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FEATURED INNOVATION

Transcatheter Potts shunt creation in patients with severe pulmonary arterial hypertension: Initial clinical experience

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BACKGROUND: Patients with severe pulmonary arterial hypertension (PAH) face significant morbidity and death as a consequence of progressive right heart failure. Surgical shunt placement between the left PA and descending aorta (Potts shunt) appears promising for PAH palliation in children; however, surgical mortality is likely to be unacceptably high in adults with PAH.

METHODS: We describe a technique for transcatheter Potts shunt (TPS) creation by fluoroscopically guided retrograde needle perforation of the descending aorta at the site of apposition to the left PA to create a tract for deployment of a covered stent between these vessels. This covered stent—anchored by the vessel walls and surrounding tissue—serves as the shunt.

RESULTS: TPS creation was considered in 7 patients and performed in 4. The procedure was technically successful in 3 patients; 1 patient died during the procedure as a result of uncontrolled hemothorax. One acute survivor, critically ill at the time of TPS creation, later died of comorbidities. The 2 mid-term survivors (follow-up of 10 and 4 months) are well at home, with symptomatic improvement and no late complications. The 3 candidate patients in whom the procedure was not performed died within 1 month of consideration, underscoring the tenuous nature of this population.

CONCLUSIONS: TPS creation is feasible and may offer symptomatic relief to select patients with refractory PAH. Further study of this innovative approach is warranted.

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Pulmonary arterial hypertension (PAH) imposes a significant burden of morbidity and death on affected patients.[1] Survival in recalcitrant, World Health Organization (WHO) functional class IV patients is measured in months and is associated with progressive decline of right ventricular (RV) function. This final common pathway leads to worsening symptoms and sudden death. Lung transplantation is an option for some patients, although waiting list mortality is significant and the long-term prognosis remains guarded.[2,3] The value of altering RV loading conditions by creating an atrial septal defect (ASD) is debated; its role, therefore, in the management of severe PAH remains limited.[4]

Given reports of long-term survival in patients with Eisenmenger syndrome due to persistent patent ductus arteriosus,[5–7] an anastomosis between the left PA (LPA) and the descending thoracic aorta (DAo)—a Potts shunt—may

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present an alternative palliative strategy. Surgical creation of a Potts shunt for management of PAH[8] has been pursued. Although procedural mortality is high (25%), late results are encouraging, with all procedural survivors having improved functional status and no late deaths.[9]

Catheter-based creation of a Potts shunt, previously reported in animals without PAH,[10,11] may be an attractive option. Since April 2012, we have considered transcatheter Potts shunts (TPSs) in 7 patients and referred 4 for this novel approach. This report describes patient selection, technical details, and short-term results.

Methods

This study was conducted with institutional oversight provided through an "innovative therapy" framework. This approach ensures patient protection and arms-length review for therapies driven primarily by clinical need and considered too novel to yet conform to a research protocol.

Patient selection

Patients with severe PAH and intractable symptoms, despite intensive advanced therapies, who were at significant risk of sudden death, were identified by their primary cardiologist or pulmonologist. Pre-procedural clinical features and imaging data were reviewed by a multidisciplinary team to assess anatomic suitability (Figure 1). If multidisciplinary review recommended proceeding, knowledgeable physicians and surgeons not directly involved in the care of the candidate patients performed peer review before approving the procedural attempts. Informed consent detailed potential risks from bleeding, uncontrolled cyanosis, thromboembolism, or hemodynamic decompensation.

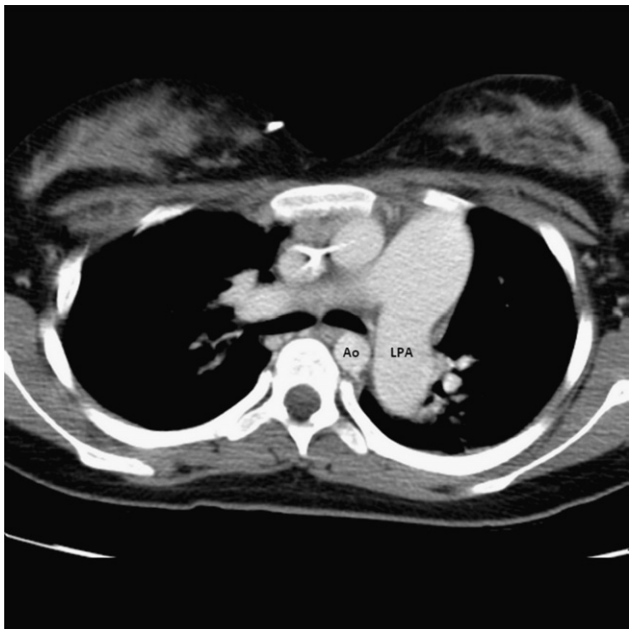

Figure 1 Chest computed tomography of Patient 3 demonstrates the close apposition of the dilated left pulmonary artery (LPA) and descending aorta (Ao). Pre-procedural computed tomography was performed in all patients.

Description of the procedure

With the patient under general anesthesia and using mechanical ventilation, access was obtained in the femoral artery (9F short sheath) and vein (7F short sheath) in a biplane catheterization laboratory. Hemodynamic right heart catheterization was performed. Angiography delineated the relationship of the LPA and DAo, and camera angles used pre-procedural imaging to maximize the separation between the 2 vessels at their point of apposition.

A 7F Judkins Left catheter (Boston Scientific, Maple Grove, MN) positioned a vascular snare in the LPA at the target site (Figure 2A). The back ("stiff") end of a 0.014-inch" Stabilizer wire (Cordis, Bridgewater, NJ) was sharpened using a sterile Diamond-Tip Rasp bone file (CareFusion, San Diego, CA). A Brockenbrough transseptal needle was shaped to exaggerate the distal bend to increase the angle of attack against the aortic wall. A 7F long sheath was placed in the upper DAo. The shaped transseptal needle was then advanced through the aortic sheath over a standard 0.014-inch wire to prevent the tip of the needle from damaging the dilator wall. The needle/long sheath unit engaged the aortic intima/media, and contrast was injected to stain the aortic wall at the intended level of the shunt (Figure 2B). With the intramural position of the needle tip confirmed—and the angle relative to LPA lumen considered adequate—the sharpened stiff end of the 0.014-inch wire was introduced and thrust out of the distal lumen of the needle into the LPA.

Once the sharp wire was in the LPA, the needle and dilator of the long sheath were replaced with a low-profile 3.5- × 20-mm Quantum Maverick coronary balloon catheter (Boston Scientific) advanced into the LPA, and the wire was removed. Contrast injected through the lumen of the balloon catheter confirmed that its tip was free in the LPA. The soft end of a new wire advanced through the catheter was captured with the pre-positioned vascular snare. The long sheath was advanced to the aortic wall, and the balloon was retracted and inflated so that the taper of the balloon engaged the end of the long sheath. This balloon-sheath complex was then advanced into the LPA by simultaneously pushing on the long sheath and pulling on the snared wire tip, with the balloon effectively functioning as a "dilator" for the sheath (Figure 2C). By using this method, the perforations in the DAo and LPA walls were nearly continuously tamponaded by the balloon catheter, the inflated balloon, or the long sheath.

With the long sheath in the LPA, the balloon was deflated, removed, and replaced with an iCAST 7- × 22-mm covered stent (Atrium Medical, Hudson, NH). The stent was positioned to span the LPA and DAo walls. The LPA end was partially unsheathed and inflated; this distal "trumpet" was retracted until it engaged the LPA wall. Balloon inflation proceeded with continued steady retraction of the sheath, gradually uncovering the aortic end of the stent. The balloon was deflated, leaving the stent anchored by the elastic recoil of the aortic and LPA walls (Figure 2D). Aortography was repeated and final hemodynamics recorded (aortic and LPA pressure and saturation). Sheaths were removed, and hemostasis was achieved with direct pressure.

Results

Of 7 patients considered for TPS creation, 4 were catheterized with the intent to perform TPS. TPS creation was performed successfully in 3 patients; in the fourth (our most recent patient), the case was complicated by intrathoracic bleeding, which was fatal. Demographic and

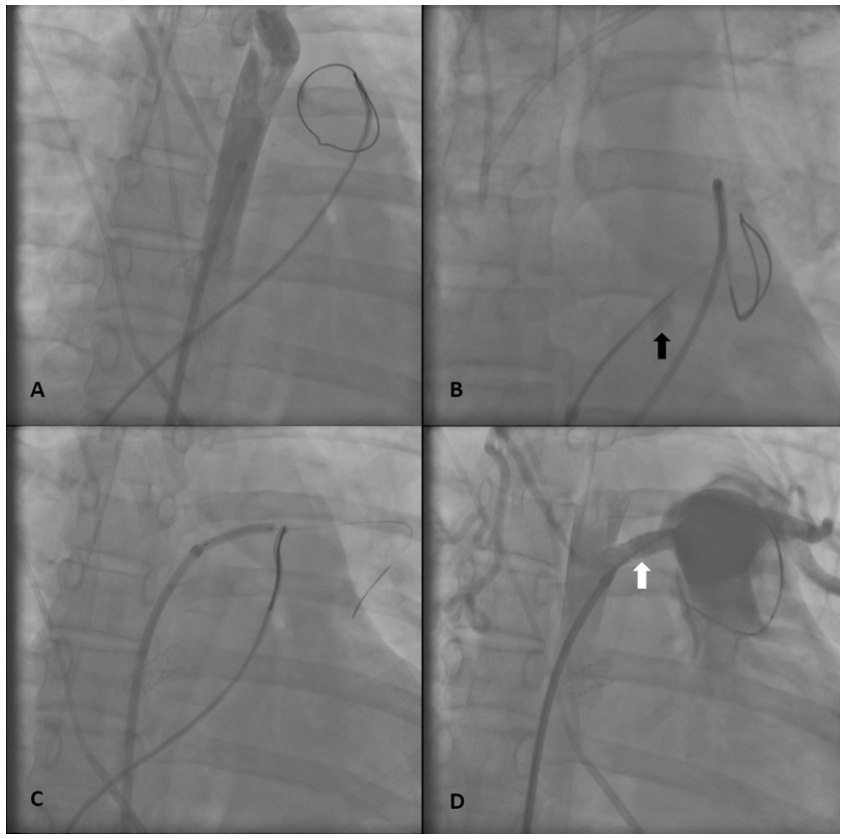

Figure 2 (A) A snare is positioned in the left pulmonary artery (LPA). A descending aortogram demonstrates proximity of the descending thoracic aorta (DAo) to the LPA. (B) The aortic wall has been engaged and stained (black arrow) with a transseptal needle. The sharpened end of a Stabilizer wire has been advanced through the vessel walls into the lumen of the LPA. (C) With a Maverick balloon used as a "dilator," the long sheath is advanced from DAo into the LPA. The Stabilizer wire has been snared to allow the balloon-sheath complex to be both pulled and pushed across the vessel walls. (D) Descending aortogram after covered stent placement delineates the newly created Potts shunt (white arrow).

procedural data are summarized in Table 1, with additional clinical observations outlined below.

Patient 1

A 35-year-old woman with longstanding idiopathic PAH suffered from worsening dyspnea, hypoxemia, and extreme exercise intolerance despite therapy with epoprostenol, ambrisentan, sildenafil, and oxygen. She was deemed ineligible for lung transplantation and subsequently developed new-onset angina. Echocardiography demonstrated a dilated RV with moderate systolic dysfunction and compression of her LV by the hypertensive RV. Chest computed tomography revealed severely dilated PAs and raised concern for left main coronary artery (LCA) compression by the LPA (vs RV ischemia due to severe PAH). She was referred for diagnostic catheterization and possible TPS creation.

LCA angiography suggested compression of the LCA, but this was not felt to be flow-limiting. There was no evidence of more distal coronary disease. Systolic PA and RV pressures were supra-systemic. A TPS was created, producing predominantly right-to-left shunt flow. The shunt was pressure restrictive; PA pressure remained supra-systemic.

Intermittent systemic hypotension occurred throughout the procedure, requiring dopamine infusion and boluses of phenylephrine. Of note, before TPS placement, the balloon traversing the aortic and LPA walls ruptured, resulting in extravasation of a small volume of contrast into the mediastinum. The tract was re-crossed to allow placement of the stent, and repeat angiography did not reveal any residual extravasation. The patient was extubated and transported to the cardiac intensive care unit (ICU). Her anginal symptoms improved, and post-procedural imaging revealed a patent stent in stable position (Figure 3A and B). She was discharged home 6 days later.

With worsening anginal symptoms 4 months later, the patient underwent repeat catheterization. Her PA pressures were systemic. Saturations were 68% in the LPA, 92% in the ascending aorta, and 86% in the DAo, suggesting significant right-to-left shunting via the TPS. Coronary angiography revealed significant LCA compression, as evidenced by collaterals from the right coronary circulation supplying the left anterior descending territory. Intravascular ultrasound imaging confirmed a slit-like orifice of the LCA consistent with compression. A bare-metal stent was placed.

Table 1 Patients Considered for Transcatheter Potts Shunt Creation

Pt	Age (years)	Diagnosis	Associated diagnoses	Indication	PAP/AoP[a]	Case time (min)	Fluoroscopy time (AP, lateral) (min)	Cause of death	Follow-up
1	33	IPAH	…	Angina, exercise intolerance	1.1	72	26.9, 6.2	N/A	10 months
2	40	IPAH	BMT, GVHD	End-stage RV failure	1.0	152	57.9, 18.3	Pneumonia	5 days
3	18	IPAH	…	Recurrent near-syncope	0.9	74	35.4, 12.1	N/A	4 months
4	47	IPAH	Hepatitis C, BAD	Exercise intolerance	1.3	240	105.1, 17.8	Massive hemothorax	…
5	75	COPD	Pneumonectomy	Exercise intolerance	1.0	…	-	Sudden death	1 month
6	20	IPAH	Viral pneumonia	Recurrent syncope (in-hospital)	0.9	…	…	PAH crisis	1 day
7	62	IPAH	DIP	Exercise intolerance	0.9	…	…	PEA arrest	1 month

AoP, aortic pressure; AP, anteroposterior; BAD, bipolar affective disorder; BMT, bone marrow transplantation; COPD, chronic obstructive pulmonary disease; DIP, desquamative interstitial pneumonitis; GVHD, graft-vs-host disease; IPAH, idiopathic pulmonary arterial hypertension; PAP, pulmonary arterial pressure; N/A, not applicable; PEA, pulseless electrical activity; Pt, patient; RV, right ventricle.

[a]Ratio of systolic pulmonary artery pressure to systolic aortic pressure measured at cardiac catheterization.

The patient is angina-free at home 10 months after the procedure. She participates in a cardiopulmonary rehabilitation program. Her shunt remains patent, and her systemic saturation is 90%.

Patient 2

A 40-year-old man developed graft-vs-host disease 6 years after stem cell transplantation for acute myelogenous leukemia, resulting in exercise intolerance (WHO class III) due to PAH. Near-systemic RV pressures were demonstrated at catheterization, and he was started on intravenous treprostinil with modest clinical improvement. Progressive RV failure unresponsive to inhaled milrinone and epoprostenol developed 2 weeks before TPS creation. Echocardiography showed severe tricuspid regurgitation, severe RV dysfunction, and systolic bowing of the interventricular septum into the LV. His clinical course deteriorated despite aggressive ICU management (requiring 3 inotrope infusions), with elevated central venous pressure (CVP) and acute kidney injury.

He was brought to the catheterization laboratory in hopes of rescuing the failing RV. Although the initial PA systolic pressure was sub-systemic, a minor reduction in his level of pharmacologic support resulted in isosystemic PA pressure. A Potts shunt was created. Six passes with the sharp wire were needed to convincingly enter the LPA lumen. Notably, the tracts created by this 0.014-inch wire did not produce any detectable aortic bleeding. After placing the covered stent, we noted that its LPA end only just reached the LPA lumen. To prevent stent displacement, a bare-metal stent was telescoped within the iCAST stent, projecting approximately 2 mm further into the LPA. He was transported back to the cardiac ICU. He improved over 48 hours, with declining inotrope requirements, a reduction in CVP, and improved urine output. However, he developed ventilator-associated pneumonia with multiorgan dysfunction and he died on Post-procedure Day 5 of reasons clinically felt to be unrelated to the TPS. Request for autopsy was declined.

Patient 3

An 18-year-old woman with longstanding idiopathic PAH had recurrent near-syncope despite treatment with continuous intravenous treprostinil, sildenafil, and oxygen, and placement of an atrial septal stent. Echocardiography demonstrated a dilated RV with normal systolic function and a mildly restrictive ASD stent. A 7-mm TPS was placed without incident. As in Patient 1, the Maverick balloon burst while advancing the long sheath into the LPA, without detectable bleeding. She was extubated at the end of the procedure and was discharged on Post-procedure Day 2.

On Post-procedure Day 8 she was seen in outpatient follow-up. She felt well, and recorded her best-ever 6-minute walk distance (1,300 feet vs 1,132 feet pre-TPS). Arterial saturations by finger oximetry were 98% before exertion and 92% after exertion. Echocardiogram confirmed stable stent position with bidirectional shunting (Figure 3C and D). At 4 months of follow-up, she was clinically stable with improved symptoms.

Patient 4

A 47-year-old man with a 6-year history of idiopathic PAH developed worsening exercise intolerance during the 6 months before referral. He was treated with bosentan, sildenafil, inhaled treprostinil, and the investigational agent nilotinib. For psychiatric and social reasons, he and his family were not able to administer continuous intravenous prostanoids nor was he deemed eligible for lung transplantation. A recent diagnostic catheterization revealed borderline cardiac output, low mean right atrial (RA) pressure, and near-systemic PA pressure. Echocardiography

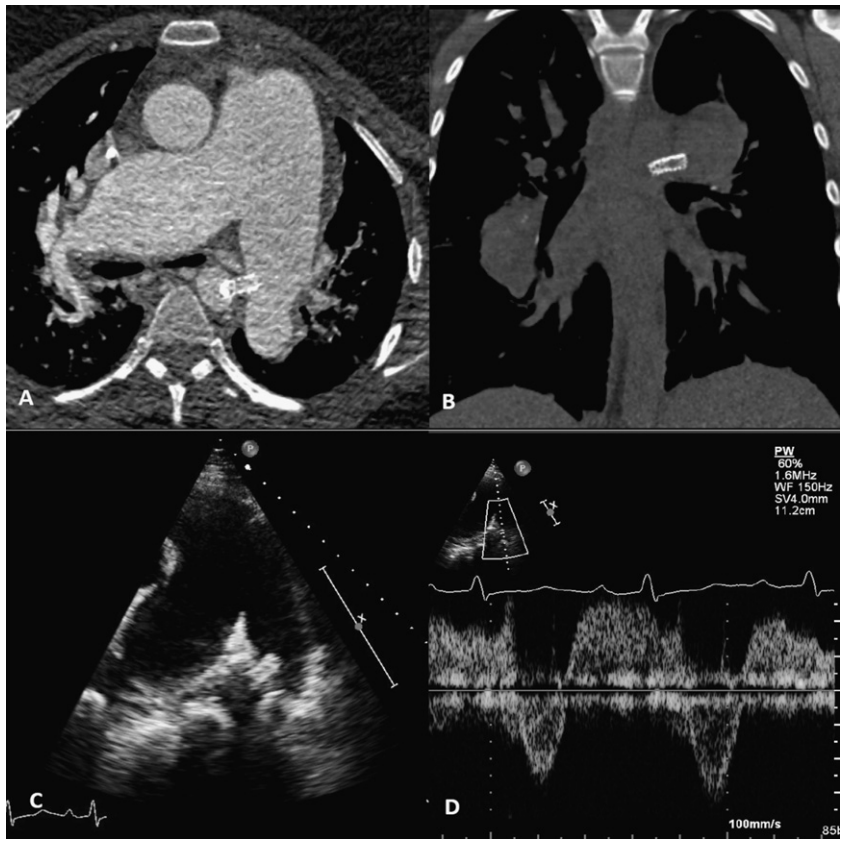

Figure 3 (A) Axial slice from post-procedure computed tomography (CT) in Patient 1 reveals the stent to be in the expected location, bridging the left pulmonary artery (LPA) and descending thoracic aorta (DAo). (B) Coronal slice from post-procedure CT in Patient 1 further demonstrates the relationship between the LPA, DAo, and covered stent. (C) Post-procedure echocardiogram from Patient 3 delineates the Potts shunt. (D) Pulse wave Doppler through the covered stent in Patient 3 reveals flow to be bidirectional.

demonstrated moderate RV dysfunction and moderate tricuspid valve regurgitation.

The procedural catheterization revealed marked hemodynamic deterioration relative to his prior baseline: cardiac index was reduced, there was severe RA hypertension, and systolic RV/PA pressures were 20 mm Hg supra-systemic. The case was uniquely challenging due to the patient's height (191 cm), requiring several substitutions of standard sheaths and catheters. Ultimately, a long sheath was passed from the DAo into the LPA. Snare malfunction (failure to release snared wire) necessitated complex manipulations to remove the Maverick balloon, and during this process, the long sheath fell back into DAo. Although position was re-established, extravasation of blood and contrast into the mediastinum led to a dynamic increase in the distance between the DAo and LPA. This change in distance rendered the length of the chosen stent (22 mm) several millimeters too short to span the tract between the great vessels. Covered stent placement thus left the aortic defect uncovered and resulted in uncontrolled intrathoracic bleeding. Despite massive volume resuscitation, surgical consultation, and extracorporeal membrane oxygenation cannulation, the bleeding could not be controlled and the patient died.

Of the 3 additional patients considered for TPS placement, 1 died suddenly 1 week before multidisciplinary review, 1 was reviewed and deemed insufficiently symptomatic yet died suddenly 1 month later, and 1 (in the ICU) died 12 hours after review. The precipitous deaths of these 3 patients underscore the degree of morbidity and mortality in our target population and the ongoing need for effective strategies for RV rescue.

Discussion

Idiopathic PAH has a bleak natural history, and medical intervention remains inadequate.[12] Progressive RV failure and/or sudden death may be due to arrhythmia, RV ischemia, or acute RV decompensation with impairment of cardiac output.[12–14] Measures of RV function carry important prognostic significance,[12–14] and altering the RV loading conditions is the ultimate goal of all PAH treatment.

Strategies for management of severe PAH comprise drug therapy, transplantation, and anatomic modification. Pulmonary vasodilators and advanced PAH medical therapies are effective,[4,15] and registries and randomized controlled trials both suggest that these therapies have favorably modified the natural history of PAH.[16] Lung transplantation is often considered "definitive" therapy, but a large single-center experience reported that 46% of PAH patients were ineligible, refused transplantation, or died before assessment and listing.[3] Attrition after transplantation is significant.[2,3]

Anatomic therapy has been limited to ASD creation or—recently—surgical placement of a Potts shunt. ASD creation has had limited success: reports suggest 7% mortality within 24 hours of the procedure and 15% at 1 month.[17] Deaths have been due to hypoxia, progressive RV failure, direct procedural complications, multiorgan failure, and hemoptysis. Morbidity may arise from exposure of the cerebral circulation to hypoxemia and paradoxical emboli. Spontaneous ASD closure is common.[18,19]

Thus, Blanc et al[8] described surgical Potts creation for PAH palliation in 2004, and a 2012 report described experience with 8 children (median age, 8 years).[9] All were in WHO functional class IV; 6 had recurrent syncope. The surgical shunt in these patients was large (9 ± 3 mm). Two patients died within 14 days of the procedure of pulmonary hypertensive crises after advanced PAH medical therapy was discontinued. The 6 surviving patients remained alive at a mean follow-up of 63 months. All had improved functional status, as well as improved 6-minute walk distances and lower brain natruretic peptide levels.

In the setting of systemic and supra-systemic PA pressure, several potential advantages of a Potts shunt over ASD are apparent. Because right-to-left shunting is into the DAo, the brain and myocardium are spared exposure to desaturated blood and paradoxic emboli. TPS patency may be more reliable than that of an ASD, and shunting does not depend on RA hypertension. Uncontrolled hypoxemia can be avoided by use of a pressure-restrictive shunt. Such a shunt could potentially be closed at future catheterization should the clinical situation warrant. Finally, because this strategy directly alters the effective resistance faced by the RV, there is reason to suggest that it may be a more effective method of reducing RV afterload.

Surgical Potts shunt creation therefore appears promising as a rescue for pediatric patients with severe PAH. However, the risks of thoracotomy and sternotomy in adults with refractory PAH are significant; indeed, the patients in whom we created a TPS could not reasonably be put forward as candidates for surgical creation of a Potts shunt.

In 3 of our patients, TPS creation was technically successful and well tolerated. In particular, small amounts of intrathoracic bleeding due to balloon rupture and vessel perforation with a 0.014-inch wire were clinically inapparent. The death of our fourth patient highlights the risks of this procedure: in patients this fragile, uncontrolled intrathoracic bleeding is unlikely to be recoverable. The dynamic nature of the geometry involved with shunt placement—that is, the potential for the distance between the DAo and LPA to increase during the procedure as a result of blood or contrast extravasation into the mediastinum—presents a challenge uncommonly encountered in interventional cardiology.

Several modifications to the procedure could help overcome this challenge. Placement of additional angiographic catheters in the LPA and DAo would allow repeated reassessment of tract length during stent placement. Use of a longer stent could provide a greater safety margin, although an excess of covered stent projecting into the great vessels might adversely affect thromboembolic risk and/or shunt patency. Focused attention to patient size and height and appropriate planning may reduce the need for excessive catheter and sheath manipulation with resultant loss of control of the arteriotomy sites.

We chose a pressure-restrictive shunt to help patients who were only intermittently supra-systemic and to avoid profound lower body cyanosis. If too small, the stent could be post-dilated to a greater diameter. Optimal shunt size remains to be determined, and resistance to flow will obviously be affected by shunt length.

Although this procedure and the resultant physiology have been well tolerated in the short-term, we recognize the potential for late complications. As in patients with Eisenmenger syndrome, chronic lower extremity cyanosis could result in erythrocytosis, renal dysfunction, hypertrophic osteoarthropathy, or gout.[20] There remains the possibility of paradoxic embolism to the lower body. The durability of a covered stent in this position is unclear.

Given the markedly contracted lifespan and the functional impairment facing patients with severe refractory PAH, new strategies for RV salvage—even ones with significant associated risk—remain worthy of pursuit. Although many questions remain unanswered about the efficacy and long-term safety of TPS creation, this approach warrants further cautious and deliberate study. Attempts to move forward with this procedure must address the potential for catastrophic hemothorax, and patient selection must proceed with this risk in mind. We remain hopeful that further technical refinement can minimize procedural mortality and that further study will more clearly define the full potential of TPS creation as a therapy for this fragile and challenging population.

Disclosure statement

None of the authors has a financial relationship with a commercial entity that has an interest in the procedure described in the presented manuscript or other conflicts of interest to disclose.

References

1. Humbert M, Sitbon O, Chaouat A, et al. Pulmonary arterial hypertension in France: results from a national registry. Am J Respir Crit Care Med 2006;173:1023-30.
2. Chen H, Shiboski SC, Golden JA, et al. Impact of the lung allocation score on lung transplantation for pulmonary arterial hypertension. Am J Respir Crit Care Med 2009;180:468-74.
3. de Perrot M, Granton JT, McRae K, et al. Outcome of patients with pulmonary arterial hypertension referred for lung transplantation: a 14-year single-center experience. J Thorac Cardiovasc Surg 2012;143:910-8.
4. McLaughlin VV, Archer SL, Badesch DB, et al. ACCF/AHA 2009 expert consensus document on pulmonary hypertension: a report of the American College of Cardiology Foundation task force on expert consensus documents and the American Heart Association: developed in collaboration with the American College of Chest Physicians,

American Thoracic Society, Inc., and the Pulmonary Hypertension Association. Circulation 2009;119:2250-94.
5. McManus BM, Hahn PF, Smith JA, Roberts WC, Jackson JH. Eisenmenger ductus arteriosus with prolonged survival. Am J Cardiol 1984;54:462-4.
6. Saha A, Balakrishnan KG, Jaiswal PK, et al. Prognosis for patients with Eisenmenger syndrome of various aetiology. Int J Cardiol 1994;45:199-207.
7. Wood P. The Eisenmenger syndrome or pulmonary hypertension with reversed central shunt. Br Med J 1958;2:755-62.
8. Blanc J, Vouhe P, Bonnet D. Potts shunt in patients with pulmonary hypertension. N Engl J Med 2004;350:623.
9. Baruteau AE, Serraf A, Levy M, et al. Potts shunt in children with idiopathic pulmonary arterial hypertension: long-term results. Ann Thorac Surg 2012;94:817-24.
10. Levi DS, Danon S, Gordon B, et al. Creation of transcatheter aortopulmonary and cavopulmonary shunts using magnetic catheters: feasibility study in swine. Pediatr Cardiol 2009;30:397-403.
11. Sabi TM, Schmitt B, Sigler M, et al. Transcatheter creation of an aortopulmonary shunt in an animal model. Catheter Cardiovasc Interv 2010;75:563-9.
12. D'Alonzo GE, Barst RJ, Ayres SM, et al. Survival in patients with primary pulmonary hypertension. Results from a national prospective registry. Ann Intern Med 1991;115:343-9.
13. Benza RL, Miller DP, Gomberg-Maitland M, et al. Predicting survival in pulmonary arterial hypertension: insights from the registry to evaluate early and long-term pulmonary arterial hypertension disease management (REVEAL). Circulation 2010;122:164-72.
14. McLaughlin VV, Presberg KW, Doyle RL, et al. Prognosis of pulmonary arterial hypertension: ACCP evidence-based clinical practice guidelines. Chest 2004;126:78-92S.
15. McGoon MD, Miller DP. REVEAL: a contemporary US pulmonary arterial hypertension registry. Eur Respir Rev 2012;21:8-18.
16. Benza RL, Gomberg-Maitland M, Miller DP, et al. The REVEAL registry risk score calculator in patients newly diagnosed with pulmonary arterial hypertension. Chest 2012;141:354-62.
17. Keogh AM, Mayer E, Benza RL, et al. Interventional and surgical modalities of treatment in pulmonary hypertension. J Am Coll Cardiol 2009;54:S67-77.
18. Rich S, Lam W. Atrial septostomy as palliative therapy for refractory primary pulmonary hypertension. Am J Cardiol 1983;51:1560-1.
19. Law MA, Grifka RG, Mullins CE, Nihill MR. Atrial septostomy improves survival in select patients with pulmonary hypertension. Am Heart J 2007;153:779-84.
20. Oechslin E, Mebus S, Schulze-Neick I, et al. The adult patient with Eisenmenger syndrome: a medical update after Dana Point part III: specific management and surgical aspects. Curr Cardiol Rev 2010;6:363-72.