passed behind the heart to reach the IVC (Figure 1). A ringed polytetrafluoroethylene (Gore-Tex) conduit was used to mitigate against compression by the heart. Warfarin was given for 6 months postoperatively with a goal international normalized ratio of 1.5 to 2.0, followed by aspirin therapy alone. One year after discharge, an echocardiogram showed unobstructed conduit flow.

DISCUSSION

Takedown of a Glenn shunt has been reported, but it is uncommon. In particular, there is a paucity of information on take-down and reconstruction of a left-sided Glenn in patients with atrial situs solitus.^{1,2} Coloni and colleagues³ describe using ringed and non-ringed PTFE grafts, as well as a conduit made from autologous or bovine pericardium to reconstruct the SVC and left brachiocephalic veins. Mahesh and Ratnatunga⁴ reported reconstruction of the SVC with aortic and pulmonary homograft in patients with SVC occlusion due to benign or malignant pathology.

CONCLUSIONS

The technique we have described is most relevant in the pediatric population, in whom chest wall compression of an

anteriorly located conduit used for reconstruction of the left SVC has the greatest potential to be problematic. The major disadvantage to the technique we describe is the potential for thrombosis in the relatively long, small-caliber PTFE (Gore-Tex) graft. As has been our practice with patients undergoing Fontan by the extracardiac conduit technique, we plan to anticoagulate with warfarin (international normalized ratio, ~2.0) for approximately 6 months and then transition to aspirin.

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Venovenous extracorporeal membrane oxygenation using a single cannula in patients with pulmonary hypertension and atrial septal defects

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Adults with unrepaired congenital septal defects are at risk of developing Eisenmenger's syndrome, characterized by pulmonary hypertension and right ventricular failure. If such patients fail medical therapy and acute on chronic cardiopulmonary failure develops, they can be supported with venoarterial extracorporeal membrane oxygenation (ECMO) until they recover or receive a transplant.¹

Standard approaches to venoarterial ECMO require both venous and arterial cannulation. In addition to requiring a second cannula, without a concomitant ancillary antegrade catheter, peripheral arterial cannulation is associated with the risk of limb ischemia.

The Avalon Elite Bicaval Dual Lumen catheter (Avalon Laboratories, LLC, Rancho Dominguez, Calif) allows for adult venovenous ECMO through a single cannulation site.² The catheter has a right atrial infusion port that can take advantage of the congenital atrial septal defect (ASD) (Figure 1) and shunt oxygenated blood into the left side of the heart while the other lumen drains the venae cavae.² Camboni and colleagues³ confirmed right to left atrial shunting of oxygenated blood when using this cannula for ECMO in sheep. We present the novel use of this catheter to provide venovenous ECMO with a physiologic shunt and right ventricular decompression without an arterial cannula.

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FIGURE 1. A dual lumen ECMO catheter with a right atrial infusion port (blue arrow).

CLINICAL SUMMARY

Two adults with secundum ASDs and Eisenmenger's syndrome were selected for this modified cannulation technique after conventional medical therapy failed to treat their acute decompensations. Both patients were on the transplant list. Patient 1 was admitted to the intensive care unit (ICU) in respiratory failure with elevated pulmonary artery pressures. After another pulmonary hypertensive crisis, cardiopulmonary arrest occurred and she was taken to the operating room for emergency ECMO cannulation. Patient 2 presented with hemoptysis refractory to embolization of aortopulmonary collaterals. On admission, she had suprasystemic pulmonary artery pressures. While on inhaled nitric oxide in the ICU, she had ongoing hemoptysis and an arterial oxygen desaturation to 60%. She progressed to respiratory failure and was placed on ECMO as a bridge to transplant.

A 23F Avalon Elite (Avalon Laboratories, LLC) was inserted into the right internal jugular vein of each patient under standard image guidance.² Transesophageal echocardiogram was used to ensure that the cannula's right atrial infusion port was positioned with flows directed across the ASD (Figure 2). Each cannula was attached

to a standard venovenous ECMO circuit. Improvements in pulmonary artery pressure and right ventricular unloading were confirmed on transesophageal echocardiogram before securing the catheter in place. Afterward, the patients were managed on ECMO according to established low-dose anticoagulation and lung-protective ventilation protocols.⁴

RESULTS

Adequate flows, good gas exchange, improved hemodynamics, and ventricular decompression were immediately recorded (Table 1). Both patients had an uncomplicated ECMO course. Patient 1 recovered after resting on venovenous ECMO for 23 days. She remained neurologically intact despite her cardiopulmonary arrest and was weaned from the ventilator. She was discharged from the ICU and lived 4 months before dying of an episode of acute pneumonia. Patient 2 was extubated on ECMO shortly after cannulation. After 6 days on venovenous ECMO, she was bridged to double lung transplantation with ASD repair. The patient did not require ECMO post-transplant. She was discharged from the hospital with improved right heart function and has returned to normal activities.

CONCLUSIONS

Venovenous ECMO with the Avalon Elite can be used as a bridge to recovery or transplantation in adults with ASDs presenting with exacerbations of chronic lung disease and right heart failure. Both patients were extubated and ultimately weaned from mechanical circulatory support. For patient 2, the benefits of early extubation while still on ECMO included markedly less sedation requirements, resumption of traditional enteral intake, increased mobility, participation in physical therapy, and avoidance of a ventilatory associated pneumonia.

The unique physiology of these patients, including the markedly elevated pulmonary artery pressures, requires that oxygenated blood reach the left side of the heart. This was accomplished with one cannula by directing flow across the ASD, thereby creating an oxygenated physiologic right to left shunt. This form of venovenous ECMO offers patients improved oxygenation while partially unloading the right side of the heart, without the complications associated with standard peripheral arterial cannulation.

Although this technique was performed in only 2 patients, these results show that the concept is feasible. The single-site approach mimics venoarterial ECMO through venovenous cannulation, but requires a preexisting congenital atrial defect. Both in patients with Eisenmenger's syndrome who do not have an ASD and in other patients with severe pulmonary artery hypertension, an atrial blade septostomy should be considered.^{3,5} By percutaneously

FIGURE 2. The right atrial infusion port (blue arrow) shunts oxygenated blood across the ASD (white arrow).

TABLE 1. Patients with congenital pulmonary hypertension

Demographics			Respiratory parameters*		Cannula performance measurements	
Patient 1			Pre-ECMO	During ECMO		
Age	41 y	PAO ₂ :FIO ₂ ratio	36			
Body mass index	14	pH	7.43	7.48	Cannula size	23F
		PCO ₂ (mm Hg)	52	46	Days of pre-ECMO intubation	0
		PAO ₂ (mm Hg)	36	79	Duration of ECMO support (d)	23
		SAO ₂	64%	92%	Median ECMO flow rates (L/min)	2.4 (2.1–2.6)
		Systemic blood pressure (mm Hg)	Arrest	125/55	pRBC transfused (units)‡	7
		Pulmonary artery pressure (mm Hg)§	100/66	58/17	Platelets transfused (mL)‡	643
		Evidence of right ventricular decompression on echocardiogram	No	Yes	EBL during cannulation (mL)	25
Patient 2†			Pre-ECMO	During EMCO		
Age	22 y	PAO ₂ :FIO ₂ ratio	60			
Body mass index	17	pH	7.36	7.38	Cannula size	23F
		PCO ₂ (mm Hg)	41	41	Days of pre-ECMO intubation	0.5
		PAO ₂ (mm Hg)	60	108	Duration of ECMO support (d)	6
		SAO ₂	75%	98%	Median ECMO flow rates (L/min)	2.6 (2.3–2.8)
		Systemic blood pressure (mm Hg)	92/40	133/57	pRBC transfused (units)‡	0
		Pulmonary artery pressure (mm Hg)§	116/66	35/17	Platelets transfused (mL)‡	0
		Evidence of right ventricular decompression on echocardiogram	No	Yes	EBL during cannulation (mL)	50

PAO₂, Arterial oxygen tension; FIO₂, fraction of inspired oxygen; SAO₂, arterial oxygen saturation; pRBC, packed red blood cells; EBL, estimated blood loss. *Median values.

†Pre-lung transplant values. ‡During entire ECMO run. §Both patients experienced a pulmonary hypertensive crisis.

creating an ASD, a surgeon can offer venovenous ECMO with a physiologic shut and right ventricular decompression to larger patient populations, while using a single cannulation site.

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