"Percutaneous" technique for direct external access to and stenting of obstructed pediatric ventricular assist device inflow cannula

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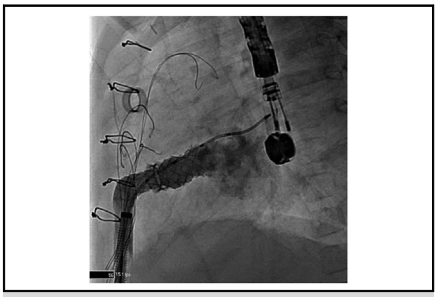


Stented Berlin Heart ventricular assist device inflow cannula with resolution of obstruction. Angiographic injection from the 8 Fr Flexor Ansel long sheath within the Berlin Heart inflow cannula following placement of an 8 × 29 mm Viabahn VBX covered stent within the Gore-Tex chimney inflow cannula apparatus.

Video clip is available online.

CENTRAL MESSAGE

We used a novel approach to access the Berlin Heart inflow cannula to stent the obstructed Gore-Tex chimney inflow apparatus, resulting in relief of the obstruction and resolution of left atrial hypertension.

The Berlin Heart EXCOR pediatric ventricular assist device (VAD) is the preferred durable mechanical support in small infants.[1,2] Alternative cannulation strategies have emerged to better support small or restrictive ventricles. Mechanical device malfunctions include inflow or outflow cannula obstructions secondary to thrombosis, fibrin deposit, cannula

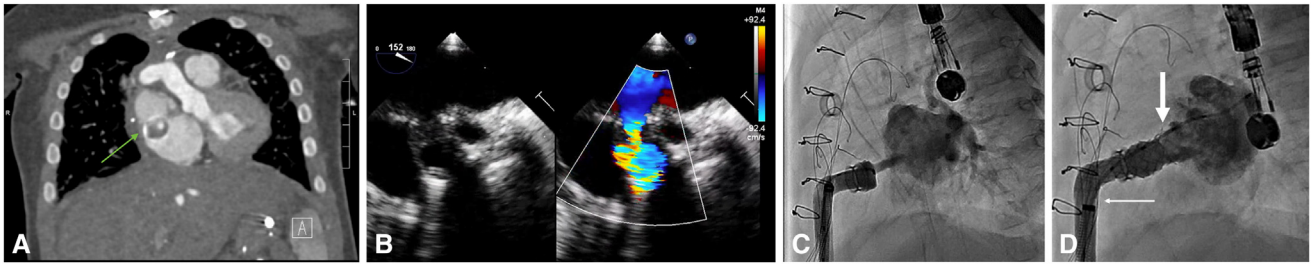


FIGURE 1. A, Computed tomography scan coronal projection with in-cannula narrowing (*green arrow*). B, Transesophageal echocardiogram showing narrowing within the Gore-Tex graft (mean inflow gradient, 87 mmHg). C, Lateral projection angiography demonstrating longitudinal narrowing within the Gore-Tex graft distal to the EXCOR inflow ring and proximal to the LA. D, Lateral projection angiography following stent placement showing the distal aspect of the stent apposed to the atrial septum at the entrance to the LA (*thick arrow*) and the proximal aspect of the stent within the inflow cannula (*thin arrow*). The stent is 8 mm in diameter and 29 mm long; the distal end covers the length of the chimney graft. The proximal aspect of the stent was postdilated with 10- and 12-mm balloons to conform with the Berlin curvature of the inflow cannula. The stent was 9.6 mm in diameter at the LA insertion site and 23 mm long. The LA pressure following stent placement was 12 mmHg, and the echocardiographic mean gradient was <2 mmHg.

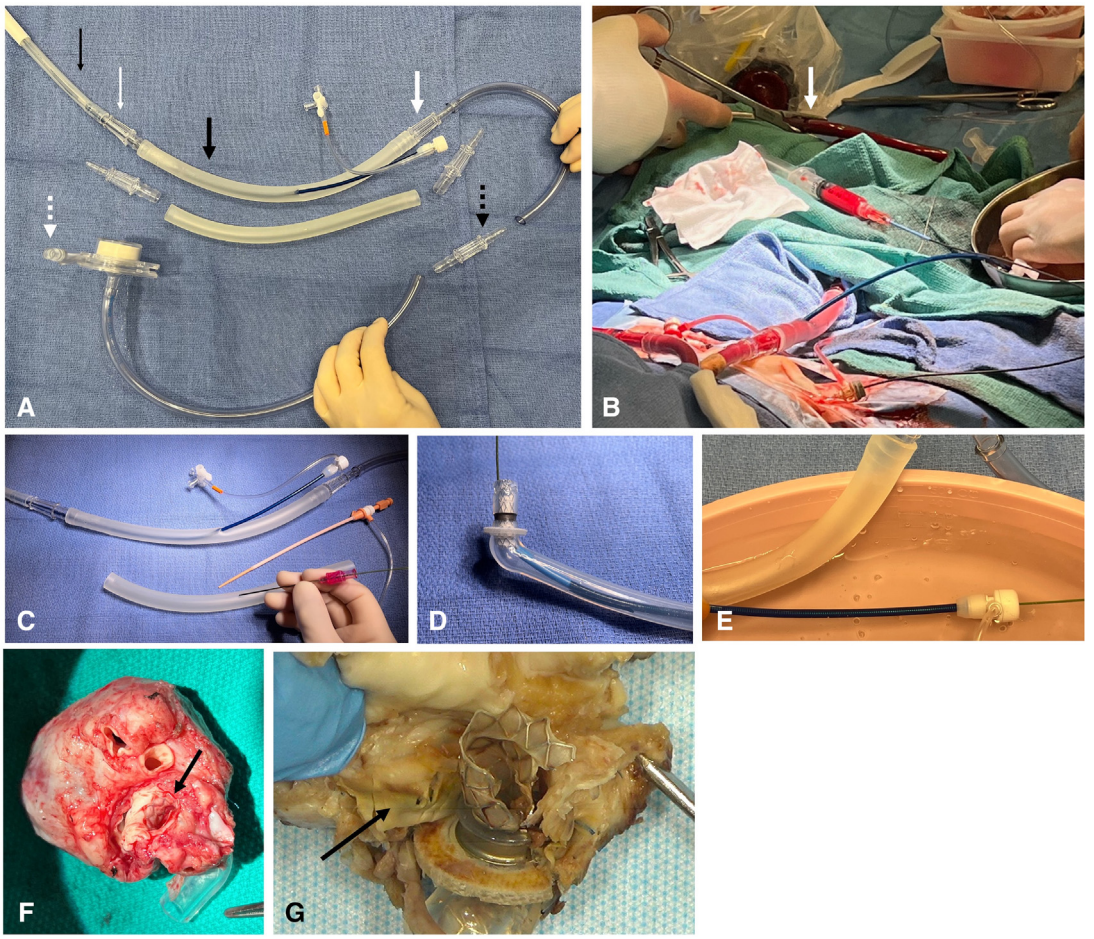
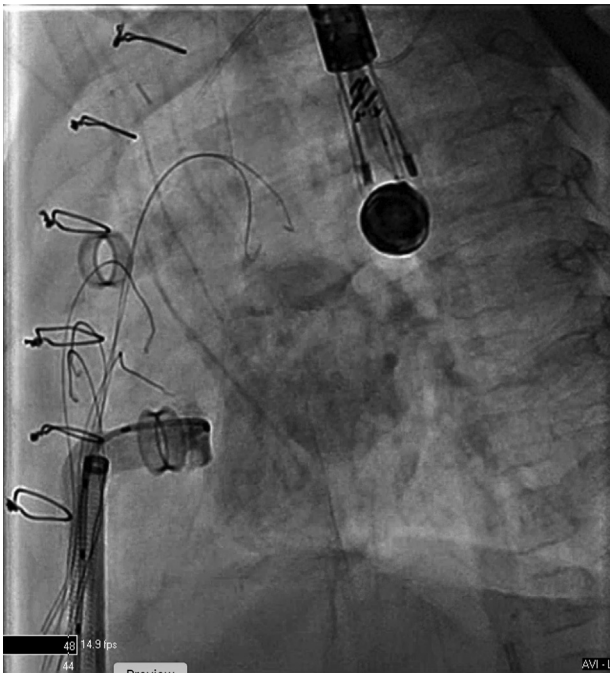


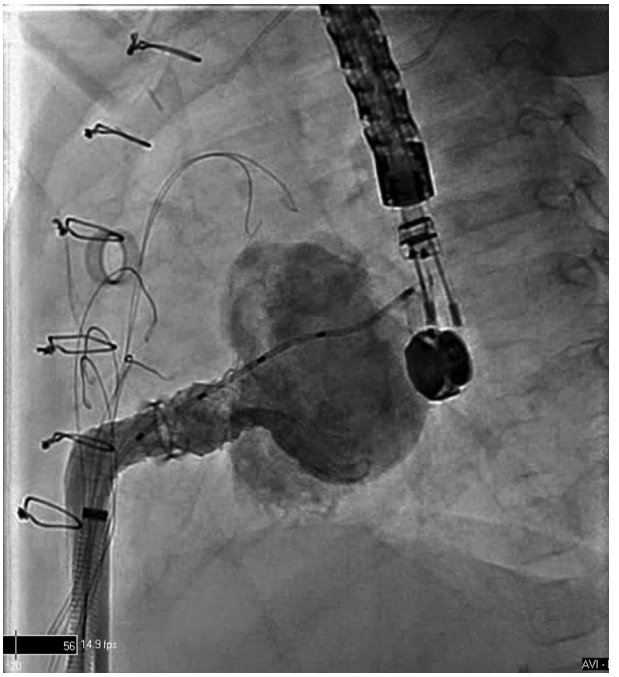
FIGURE 2. A, The 6-mm Berlin inflow cannula (*black thin arrow*) was disconnected temporarily from the Berlin Heart EXCOR pump and attached to the silicone Pleur-Evac tubing (*black thick arrow*) using a 1/4″-to-3/8″ straight connector (*white thin arrow*). The silicone tubing was connected to the Pedimag tubing using a 3/8″-to-1/4″ straight connector (*white thick arrow*). This configuration includes the option to include a right internal jugular venous inflow limb with a Y-connector if additional hemodynamic support is required during periods when the Pedimag is clamped. (The Y-connector can be placed at the position of the *black dashed arrow*.) The Pedimag outflow (*white dashed arrow*) was connected to an oxygenator membrane. The membrane outflow was connected to the previously existing patient Berlin outflow cannula, which was anastomosed to the ascending aorta. B, The Pedimag tubing distal to the silicone Pleur-Evac tubing was clamped prior to access (*thick white arrow*). (C) Using the Seldinger technique, an 18G introducer needle with a preloaded 0.035″ Magic Torque guidewire was introduced into the silicone Pleur-Evac tubing. An 8 Fr Flexor Ansel long introducer sheath was was lubricated with saline flush and advanced over the 0.035″ Magic Torque guidewire to the end of the existing Berlin inflow cannula prior to the Gore-Tex chimney. The silicone formed a very tight seal around the long sheath. Care was taken not to exit the Berlin inflow cannula into the Gore-Tex chimney graft to avoid perturbation of the graft contents. The dilator was removed, and the Magic Torque guidewire was advanced through the Gore-Tex graft to the left upper pulmonary vein. D, A GORE Viabahn VBX stent was implanted within the Gore-Tex chimney graft using transesophageal and fluoroscopic guidance. E, The sheath hemostatic valve was placed underwater during periods of wire and stent manipulation, to limit the risk of air entrainment. The Pedimag tubing was clamped intermittently during these periods (B). F, Explanted heart demonstrating the stented Gore-Tex graft at its insertion into the LA (*black arrow*). G, Preserved explanted heart following dissection of the Gore-Tex graft (*black arrow*) away from the stent, revealing no thrombus or fibrin deposition to account for graft narrowing.

malposition-related kinking/twisting, or infection.[3] Although there are reports of endovascular access to and stenting of outflow VAD cannulas, interventions within inflow cannulas are rarely reported, and direct external access to the cannula has been described only once.[4-6] We describe a novel hybrid approach of external access to the EXCOR inflow cannula to facilitate stenting of inflow obstruction. The patient's legal guardian (mother) provided verbal consent for publication of study data; Institutional Review Board approval was not required.

A female infant with Shone's-like complex underwent aortic coarctation and mitral valve repair at 75 days of age. Left atrial (LA) hypertension persisted secondary to diastolic dysfunction and mitral stenosis. At age 5 months, she



VIDEO 1. As shown in Figure 1, *C*, lateral projection angiography from the long Flexor introducer sheath within the EXCOR cannula demonstrating longitudinal narrowing within the Gore-Tex chimney graft distal to the EXCOR inflow ring and proximal to the left atrium. Video available at: https://www.jtcvs.org/article/S2666-2507(23)00272-9/fulltext.



VIDEO 2. As shown in Figure 1, *D*, angiography from the long Flexor introducer sheath demonstrating unobstructed flow from the left atrium through the stented Gore-Tex chimney and into the EXCOR inflow cannula. Video available at: https://www.jtcvs.org/article/S2666-2507(23)00272-9/fulltext.

underwent Berlin Heart EXCOR pediatric VAD implantation to decompress the LA while awaiting heart transplantation. We used a previously described novel LA cannulation strategy in which a 10-mm-diameter Gore-Tex ringed "chimney" graft was extended from the inflow cannula through a right atriotomy and anastomosed to a surgically created 10-mm-diameter atrial septal defect.[7] This approach offers enhanced atrial unloading, which is advantageous in restrictive physiology.

On VAD day 201, incomplete pump filling was noted. Progressive emesis and a rising brain natriuretic peptide level prompted surveillance catheterization, which revealed a pulmonary capillary wedge pressure (PCWP) of 24 mmHg, indicating LA hypertension, with a preserved cardiac index of 4.0 L/min/m^2 by thermodilution. The VAD heart rate was increased, with an immediate decrease in PCWP to 17 mm Hg. Following these maneuvers, there was persistent pulmonary edema, acute kidney injury, and ventilator dependence with ongoing incomplete VAD filling.

A computed tomography (CT) scan demonstrated longitudinal narrowing of the chimney graft with a residual lumen of 2 to 3 mm, suggestive of a circumferential mural clot (Figure 1, *A*). The standard prophylactic anticoagulation regimen, including bivalirudin and clopidogrel, was continued. The surgical risk of VAD replacement was deemed very high given the patient's prior sternotomies, size, and comorbid state, and thus a hybrid-based approach was preferable. The objective was to stent the obstructed chimney graft while minimizing the risks of (1) clot and air embolus, (2) new clot formation, and (3) prolonged interruption of VAD support. We describe our approach and equipment in detail in Figure 2.

The patient had normal systolic function with native aortic valve opening and thus was at risk of periprocedural thromboembolism via native left ventricular ejection. The right internal jugular vein was prepared for possible extracorporeal membrane oxygenation cannulation to reduce left ventricular preload and limit aortic valve opening. In brief, the Berlin Heart EXCOR VAD was exchanged for a Pedimag continuous-flow VAD and oxygenator membrane (Figure 2). The oxygenator membrane served as a filter to prevent aspirated clot or entrained air from entering the outflow cannula. An intervening segment of silicone Pleur-Evac tubing was placed between the distal inflow cannula and the VAD tubing. A long Flexor Ansel introducer sheath was inserted into the silicone tubing using the Seldinger technique while the VAD tubing was temporarily clamped. Given the potential for air entrainment during manipulation of the sheath hemostatic valve, the valve was submerged under water, and the VAD system was intermittently clamped during periods of wire or catheter manipulation. Angiography demonstrated long segment graft narrowing to 2.4 mm (Figure 1, *C*, Video 1). An 8 × 29 mm Viabahn VBX covered stent was implanted under transesophageal echocardiography (TEE) and

fluoroscopic guidance (Figure 1, *D*, Video 2). TEE monitoring throughout demonstrated no evidence of clot embolization.

A CT head scan before the procedure and 2 sequential CT head scans after the procedure demonstrated no evidence of a thromboembolic event. The patient was extubated 3 days later and underwent orthotopic heart transplantation on VAD day 246.

The explanted heart revealed no clot or fibrin between the stent and chimney graft (Figure 2, *G* and *H*). Given that there was no evidence of thrombus, an alternative theorized mechanism of inflow obstruction is progressive stretching and luminal narrowing of the chimney graft as a result of an LA septal position shift following decompression and reduced size of the LA, as well as normal cardiac growth, predisposing to cannula twisting or stretching. Close monitoring with a low threshold for cross-sectional image acquisition of patients supported by the Berlin Heart EXCOR for evidence of device malfunction is essential to detect such disturbances to the cannulas. Direct access to VAD cannulas as we describe can be used to accurately diagnose cannula malfunction and intervene on detection of a dysfunctional cannula.

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