in the ICU, he was scheduled for re-catheterization. At catheterization the left jugular vein was entered. SVC pressure was 13 mmHg and two veno-venous collaterals from the SVC to the paravertebral veinous system were depicted (*Figure 3A*). These were closed via a microcatheter (Progreat) using first a MVP^{TM} Q5 (Medtronic, Minneapolis, USA) and one Azur CX microcoil 4 mm × 13 cm. The other collateral

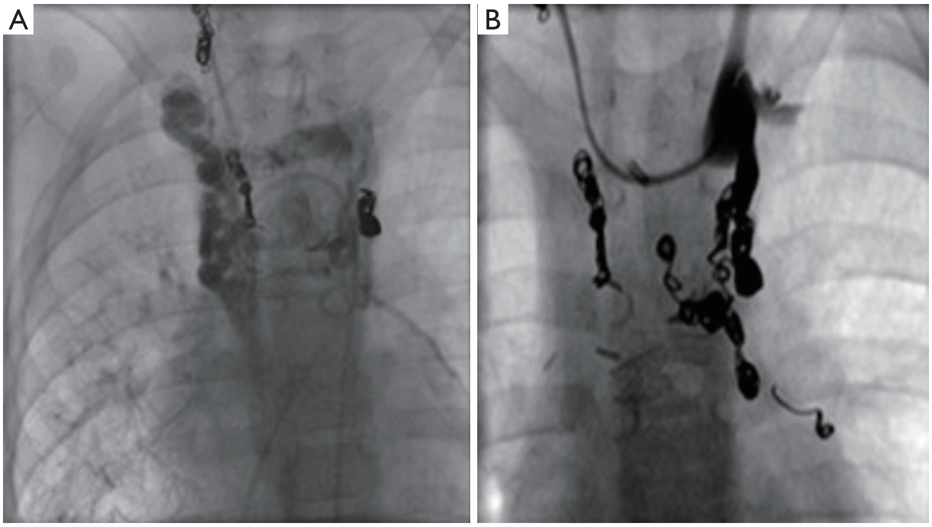

Figure 4 Angiograms showing successful closure of multiple veno-venous fistulas that connect the upper and lower part of the body. (A) Antero-posterior view showing the exact morphology of the veno-venous fistulas. (B) Antero-posterior view after closure of the fistulas using Tornado coils and Azur CX micro-coils.

was closed with 2 Azur CX microcoils (4 mm × 13 cm and 5 mm × 16 cm) (*Figure 3B*). More veno-venous collaterals were present, but the intervention was stopped due to long radiation exposure of the patient. Because of persistent cyanosis, a mBT shunt was implanted to the LPA, the central PA was closed and the PCPC was left being connected to the right PA (LPA), like a classical Glenn shunt. After a complicated post operative course, the patient was discharged home 4 weeks later with a transcutaneous oxygen saturation >85%. At the age of two years, the mBT shunt was stented with two coronary stents. At the age of two years and nine months a repeated catheterization was scheduled to evaluate for a potential TCPC operation. Arterial oxygen saturation was 80%, while the pulmonary veins only showed mild desaturation (93%); after puncture of the RJV, the pressure in the SVC was 14 mmHg mean with a TPG of 6 mmHg. The pressure in LPA reached through the mBT shunt from the right femoral artery was 13 mmHg mean. SVC angiography showed significant veno-venous collaterals from the upper body to the lower body (*Figure 4A*). First the left sided collaterals were closed with a total of 9 non detachable Tornado coils and with two detachable Azur CX microcoils coils (*Figure 4B*). The collateral between the SVC and the lower body half on the right side consisted of a re-canalized azygous vein, which could not be entered from above. Hence, via the right femoral vein the inferior vena cava (IVC) was blocked with a balloon catheter (*Figure 5A*). Connections to the paravertebral veins were depicted which had access to the azygos system. A regular 6-F right coronary guide catheter was advanced on this tortuous route into the azygos vein. Two Amplatzer vascular plugs II (6/6 and 8/7) (Abbott, Polymouth, USA) were implanted and complete occlusion was documented (*Figure 5B*). The pressure in the SVC only rose by 1 mmHg and the arterial oxygen saturation was >85%. It was then decided to postpone further surgical steps (potential TCPC) due to the high perioperative risk and the relatively good clinical status of this little patient.

***Patient 4**: A patient with early (<30 days) and late (>1 year) severe cyanosis post PCPC*

A male patient with hypoplastic left heart syndrome (HLHS), moderate to severe tricuspid valve (TrV) regurgitation, had a Norwood-Sano operation at the age of 16 days. At 3 months of age (3 kg) a diagnostic catheter showed low mean pulmonary arterial pressure (10 mmHg), a TPG of 4 mmHg, left atrium (LA) oxygen saturation of 96% and arterial oxygen saturation of 66% in room air. A PCPC was performed together with a TrV plasty and LPA-patch augmentation. Three weeks later, the child (3.9 kg) was still severely cyanotic (SaO_2 <60% under ventilation with 100% oxygen). At catheterization the right internal jugular vein was entered, SVC pressure was 14 mmHg.

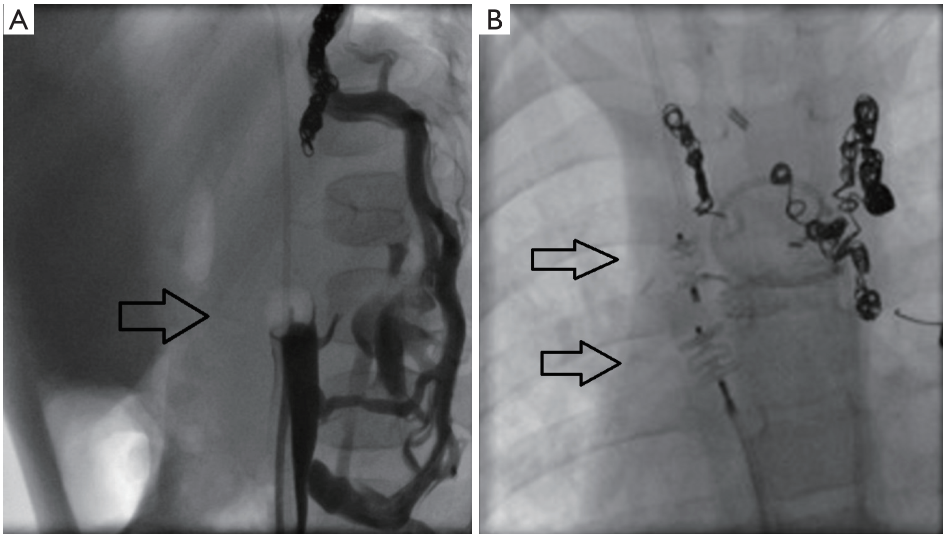

Figure 5 Angiograms showing veno-venous collaterals with connection between the paravertebral system and azygous vein. (A) Balloon occlusion of the inferior vena cava (arrow). (B) After closure of the veno-venous collaterals using Amplatzer vascular plugs (arrows).

Angiography showed an area of stenosis at the Glenn anastomosis which was successfully dilated by a Tyshak-II balloon and the SVC pressure decreased to 13 mmHg. A significant veno-venous collateral was seen arising from the brachiocephalic vein to the lower part of the body (*Figure 6A*). The collateral was closed with two Nester 0.035 embolization coils (Cook Medical Europe, Limeric, Ireland city country) (6 mm × 14 cm and 4 mm × 14 cm) (*Figure 6B*). The oxygen saturation improved and the patient was successfully extubated and weaned from inotropic support. After one year repeated TrV plasty was performed and a permanent dual-chamber (DDD) pacemaker was implanted with epicardial leads. The patient's oxygen saturation was 74% which was accepted in this severely compromised child. At the age of two years (8.8 kg) the child was re-admitted, SaO_2 74%. At catheterization the pressures were as follows: mean pulmonary artery pressure (mPAP) 17, TPG 4 mmHg, right ventricular end-diastolic pressure (RVEDP) was elevated to 13 mmHg, the RV was volume loaded because of severe tricuspid regurgitation (TR). Angiography revealed multiple AP collaterals which were closed with coils. A relatively large veno-venous collateral was closed using an ADOII AS 4×4 (Abbott Medical, Abbott Park, IL, USA) (*Figure 7A,7B*). The central venous pressure (SVC) did not change and arterial oxygen saturation rose slightly. However, the child stayed severely symptomatic, and a TrV replacement was planned, but sadly the child died one month later.

Discussion and recommendations

Despite that no specific oxygen saturation is mentioned in the literature to identify patients after PCPC who developed veno-venous collaterals, there should be a high suspicion for their development in patients presenting with desaturation (9). The pressure difference between the upper and lower half of the body after PCPC predisposes to the development of veno-venous collaterals between SVC and IVC (9), and represents a "run-off" from the higher pressure superior caval venous system to the lower pressure atria, hepatic veins/and IVC (7). Extensive veno-venous collaterals lead to desaturation and cyanosis because the blood is bypassing the lung (9). This mandates closure to improve oxygen saturation and, hence, the functional status of the patients (7). It is obvious that not every patient who presents with desaturation has venous collaterals (9), because pulmonary arterio-venous fistula (PAVF) is also an important cause for desaturation, and is considered a classical late complication of PCPC (Glenn) operation, which leads to the absence of hepatic factor in the pulmonary blood flow. The condition can be ameliorated by completion to a TCPC circuit (10), or redirection of hepatic blood flow into the pulmonary arteries (11). Therefore, if a patient is severely cyanotic after PCPC veno-venous collaterals have to be excluded or closed. Exceptionally, if at routine catheterization preceding TCPC completion at the age of 18–24 months

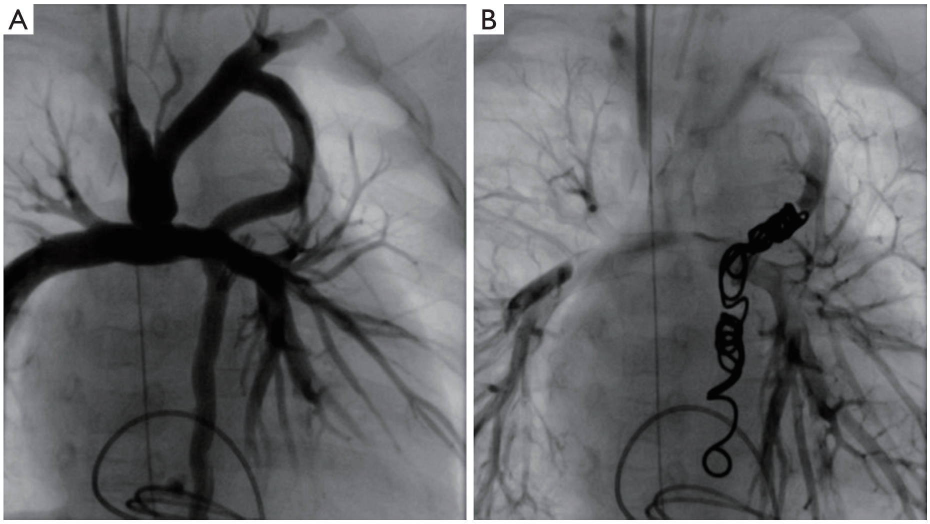

Figure 6 Angiograms showing large sized veno-venous fistula from the innominate vein angel to the lower body half. (A) Antero-posterior view of the fistula showing the exact morphology. (B) Antero-posterior view after closure of the fistula by Tornado coils.

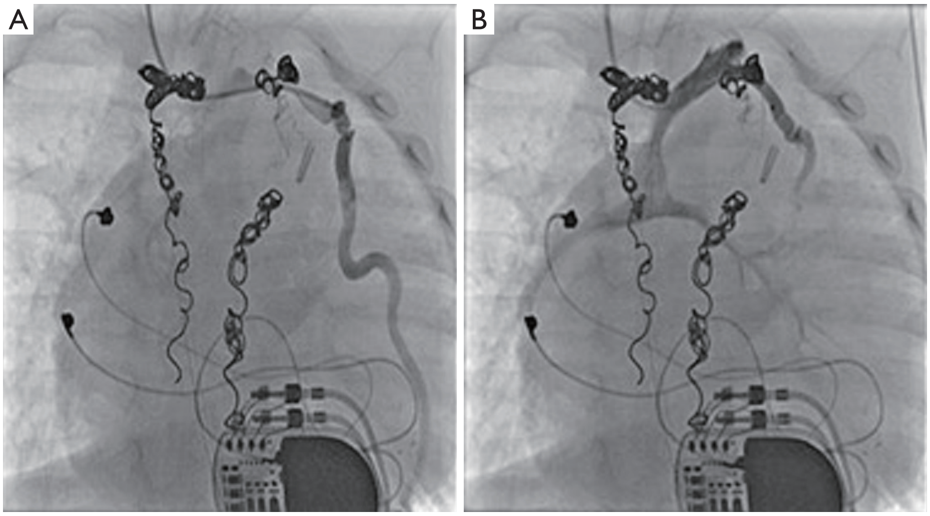

Figure 7 Angiograms showing large sized veno-venous fistula from the left internal jugular vein draining into the left atrium. (A) Antero-posterior view of the fistula showing the exact morphology. (B) Antero-posterior view after closure of the fistula by ADOII AS.

small veno-venous collaterals between the SVC and IVC without connection to the heart, or pulmonary veins were discovered, they are of no clinical significance and don't need to be closed (9). On the other side, if they are so large to significantly reduce effective pulmonary blood flow in the short term, resulting in systemic desaturation and inadequate growth of pulmonary arteries, closure is mandatory (7).

Technical aspects of transcatheter closure of veno-venous collaterals

An important technical step prior to occlusion of venous collaterals is the measurement of the pressure in the caval system. Patients who have pressures >15 mmHg have to be tested first by balloon test occlusion. A sizing balloon has to be placed to totally occlude the collateral for

15 minutes, then the pressures and saturations are to be re-measured (12). The sizes of the collaterals, morphology, and accessibility are the most important determinant factors in the selection of the closure technique. After angiographic assessment and visualization of the vessels, a catheter can be placed in the jugular or innominate veins to introduce the closure device and/or coils. The site of closure of the collaterals must be as distal as possible and if the collaterals are draining in the pulmonary veins, a retrograde approach can be a better alternative to access those vessels. In addition, this technique ensures complete closure of the draining site of unsaturated blood into the pulmonary veins. There is a wide range of devices and coils that can be used safely and effectively to close such abnormal vessels (5). The Amplatzer vascular plugs are commonly used for this purpose and this is in accordance with several studies which stated that "Amplatzer vascular plugs I and II have been shown to deliver high rates of complete vascular occlusion in various target vessels without major complications" (13,14). However vascular plugs, usually require a relatively large diameter sheath for implantation (15). In such cases, microplugs, or coils can be suitable alternatives (15). Several reports described the embolization of venous fistulas with coils (15-17). Nowadays, there is a wide range of different types of coils that can be used for this purpose. Based on the manufactured material, coils can be classified as: platinum made fibre coated coils and hydrogel-coated coils. However, the new generation of detachable hydrogel coils (AZUR™, Terumo, Eschborn, Germany) is advantageous because they are made of platinum alloy with an inner hydrogel core which has 3D spherical shape (17). In addition, they have a high degree of delivery control due to the controlled electrical coil detachment and until final detachment, the coils are completely retrievable and may be re-positioned for a more convenient location (15). Moreover, hydrocoils lead to mechanical occlusion that does not rely on thrombus formation. This mechanism is thought to lower the risk of post-procedural thromboembolism, compared with alternative methods of vascular occlusion (15). The use of hydrocoils can be reserved to the last coil due to the second-generation hydrocoil technology and the cross-sectional coverage on the interior, which enables expansion between the gaps with hydrogel forming a solid coil core that increases the volume fill so they can act as a glue that adheres all the coils together (17). Selection between micro and macro-coils basically depends on the size and accessibility. "0.018" micro-coils can be delivered through a small calibered micro-catheter, which allows access to difficult and tortous collaterals (15), and allows coaxial placement and positioning in a peripheral vessel through a 4-F catheter (17). These coils are detached using the Azur detachment controller (17), and after reaching the target zone within the vessel, they enlarge by swelling after being in contact with blood. Hence, they reach their final occlusion properties 30–60 minutes after implantation (15). Coil sizing is determined based on target vessel diameter at intended location of deployment, with the goal of placing a coil with diameter approximately equaling 1.5 to 2.5 times the target vessel diameter (15). Oversizing the coil was always preferred to ensure complete closure of the vessels. Needless to say that the length of the collaterals does not determine the length of the coil because the coil loops have to be folded over each other. The only disadvantage of detachable hydrogel coils is their relatively high price, in comparison to the stainless steel Gianturco coil, but they are more or less equivalent in cost to the Amplatzer vascular plug II (15). Any anatomical stenosis in the cavo-pulmonary system, which leads to increased pressure, and hence, is a risk for the development of collaterals must be treated as well for e.g., stenosis at the PCPC anastomosis and PA branch stenosis, and even significant AP-collaterals. Additionally, a re-coarctation may lead to increased LVEDP, passively increasing the PA pressure and should also be addressed.

Conclusions

Veno-venous collaterals are an important cause of cyanosis in post PCPC patients which may occur early or late after operation. Drainage in the pulmonary venous atrium/pulmonary veins is an absolute indication for closure. Closure of small collaterals draining below the diaphragm is controversial based on the timing of the planned TCPC completion. Several devices and coils can be used safely and effectively to close the collateral vessels. Coil closure represents the most convenient method; however large collaterals can also be closed with devices mainly vascular plugs. Selection of device/coil size depends mainly on the size of the collaterals and oversizing is preferred. Hydrogel expandable coils can achieve the highest rate of success and are fully retrievable until final detachment.

Strengths and limitations

Our study discussed the guidelines for management of such conditions and explains in details our institutional approach.

We showed four cases with variable timing of closure of collaterals. However, there are different approaches and techniques that vary in each case scenario. Despite that safety and efficacy of different types of coils cannot be determined from such small sample size, the indications for use and technical aspects were explained in detail.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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