Transcatheter Closure of Large Coronary-Cameral Fistulas Using the Patent Ductus Arteriosus Occluder or Amplatzer Vascular Plugs
Focus on Technical Aspects and Long-Term Outcomes

Liang Tang, MD, Zhao-jun Wang, MD, Jian-jun Tang, MD, Zhen-fei Fang, MD, Xin-qun Hu, MD, Shi Tai, MD, Zhen-hua Xing, MD, Xiang-qian Shen, MD, Yan-shu Zhao, MD and Sheng-hua Zhou, MD

Summary
Transcatheter closure (TCC) has emerged as the first-line treatment for coronary artery fistulas. However, limited data exist regarding the long-term outcomes and technical aspects of this procedure. We aimed to report the long-term outcomes and technical aspects of TCC of large coronary-cameral fistulas (CCFs).

All patients with large CCFs who underwent attempted TCC using the patent ductus arteriosus (PDA) occluder or Amplatzer vascular plug (AVP), from June 2002 to December 2017, were retrospectively reviewed. A total of 23 patients with large CCFs underwent attempted TCC using the PDA occluder or AVP. Most CCFs originated from the right coronary artery and drained predominantly into the right heart chamber. Procedural success was achieved in 21 (91.3%) patients. Devices were deployed using the arteriovenous loop in 15, transarterial approach in 4, and arterio-artery loop approach in 2 patients. Procedural complications included coronary spasm in one and side branch occlusion in one patient. Among these 21 patients with successful device implantation, follow-up angiograms or computed tomography angiograms were obtained in 14 (66.7%) patients at a median of 11.0 (range, 9.8-16.3) months. Late complications included thrombosis of residual fistula segment without myocardial infarction (MI) in one, coronary thrombosis resulting in MI in one, and recanalization necessitating re-intervention in one patient. No death and device embolization occurred.

TCC of large CCFs using the PDA occluder or AVP is an effective therapy in anatomically suitable candidates, with favorable long-term outcomes. Given that potentially hazardous complications may occur late after the procedure, long-term periodic evaluation is mandatory. (Int Heart J 2020; 61: 1220-1228)

Key words: Coronary artery fistula, Congenital heart disease, Treatment, Device, Follow-up

A coronary artery fistula (CAF) is an abnormal direct connection between one or more of the coronary arteries and a cardiac chamber (coronary-cameral fistula, CCF) or a great vessel, bypassing the myocardial capillary network. It is a rare clinical entity, with an estimated incidence of 0.3-0.8% in patients undergoing diagnostic cardiac catheterization. While small CAFs are usually clinically silent with the possibility of spontaneous regression, large-sized CAFs can be hemodynamically significant and may result in myocardial ischemia, congestive heart failure, and arrhythmia. Additionally, infective endarteritis and aneurysmal fistula rupture have also been described, though they are uncommon. Current guidelines for the management of adults with congenital heart disease recommended the closure of all large CAFs, regardless of symptomology, or symptomatic CAFs, irrespective of their size. Surgical closure was viewed traditionally as the mainstay therapeutic method for CAF. However, surgery requires cardiopulmonary bypass, which may be difficult to perform owing to poorly visualized, typically distal fistulous connections. Transcatheter closure (TCC) has recently emerged as the first-line therapeutic option in appropriate patients, particularly in patients with comorbidities that may augment surgical risk.

Thus far, however, limited data are available on the long-term outcomes and technical aspects of the TCC approach, particularly in patients with large-sized CCFs. Therefore, in this report, we aimed to describe our experience with TCC of large CCFs using the patent ductus arteriosus (PDA) occluder (Lifetech Scientific Co., Shenzhen, China) and Amplatzer vascular plug (AVP; AGA Medical, Golden Valley, MN, USA) in a relatively large cohort of patients, focusing on the long-term outcomes.

From the Department of Cardiology, The Second Xiangya Hospital of Central South University, Changsha, China.
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Address for correspondence: Sheng-hua Zhou, MD, Department of Cardiology, The Second Xiangya Hospital of Central South University, No.139, Middle Ren-min Road, Changsha, Hunan, 410011, China. E-mail: zhoushenghua@csu.edu.cn
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and technical aspects of the procedure.

Methods

Patient population: All patients with congenital CAF who underwent attempted TCC at our institute between June 2002 and December 2017 were identified from the cardiac catheterization database. All patients with large-sized CCFs who underwent attempted TCC using the PDA occluder or AVP were enrolled in this study. Patients with additional complex cardiac lesions requiring surgical management, and those with small or moderate CAF were excluded. Their medical records, including clinical evaluations, imaging results, angiographic findings, procedural characteristics, and follow-up data, were retrospectively reviewed. Written informed consent was obtained from all patients or children’s parents/guardians after a detailed explanation of the procedure, which included information on therapeutic alternatives, the potential procedural risks, and the “off-label” use of closure devices. The study protocol was approved by our Institutional Review Board, and the need for informed consent to use the medical records was waived owing to the retrospective nature of the study.

Definitions: 1) Large fistulas: Fistulas that, at any point, are larger than three times the normal proximal coronary artery diameter are considered as large.10) 2) Types of CCF: A CCF was classified into proximal or distal types based on its anatomical origin, as described previously. Briefly, the proximal type of CCF arises from the proximal segment of a major coronary artery. The distal type of CCF originates from the distal end of a main coronary artery. The conduit coronary artery close to the drainage site usually gives rise to normal coronary branches supplying the myocardium.11)

TCC procedure: Written informed consent was obtained from all patients or their guardians prior to the procedure. The procedure was performed under general anesthesia for patients < 12 years of age and under local anesthesia for adult patients or children ≥ 12 years of age. Before the procedure, patients routinely received a loading dose of aspirin. Heparin (100 IU/kg) was injected intravenously during the procedure. Aortogram and selective coronary angiography were performed in multiple views to delineate the anatomy of the fistula, in terms of the origin, course, size, drainage site, and number of feeding vessels. Then, a conventional cardiac catheterization was performed to obtain hemodynamic data and to assess the magnitude of the left to right shunt.

Devices were deployed using a retrograde (via the radial or femoral artery) or antegrade (via the femoral vein) approach, depending on the location of the drainage, accessibility, and tortuosity of the fistulas. The transarterial retrograde approach was attempted initially if the fistula was without an extremely tortuous course. Antegrade deployment using an arteriovenous wire loop (A-V loop) was preferred. After the selective engagement of the affected coronary artery with a Judkins or Tiger diagnostic coronary catheter, a 260-cm, 0.035” hydrophilic exchange wire (Terumo, Tokyo, Japan) was advanced through the fistula into the pulmonary artery or superior vena cava. The exchange wire was then snared with a gooseneck snare (AGA Medical) and exteriorized out of the femoral vein, establishing an A-V loop. Similarly, in patients with fistulas draining into the left ventricle (LV), an arterioarterial circuit (A-A loop) was created.5,10,12) Over the A-V or A-A loop, an appropriate-sized delivery sheath was introduced from the femoral vein or artery into the distal part of the fistulous tract. Once a suitable position was achieved within the fistulous tract, the occluder was deployed under fluoroscopic control. Repeat coronary angiography was performed to ascertain that the fistula was closed, and to evaluate the precise position of the devices. After the procedure, patients were transferred to the general wards. Continuous electrocardiogram (ECG) monitoring was used during the first 24 hours following the procedure. All patients were treated routinely with oral antiplatelet therapy with aspirin (5 mg/kg daily) or clopidogrel for at least 6 months. In addition, warfarin was administered in selected cases with very dilated fistulous vessels or in the presence of persistent aneurysmal dilatation of the native coronary arteries.

Occluder device: In this study, the occluder devices used most commonly are the PDA occluder (Lifetech Scientific Co.) and the AVP (AGA Medical).13,14) The size of the AVP selected for embolization was approximately 1.5-2 times the caliber of the feeding vessel, while the PDA occluder size was determined by oversizing the waist of the device 2 mm greater than the fistulous vessel diameter at the intended site of implantation. Additional embolization with Tornado coils (Cook Medical, Bloomington, IN, USA) was performed when residual shunting was noted.

Follow-up: Medical records, including clinical evaluation, ECG, and transthoracic echocardiography (TTE), were reviewed manually. Follow-up angiograms and multidetector computed tomography (MDCT) were performed in selected patients. The presence and degree of residual flow after TCC were determined by the most recent echocardiographic or angiographic data. Complications, including device embolization, coronary thrombosis, fistula recanalization, hemolysis, and infective endocarditis, were particularly evaluated by experienced operators.

Statistical analysis: Continuous variables were tested for normal distribution by the Kolmogorov-Smirnov test. Continuous data were reported as the mean ± standard deviation or the median with the 25th and 75th percentiles (interquartile range, IQR) if not normally distributed. Categorical data were expressed as percentages. All statistical tests were performed using SPSS software, version 17.0 (SPSS Inc., Chicago, IL, USA).

Results

Demographics, clinical features, and pre-procedural image findings: During the study period, 23 patients with large CCFs who underwent attempted TCC using the PDA occluder or AVP were enrolled in the analysis. Their demographics, clinical presentation, ECG, and TTE findings are detailed in Table I. The mean age of the patients at the time of the intervention was 31.6 ± 22.8 (range, 3-76) years; 13 (56.5%) patients were asymptomatic, while 10 (43.5%) patients presented with symptoms. All patients had TTE before the procedure and 12 patients had evi-
Angiographic characteristics: The angioGraphic characteristics of the CCFs are summarized in Table II. The CCF originated most commonly from the right coronary artery (RCA; 14 [60.9%]), followed by the left anterior descending (LAD; 4 [17.4%]) artery, the left main (LM) artery (3 [13.0%]), and the left circumflex artery (LCX; 2 [8.7%]). The drainage sites included the right ventricle (RV) in 12 (52.2%), right atrium (RA) in 8 (34.8%), and LV in 3 (13.0%) patients. Two patients had associated congenital cardiovascular anomalies: one had an anatomic origin of the LCA from the right coronary sinus and the other had isolated coronary artery anomalies (single left coronary artery; Figure 1). Twenty patients had a single fistula and three had multiple fistulas. Of these three patients with multiple fistulas, one had concomitant RCA-and LAD-originating fistulas that drained into the LV through different exits, and one patient (case #4) had a large fistula originating from the RCA, with two small CAFs originating from the LCX, which were confluent at the distal ends and drained into the RV. The remaining patient had an extremely tortuous, aneurysmal dilated fistula, with two large exit draining into the RA. The mean calculated pulmonary-to-systemic blood flow ratio (Qp/Qs) ratio was 1.77 ± 0.42. Ten patients (43.5%) had a proximal type of CCF and 13 (56.5%) patients had a distal type of CCF.

Procedural details: The TCC procedure was attempted in
A VP in 2, and a combination of A VP with coils was used for surgical closure. Among these 21 patients with successful DE-1 occlusion (case #23), these two patients then underwent successful occlusion of A-A loop (case #22) or extreme tortuosity with multiple aneurysms that led to difficulty in creating an A-A loop. Immediate post-deployment angiography demonstrated complete occlusion was obtained in 21 of 23 patients. Of these, one patient with multiple fistulas underwent a staged closure for the residual fistula and one patient underwent a second closure for significant residual shunting, resulting in a total of 25 closure procedures. The details regarding the treatment approaches and results are shown in Table II. Occlusion devices were placed successfully in 21 of 23 patients. The attempted closure was aborted in two patients because of the presence of side branches close to the fistulous orifice and because the ECG showed transient ST elevation during test occlusion (case #22) or extreme tortuosity with multiple aneurysms that led to difficulty in creating an A-A loop.

Table II. Procedural Data (n = 23)

| Patient no. | Origin site | Drainage site | Proximal vs. distal fistula | Multiple fistula | Approach | Devices | Device size | Occlusion site | Procedural success | Residual shunt |
|-------------|-------------|---------------|-----------------------------|------------------|----------|---------|-------------|----------------|-------------------|---------------|
| 1           | LM          | RA            | Proximal                    | No                | A-V loop | Ductus occluder | 6-8 mm       | Drainage site | Yes               | No              |
| 2           | RCA         | RA            | Distal                      | No                | A-V loop | Ductus occluder | 10-12 mm     | Drainage site | Yes               | No              |
| 3           | LM          | RV            | Proximal                    | No                | A-V loop | Ductus occluder | 12-14 mm     | Distal discrete narrow part | Yes               | No              |
| 4           | RCA         | RV            | Distal                      | Yes               | A-V loop | Ductus occluder | 10-12 mm     | Drainage site | Yes               | No              |
| 5           | L CX        | LV            | Proximal                    | No                | A-A loop | Ductus occluder | 8-10 mm      | Drainage site | Yes               | No              |
| 6           | RCA         | RV            | Distal                      | No                | Retrograde arterial | Two AVPs | 6 mm, 8 mm | Drainage site | Yes               | No              |
| 7           | RCA         | RA            | Distal                      | No                | Retrograde arterial | AVP     | 12 mm       | Drainage site | Yes               | Trivial         |
| 8           | LM          | RV            | Proximal                    | No                | A-V loop | Ductus occluder | 12-14 mm     | Drainage site | Yes               | No              |
| 9           | RCA         | RV            | Distal                      | No                | Retrograde arterial | AVP + Tornado coils | 10 mm, MWCE-18S-7-3 × 2 | Distal discrete narrow part | Yes               | No              |
| 10          | RCA         | RV            | Distal                      | No                | A-V loop | Ductus occluder | 12-14 mm     | Distal discrete narrow part | Yes               | No              |
| 11          | RCA         | RV            | Distal                      | No                | A-V loop | Ductus occluder | 6-8 mm       | Distal discrete narrow part | Yes               | No              |
| 12          | RCA         | RA            | Proximal                    | No                | A-V loop | Ductus occluder | 14-16 mm     | Proximal narrow part before aneurysm | Yes               | No              |
| 13          | RCA         | RA            | Proximal                    | Yes               | A-V loop | Two ductus occluders | 8-10 mm, 6-8 mm | Drainage site | Yes               | No              |
| 14          | RCA         | LV            | Distal                      | Yes               | A-A loop | AVP + Tornado coils | 8 mm, MWCE-18S-7-3 × 2 | Distal discrete narrow part | Proximal, acute turn in the vessel | Yes               | No              |
| 15          | L CX        | RV            | Proximal                    | No                | A-V loop | Ductus occluder | 10-12 mm     | Distal discrete narrow part | Proximal, acute turn in the vessel | Yes               | No              |
| 16          | RCA         | RV            | Distal                      | No                | A-V loop | Ductus occluder | 6-8 mm       | Drainage site | Yes               | No              |
| 17          | L AD        | RV            | Distal                      | No                | A-V loop | Ductus occluder | 6-8 mm       | Distal discrete narrow part | Yes               | No              |
| 18          | L AD        | RV            | Distal                      | No                | A-V loop | AVP + Tornado coils | 8 mm, MWCE-18S-6-2 × 2 | Distal discrete narrow part | Proximal, acute turn in the vessel | Yes               | Trivial         |
| 19          | L AD        | RA            | Proximal                    | No                | Retrograde arterial | AVP + Tornado coils | 11 mm, MWCE-35-5-5 × 2 | Distal discrete narrow part | Middle discrete narrow part | Yes               | No              |
| 20          | RCA         | RA            | Proximal                    | No                | A-V loop | Ductus occluder | 12-14 mm     | Drainage site | Yes               | No              |
| 21          | RCA         | RA            | Proximal                    | No                | A-V loop | Ductus occluder | 16-18 mm     | Yes               | No              |
| 22          | L AD        | RV            | Distal                      | No                | A-V loop | N/A              | N/A          | N/A              | No*              | N/A            |
| 23          | RCA         | LV            | Distal                      | No                | A-A loop | N/A              | N/A          | N/A              | No*              | N/A            |

A-A loop indicates arterio-arterial loop; A-V loop, arterio-venous loop; AVP, Amplatzer vascular plug; LAD, left anterior descending artery; L CX, left circumflex artery; LM, left main; LV, left ventricle; N/A, non-applicable; RA, right atrium; RCA, right coronary artery; and RV, right ventricle. *The procedure was aborted because of the presence of side branches next to the fistulous orifice and because the ECG showed transient ST elevation during test occlusion; *the procedure was aborted owing to extreme tortuosity with multiple aneurysms that led to difficulty in creating an A-A loop.
embolization, fistula dissection, or significant arrhythmias. In one patient, a small side branch adjacent to the draining site was occluded inadvertently, but it did not cause ischemic symptoms. In another patient, a coronary spasm occurred during the establishment of the A-V wire loop, which was resolved successfully with intracoronary nitroglycerin.

**Long-term outcomes:** Clinical follow-up data were available in 19 of the 21 patients who underwent initial successful TCC. Of these, 16 patients were asymptomatic at the last follow-up, but 1 patient had chest pain and 2 had palpitations secondary to atrial arrhythmias. During a median follow-up period of 31.0 (IQR, 18.0-83.0) months, no death, hemolysis, and infective endocarditis occurred. A follow-up angiogram or MDCT (follow-up MDCT was performed in 2 patients) was obtained in 14 (66.7%) patients at a median of 11.0 (IQR, 9.8-16.3) months after the initial procedure. For patient #8 who had reversible perfusion abnormality on SPECT prior to the procedure, a 6-month follow-up SPECT showed normal myocardial perfusion, indicating that the perfusion abnormality was altered by the intervention. In patient #19 with a LAD-to-RA fistula, which was occluded initially with an AVP and coils, late recanalization (the last angiography showed a moderate shunt) occurred at 1 year. Although he was asymptomatic, this patient underwent re-intervention and the recanalized fistula was treated successfully using two additional coils with complete occlusion. Patient #13 had a proximal RCA-to-RA fistula, with a grossly aneurysmal dilation that was closed at the distal drainage site. MDCT performed at 11 months showed thrombosis in the residual proximal cul-de-sac, without propagation to major coronary artery. This patient was maintained on warfarin indefinitely. In patient #6 with a distal RCA-to-RV fistula, which was occluded with two AVPs, MDCT performed at 6 months documented middle RCA chronic total occlusion and ECG showed old inferior wall myocardial infarction. This patient was still asymptomatic and treated with aspirin indefinitely.

**Discussion**

In the present study, we have described the long-term outcomes of TCC therapy in an exclusively selected cohort of patients with large-sized CCFs. Our series demonstrated favorable immediate and long-term outcomes as well as a relatively low complication rate. Thus far, the experience with TCC of large-sized CCFs is still limited. Most previous publications have described a heterogeneous group of patients with different dimensions and types of CAFs. To the best of our knowledge, our cohort might represent one of the largest series of patients who underwent TCC of large-sized CCFs using PDA occluders and AVP devices. Our investigation has reinforced the safety and efficacy of TCC therapy in anatomically appropriate patients with large-sized CCFs. Our data might have additional clinical value to potentially improve care for this patient population.

**Patient selection:** While our data demonstrate that most large CCFs could be occluded successfully, TCC therapy

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**Figure 1.** Case #18. A large fistula from a single left coronary artery (LCA) to the right ventricular (RV) was occluded successfully using an Amplatzer vascular plug (AVP) combined with coils. A and B: Three-dimensional volume-rendered CT images demonstrating a large and tortuous fistula (arrowhead) from the proximal part of the LCA coursing in the anterior right atrioventricular groove in the region of the RCA and terminating in the RV. C: Aortic root angiography showing the absence of the RCA with faint opacification of the LCA. D: LCA angiography confirming the CTA findings. E: A 0.014” hydrophilic guidewire was advanced through the tortuous fistula into the main pulmonary and snared, creating an arteriovenous loop. F: An 8-mm AVP was deployed at the distal narrowest position of the fistula. G: Control angiogram after AVP deployment, demonstrating a significant residual shunt. H: Therefore, two additional Tornado coils (MWCE-18S-6/2 mm) were implanted, resulting in complete occlusion of the fistula.
was unfeasible in a few patients owing to extreme vessel tortuosity and the inability to advance a catheter/sheath to the target occlusion site, or the presence of large coronary branches too close to the drainage site to allow optimal device positioning. Appropriate patient selection is of vital importance for successful TCC. According to our series and previous reports, we summarized the anatomical suitability of TCC for large CCFs. From a practical standpoint, suitable anatomical conditions for safe and successful TCC of CCFs include the following criteria: patients without additional complex cardiac anomalies that require surgical correction, the feeding coronary artery without excessive tortuosity and that can be safely cannulated (the guidewire, catheter, or delivery sheath should be able to advance through the fistulous tract), a fistula with a narrow restrictive drainage site, the absence of large normal branches at or distal to the occlusion site that might be inadvertently embolized, and a long fistulous tract with an “elbow” or a discrete narrow point within the fistulous tract for robust anchoring of the occluder device. In cases with a very short and unrestricted fistulous route, for example, a left coronary-to-left heart chamber fistula without an ideal landing zone, TCC may lead to a high risk of device embolization and therefore, should be attempted with caution in these patients.7,10,15,16 Surgical closure should still be employed in these clinical scenarios: CCFs accompanied by a large saccular coronary artery aneurysm formation, especially in the case of an aneurysm compressing the adjacent structures, necessitating concomitant arterialplasty and aneurysmectomy; a large and wide CCF without a narrow part to safely anchor the occluder device; extreme vessel tortuosity that causes the inability to deliver a catheter far enough distally; the presence of diffuse or multiple drainage sites and difficulty in achieving complete occlusion; the presence of normal coronary branches too close to the drainage site to allow optimal device positioning; patients with significant coronary artery stenotic lesions who need concomitant coronary artery bypass surgery or need concomitant surgery for other cardiac malformations; or young patients with body weight less than 5 kg (the catheter size is not sufficiently small to be introduced into small coronary arteries).7,10,15,16

Procedural technical aspects: TCC of large CCFs remains one of the most complicated interventional procedures. Given the substantial anatomical variability seen in CCFs, multiple techniques for structural heart disease interventions are required. As the procedural success may be affected by many procedural aspects, we separately reviewed the major techniques applied in the present series. A-V loop establishment In our cohort, the A-V or A-A loop approach was used in the majority of cases, and a retrograde arterial approach was utilized for AVP deplo-
ment in four cases in which the fistula was absent in an extremely tortuous course. In six patients of our series, it was difficult for the 0.035” hydrophilic exchange wire to cross the fistulas, but a 0.014” hydrophilic guidewire was advanced smoothly through the fistula into the main pulmonary or superior vena cava and snared, creating an A-V loop. As observed frequently, in cases where the fistulous tract is extremely tortuous, a 0.035” hydrophilic exchange wire may be too stiff to manipulate through the tract. In such instances, the floppy 0.014” coronary guidewires may be easier to advance along the tortuosity to cross the exit and enter the cardiac chamber. In our patients, the 0.014” coronary guidewire was usually supported by a Cobra catheter. After the supportive catheter was pushed over the guidewire distally enough or entered the cardiac chamber, the 0.014” coronary guidewire was exchanged for the 0.035” hydrophilic exchange wire. Notably, large tortuous fistulas usually have thin and fragile walls, especially in the case of aneurysmal dilation and therefore, care must be taken when advancing and maintaining the guidewire through the fistulous tract to avoid injury. Tensing of the wire loop can damage the coronary arteries and the cardiac valves, so the wire should be encompassed by a catheter along its entire length to avoid exposure during the process of A-V loop formation.183

In some patients with complex fistulas, the occluder selected initially might be inappropriate or the occluder may not be positioned ideally. Using the “arteriovenous wire-maintaining” technique, the re-establishment of the A-V wire loop could be avoided, thus facilitating occluder exchange or redeployment. In our cohort, this technique was applied commonly in patients with tortuous CCFs where the establishment of the A-V wire loop was a relatively difficult process.

Delivery sheath advancement In some cases, it can be difficult to advance the delivery sheaths over the A-V loop through the fistula as it requires acute catheter angulation, especially when navigating tortuous vessels. In such a situation, forced advancement inside the fistulous tract might lead to vessel trauma and dissection. Bruckheimer, et al. previously described a gentler method for sheath advancement using a balloon-tipped catheter instead of a dilator. The soft catheter is advanced along the wire and the balloon is inflated to anchor the catheter. Then, the delivery sheath is advanced slowly along the balloon catheter to the target position. In our series, we usually removed the dilator and telescoped a multipurpose catheter over the A-V loop. We found that the delivery sheath can also be advanced safely along the multipurpose catheter to the closure site.

Occlusion site choosing The basic principle for choosing the closure site is complete obliteration of the CCF without compromising normal coronary blood flow. Patients with the proximal type of CCFs can be occluded proximally close to the origin or distally at the drainage site, but proximal closure has been postulated to be more appropriate than distal closure as it confers a lower risk of thrombosis extension. Gowda, et al. reported a series of 16 subjects with CAF who underwent TCC or surgical closure. In their series, most patients with proximal CAF had device closure at the proximal origin and no coronary thrombosis occurred in these patients. Recently, a French multicenter study by Mottin, et al. also implied that the proximal type of CAF portends a lower risk of coronary thrombosis. In the present series, most patients with the proximal type of fistulas had distal closure and four had closure at the proximal or mid-narrowing position (Table II, Figure 3). The follow-up angiogram or MDCT (available in seven patients) showed that six patients had significant reductions in the conduit artery size without thrombosis, but one (patient #13) had thrombosis in the residual proximal cul-de-sac.

Another concern following the closure of the proximal type of fistulas is that they have a trend toward persistent aneurysmal dilation of the residual fistula tract after distal closure. We have previously described a case of a 47-year-old woman with a large LM-to-RA proximal fistula that was ligated surgically at the drainage site. This patient developed superior vena cava obstruction syndrome secondary to extrinsic compression by a grossly

Figure 3. Case #21. An aneurysmally dilated proximal fistula was occluded at the mid-narrow part. A: Angiogram through the venous sheath after arteriovenous loop formation in a patient with a large proximal fistula from the right coronary artery (RCA) to the right atrium (RA). B: Repeat angiogram after implantation of a 16-18-mm patent ductus arteriosus (PDA) occluder at the mid-discrete narrow part, demonstrating complete occlusion of the fistula and improved opacification of the native RCA. C: Follow-up angiogram at 6 months showing the reduced size of the proximal fistula stump without the extension of the thrombus to the main RCA.
aneurysmal dilation.\textsuperscript{21} Similarly, Li, et al.\textsuperscript{22} also reported a case of progressive aneurysmal dilation 2.5 years after closure at the exit point in a patient with a large proximal LCA-to-RA fistula. Their patient eventually underwent surgical treatment to prevent aneurysmal rupture. Therefore, it has been proposed that the best way to reduce the risk of thrombosis extension and persistent dilation of the residual fistula stump is to close the CCF as close to its origin as possible and to simultaneously close the distal end if possible.\textsuperscript{23} Such a strategy could effectively exclude the residual proximal cul-de-sac or dilated fistulous communication.

The distal type of CCF has a proximal feeding or conduit coronary artery segment giving rise to side branches up to its exit, so the occluder must be placed as close to the exit point as possible, thereby protecting the flow in the side branches. The larger and more distal the fistula, the greater the dilation the proximal conduit coronary artery tends to have, and the higher the risk of flow stasis and thrombosis after closure.\textsuperscript{21} In our series, coronary thrombosis occurred in one patient with distal CCF with a grossly dilated proximal conduit artery (case #6). In reports from Mottin, et al.\textsuperscript{20} and Gowda, et al.,\textsuperscript{21,23} all early ischemic complications occurred in patients with large distal CCFs with dilated proximal feeding coronary arteries. Therefore, in patients with gross enlargement of the proximal conduit vessel, closure must be considered carefully. In addition, to avoid occlusion of unidentified distal coronary branches, temporary occlusion of the fistula with ECG monitoring to assess for myocardial ischemia before deploying the device is recommended.

**Long-term follow-up outcomes:** Long-term follow-up after TCC is mandated because of the possibility of recanalization, persistent coronary dilation, and thrombosis. In the largest experience reported by Valente, et al.,\textsuperscript{20} long-term adverse events after closure, including coronary thrombosis, MI, and cardiomyopathy, occurred in 15% of patients. In their series, advanced age, modifiable coronary risk factors, and CAF draining into the coronary sinus were identified as the predictors associated with adverse outcomes. Jama, et al.\textsuperscript{21} reported the angiographic outcomes in a series of 29 patients who underwent TCC. Four patients (22%) were found to have significant recanalization and underwent a subsequent intervention. Similarly, in a recent experience reported by Ponthier, et al.,\textsuperscript{20} late fistula recanalization was identified in 31% of patients after TCC, over a 10-year follow-up period. Our study provides information on one of the longest follow-up data ever reported. In our series, all CCFs were occluded with PDA occluders or AVPs, most patients underwent TCC at a young age, and all were placed on antiplatelet or anticoagulation therapy for at least for 6 months after the procedure. These factors could help to reduce late complications such as coronary thrombosis and fistula recanalization.

**Study limitations:** The present study has some limitations. First, the present study is a single-center investigation with a limited sample size. Second, a follow-up angiogram or MDCT was available only in 67% of patients. Thus, our reported incidence of post-procedural complications might be underestimated. Third, the antithrombotic regimens in our series were just empirically administered. However, the optimal antithrombotic therapy after TCC has not been well established, particularly in patients with large distal CCFs. Further investigations with expanded cohorts and extended follow-up periods are needed to determine the optimal treatment approach and the appropriate antithrombotic regimen following the procedure.

**Conclusion**

The present investigation showed that TCC of large-sized CCFs using the PDA occluder or AVP is a safe and effective therapy in anatomically suitable candidates, with favorable long-term outcomes. Although procedural related complications were relatively low in our series, potentially hazardous complications, such as coronary thrombosis and fistula recanalization, may occur late after the procedure. Therefore, long-term periodic clinical and imaging evaluations are mandatory.

**Disclosure**

**Conflicts of interest:** None declared.

**References**

1. Sivakumar K, Mullasari A, Dalvi B. Catheter closure of coronary artery fistula. In: Butera G, Chessa M, Eicken A, eds. Cardiac Catheterization for Congenital Heart Disease from Fetal Life to Adulthood. Germany: Springer; 2014: 527-48.

2. Gowda RM, Vasavada BC, Khan IA. Coronary artery fistulas: clinical and therapeutic considerations. Int J Cardiol 2006; 107: 7-10.

3. Reddy G, Davies JE, Holmes DR, Schaff HV, Singh SP, Alli OO. Coronary artery fistulae. Circ Cardiovasc Interv 2015; 8: e003062.

4. Habermann JH, Howard ML, Johnson ES. Rupture of the coronary sinus with hemopericardium. A rare complication of coronary arteriovenous fistula. Circulation 1963; 28: 1143-4.

5. Jama A, Barsoum M, Bjarnason H, Holmes DR Jr, Rihal CS. Percutaneous closure of congenital coronary artery fistulae: results and angiographic follow-up. JACC Cardiovasc Interv 2011; 4: 814-21.

6. Wannam CA, Williams RG, Bashore TM, et al. ACC/AHA 2008 Guidelines for the Management of Adults with Congenital Heart Disease: executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (writing committee to develop guidelines for the management of adults with congenital heart disease). Circulation 2008; 118: 2395-451.

7. Mangakuia CV. Coronary artery fistula. Ann Thorac Surg 2012; 93: 2084-92.

8. Carminati M, Giugno L, Chessa M, Butera G, Piazza L, Bussadori C. Coronary-cameral fistulas: indications and methods for closure. EuroIntervention 2016; 12: X28-30.

9. Collins N, Mehta R, Benson L, Horlick E. Percutaneous closure of congenital heart disease: technical and procedural aspects. Catheter Cardiovasc Interv 2007; 69: 872-80.

10. Latson LA. Coronary artery fistula: how to manage them. Catheter Cardiovasc Interv 2007; 70: 110-6.

11. Gowda ST, Latson LA, Kutty S, Prieto LR. Intermediate to long-term outcome following congenital coronary artery fistulae closure with focus on thrombus formation. Am J Cardiol 2011; 107: 302-8.

12. Xiao Y, Gowda ST, Chen Z, et al. Transcatheter closure of coro-
Coronary artery fistulae: considerations and approaches based on fistula origin. J Interv Cardiol 2015; 28: 380-9.
13. Wang C, Zhou K, Li Y, et al. Percutaneous transcatheter closure of congenital coronary artery fistulae with patent ductus arteriosus occluder in children: focus on patient selection and intermediate-term follow-up results. J Invas Cardiol 2014; 26: 339-46.
14. Kassaian SE, Alidoosti M, Sadeghian H, Dehkordi MR. Transcatheter closure of a coronary fistula with an Amplatzer vascular plug: should a retrograde approach be standard? Tex Heart Inst J 2008; 35: 58-61.
15. Armsby LR, Keane JF, Sherwood MC, Forbess JM, Perry SB, Lock JE. Management of coronary artery fistulae. Patient selection and results of transcatheter closure. J Am Coll Cardiol 2002; 39: 1026-32.
16. Zhang W, Hu R, Zhang L, Zhu H, Zhang H. Outcomes of surgical repair of pediatric coronary artery fistulas. J Thorac Cardiovasc Surg 2016; 152: 1123-30.
17. Yim D, Yong MS, d’Udekem Y, Brizard CP, Konstantinov IE. Early surgical repair of the coronary artery fistula in children: 30 years of experience. Ann Thorac Surg 2015; 100: 188-94.
18. Bruckheimer E, Harris M, Kornowski R, Dagan T, Birk E. Transcatheter closure of large congenital coronary-cameral fistulae with Amplatzer devices. Catheter Cardiovasc Interv 2010; 75: 850-4.
19. Zhang ZG, Xu XD, Bai Y, et al. Transcatheter closure of medium and large congenital coronary artery fistula using wire-maintaining technique. J Cardiol 2015; 66: 509-13.
20. Mottin B, Baruteau A, Boudjemline Y, et al. Transcatheter closure of coronary artery fistulae in infants and children: A French multicenter study. Catheter Cardiovasc Interv 2016; 87: 411-8.
21. Chen PF, Tang L, Liu ZZ, Hu X. Superior vena cava syndrome secondary to recurrent coronary artery fistula: A case report and literature review. Med (Baltim) 2017; 96: e9111.
22. Li YF, Zhang ZW, Wang SS, Xie ZF, Zhang X, Li YF. Transcatheter closure of congenital coronary artery fistulae with a giant coronary artery aneurysm in children: experiences from a single center. Chin Med J (Engl) 2017; 130: 1919-25.
23. Gowda ST, Forbes TJ, Singh H, et al. Remodeling and thrombosis following closure of coronary artery fistula with review of management: large distal coronary artery fistula—too close or not to close? Catheter Cardiovasc Interv 2013; 82: 132-42.
24. Valente AM, Lock JE, Gauvreau K, et al. Predictors of long-term adverse outcomes in patients with congenital coronary artery fistulae. Circ Cardiovasc Interv 2010; 3: 134-9.
25. Ponthier L, Brenot P, Lambert V, Petit J, Riou JY, Baruteau AE. Closure of isolated congenital coronary artery fistula: long-term outcomes and rate of re-intervention. Pediatr Cardiol 2015; 36: 1725-34.