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Original Article

Hybrid intraoperative pulmonary artery stenting in redo congenital cardiac surgeries

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ABSTRACT

Objective: Reconstruction of branch pulmonary arteries (PAs) can be challenging in redo congenital heart surgeries. Treatment options like percutaneous stent implantation and surgical patch angioplasty may yield suboptimal results. We present our experience with hybrid intraoperative stenting which may be an effective alternative option.

Methods: We retrospectively analyzed data of all patients with PA stenosis who underwent intraoperative PA branch stenting in our institution between January 2011 and December 2012.

Results: Ten patients [6 females, median age 10 (1.4 to 37) years], underwent hybrid stenting of the PA. Primary cardiac diagnoses were pulmonary atresia with ventricular septal defect (VSD) in three patients, pulmonary atresia with intact ventricular septum in two, Tetralogy of Fallot (TOF) in one, Double outlet right ventricle (DORV) with pulmonary stenosis (PS) in one, complex single ventricle in two and VSD with bilateral branch PA stenosis in one patient. Concomitant surgeries were revision/reconstruction of RV-PA conduit in 4, Fontan completion in 4, repair of TOF with conduit placement in 1 and VSD closure in 1 patient. The left PA was stented in 7, the right in 2 and both in 1, with a total of 11 stents. There were no complications related to stent implantation. Two early postoperative deaths were unrelated to stent implantation. At mean follow-up period of 14.8 (12–26) months, stent position and patency were satisfactory in all survivors. None of them needed repeat dilatation or surgical reintervention.

Conclusion: Hybrid stenting of branch PA is a safe and effective option for PA reconstruction in redo cardiac surgeries. With meticulous planning, it can be safely performed without fluoroscopy.

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1. Introduction

Branch pulmonary artery (PA) stenosis could be congenital occurring either as an isolated anomaly or in association with other congenital heart defects. It can also occur following a previous attempt at surgical repair. PA reconstruction in these patients could be accomplished by surgical patch angioplasty, transcatheter stenting or hybrid intraoperative stent implantation.[1] In cases of complex congenital heart disease (CHD) requiring redo surgeries, surgical patch angioplasty may be difficult and yield suboptimal results. Transcatheter stenting may also be difficult in these patients due to complex anatomy and difficult vascular access.

The limited data available on the outcome of intraoperative stent implantation in redo surgeries is that of developed countries only.[2–22] We present our experience in successfully performing hybrid stenting in redo congenital cardiac surgeries without using fluoroscopy in a series of ten patients during a two year period.

2. Technique

Intraoperative stenting procedures were performed by pediatric cardiac surgeons in collaboration with pediatric interventional cardiologists. All procedures were performed under hypothermic cardiopulmonary bypass and none of the patients required circulatory arrest. Preoperatively, either conventional angiography or computerized tomographic (CT) pulmonary angiography was done to define the size, area, and length of PA stenosis. The size of stent and delivery balloon were determined based on calibrated measurements from preoperative angiographic images, where the branch PA ostium & the distal bifurcation site were used as reference points. In addition, diameter of the stenosed segment of the branch pulmonary artery was reconfirmed intra operatively by the surgeon using a Hegar dilator that could be introduced into the PA. Only balloon-expandable stents were used. A guide wire was advanced by the surgeon under direct visualization into the PA branch, and the stent/balloon was positioned in the branch PA by the surgeon over this guide wire. The balloon was inflated to the maximum recommended pressure by the interventional cardiologist. Intraoperative fluoroscopy was not used. It was difficult to assess the uniform dilatation of the stent and the balloon in the operating room without the aid of fluoroscopy. Following inflation, surgeons assess the full expansion of the stent by inspection and gentle palpation of stent and by passing an appropriate sized Hegar dilator through the stented vessel. The proximal end of the stent was flared mildly by rotating a large size Hegar dilator and sutured to the PA to prevent stent migration [Fig. 1]. At the end of surgery, intraoperative transesophageal echocardiography was also utilized to confirm appropriate stent position. In the immediate postoperative period and at discharge, chest X-ray and color Doppler echocardiography were done to assess the stent position, size and gradients in the PAs. Doppler gradients can be highly fallacious especially

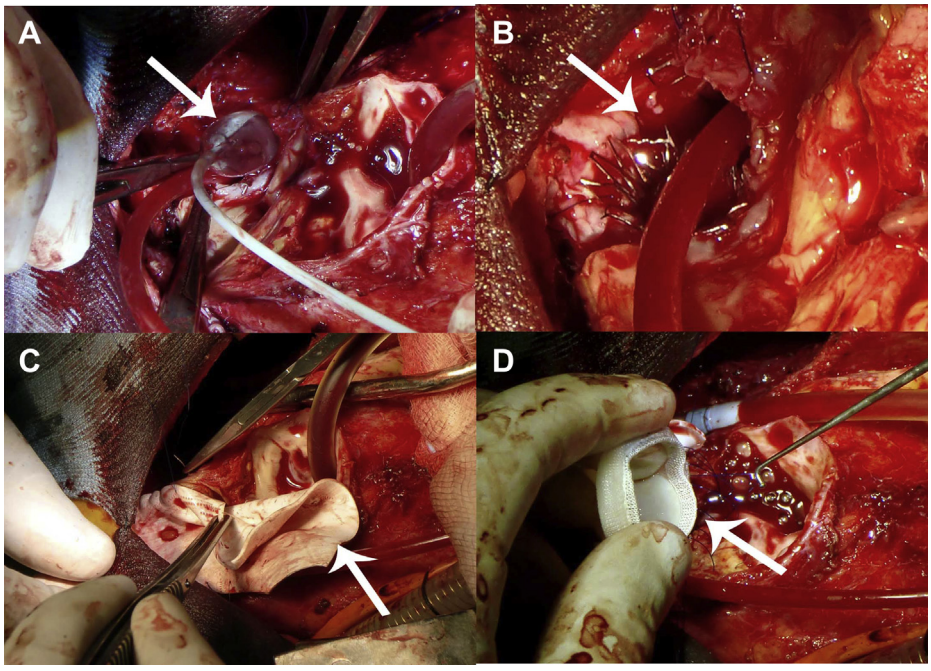

Fig. 1 – Intraoperative images of patient number 2 – [A] showing deployment of the stent mounted on high pressure balloon (arrow) in the Right pulmonary artery. [B] shows stents with flared proximal ends seen in the origin of both branch pulmonary arteries. Apart from suturing the proximal end of the stents to the pulmonary artery, the two stents were tied together across the confluence posteriorly (arrow) to prevent migration and obstruction. Suturing of on lay patch (arrow) after excision of the stenosed right ventricle to pulmonary artery (RV-PA) conduit [C] was followed by implantation of bioprosthetic valve (arrow) in the pulmonary position [D].

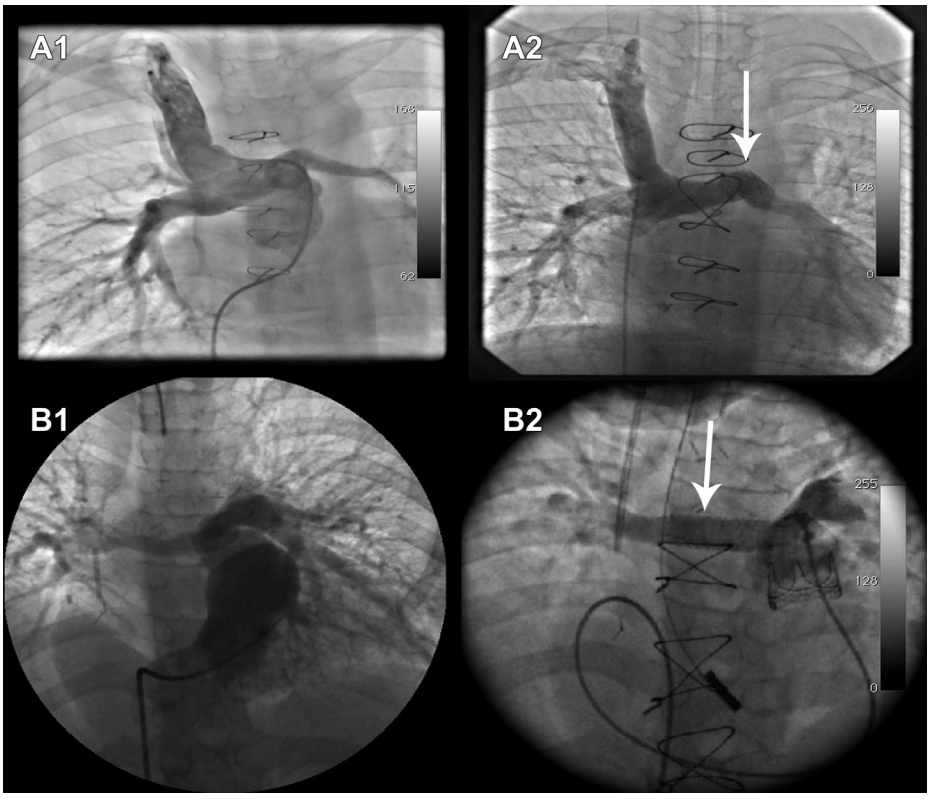

Fig. 2 – Representative pulmonary angiography before and after hybrid intraoperative stenting procedure in two patients. A1 & A2: Angiogram of a 9 year-old-girl (Patient 1) who underwent change of right ventricle to pulmonary artery (RV-PA) conduit and right pulmonary artery stenting. B1 & B2: Angiogram of a 13-year-old boy (Patient 7) who underwent extra cardiac Fontan completion and stenting of LPA origin. In both the patients, the stents (arrows) are in good position with complete expansion and there is improved peripheral arborization.

after stent placement and hence we relied on 2D echocardiographic evidence of good position and uniform expansion of the stent as well as absence of very high Doppler gradient to assess the status of stent.

Conventional angiography and CT pulmonary angiography were performed during follow-up [Fig. 2].

3. Patients and method

Between January 2011 and December 2012, hybrid intraoperative stent implantation was done in 10 consecutive patients for severe branch PA stenosis. The patient characteristics are listed in Table 1. There were 6 females and 4 males and the median age was 10 (1.4–37) years. Primary cardiac diagnoses were pulmonary atresia with intact ventricular septum in two patients, pulmonary atresia with ventricular septal defect (VSD) in three, Tetralogy of Fallot in one, Double outlet right ventricle with VSD and pulmonary stenosis (PS) in one, Complex single ventricle with transposition of great arteries and severe pulmonary stenosis in one, Unbalanced atrioventricular canal defect in one and VSD with bilateral branch PA stenosis in one patient. All patients underwent redo cardiac surgery for complex CHD. Stenting was combined with repair of TOF with right ventricle to pulmonary artery (RV-PA) conduit placement in one patient, revision/reconstruction of RV-PA conduit in four, Fontan completion in four and VSD closure in one patient. All patients had elective stenting procedure and a total of 11 stents were deployed. Seven patients received stent in left PA, two in right PA; and one in both branch PA's. Preoperative imaging (cardiac catheterization, CT scan, or MRI) helped to determine appropriate stent length, stent position to avoid side-branch "jailing", and the appropriate stent diameter to achieve complete relief of the PA stenosis without over dilation. Intraoperative pulmonary artery stenting was performed on an elective basis in all patients. The details of stenting procedure are provided in Table 2. Maximum stent diameters ranged from 8 to 12 mm. The median balloon diameter was 12 mm (range 8–16 mm).

4. Results

During stent implantation and in the immediate postoperative period, there were no complications such as pulmonary artery tear/dissection, stent thrombosis or distal stent migration. Two patients died in the immediate postoperative period, not related to the stent implantation. One is a 10-year-old girl with pulmonary atresia and VSD, who previously underwent RV-PA conduit placement with intraoperative stent implantation in

Table 1 – Preoperative patient characteristics and postoperative outcome measures ($n = 10$).

No	Age (Yrs)/Sex	Primary cardiac diagnosis	Previous surgery	Concomitant surgery	Follow-up period in months
1	9/F	PA-VSD	RMBTS & LMBTS; ICR [RV-PA conduit & Redo PA plasty]	RV – PA conduit [PTFE on lay patch & bioprosthetic pulmonary valve].	26
2	10/F	PA-VSD	RMBTS; ICR [RV-PA conduit, intraoperative RPA stenting]. Transcatheter LPA stenting.	RV – PA conduit [PTFE on lay patch & bioprosthetic pulmonary valve].	Expired
3	9/M	PA-IVS	Pott's shunt; Right BDG.	Extra cardiac completion of Fontan.	20
4	9/F	UAVCD/PS	LCBTS; Right BDG.	Extra cardiac Fontan completion, PA confluence plasty.	18
5	18/F	PA-VSD	RMBTS, ICR [RV-PA conduit]	RV-PA conduit [PTFE on lay patch & bioprosthetic pulmonary valve].	16
6	10/F	SV/TGA/PS	Right BDG.	Extracardiac Fontan completion.	15
7	13/M	PA-IVS	Right BDG.	Extracardiac Fontan completion.	13
8	19/F	TOF/PS	LMBTS	ICR [VSD closure, RV-PA conduit]	12
9	1.4/M	VSD/PS	PA banding.	VSD Closure, PA debanding and confluence plasty.	12
10	37/M	DORV/VSD/PS	ICR [RV – PA conduit]; Conduit replacement.	RV – PA conduit [PTFE on lay patch & bioprosthetic pulmonary valve].	Expired

PA-VSD – Pulmonary atresia with Ventricular septal defect, PA-IVS – Pulmonary atresia with intact ventricular septum, UAVCD – Unbalanced Atrioventricular canal defect; PS – Pulmonary stenosis, SV – Single ventricle, TGA – Transposed great arteries, PS – Pulmonary stenosis, DORV – Double outlet right ventricle, RPA – Right Pulmonary artery, LPA – Left pulmonary artery, ICR – Intra cardiac repair, RMBTS – Right modified Blalock Taussig shunt, LMBTS – Left modified Blalock Taussig shunt, LCBTS – Left classical Blalock Taussig shunt, RV-PA -Right ventricle to Pulmonary artery shunt, BDG – Bidirectional glenn shunt, PTFE – Poly tetrafluoro ethylene.

RPA at 5 years of age followed by transcatheter LPA stenting procedure. She underwent conduit replacement surgery with intraoperative replacement of stents in both branch PAs. She died three weeks postoperatively from severe neurological complication characterized by paraplegia, unresponsiveness, seizures and electrolyte imbalance. Her CT brain showed extensive hemorrhagic infarct.

The other patient was a 37-year-old male with pulmonary atresia and VSD who previously had RV-PA conduit placement at 2 years of age and replacement of conduit at 14 years of age. He presented with features of RV failure and was very symptomatic (Class III). His preoperative echocardiography and cardiac catheterization were suggestive of severe conduit stenosis, severe LPA origin stenosis, severe RV dilatation and dysfunction. He underwent change of RV-PA conduit using a 24 mm PTFE (poly tetrafluoro ethylene) tube and insertion of 25 mm CE Perimount valve. Although there was no difficulty in coming off bypass, he developed severe hypotension and bradycardia within 2 h of shifting to the intensive care unit. ECMO support was initiated immediately but he died on the third postoperative day. Eight patients were successfully discharged after the surgical intervention with concomitant stent implantation. Stent position and patency was evaluated by angiography in 2 patients, CT angiography in one and by chest X-ray and echocardiography color Doppler in all other patients at the time of discharge. There was no displacement of stent and no stent occlusion in any of the cases in the immediate postoperative period.

One child among the eight survivors (patient no.3 in Tables 1 and 2) developed dense right sided hemiplegia with aphasia during the immediate postoperative period. This child underwent Fontan completion & intraoperative stenting of left pulmonary artery. His CT brain showed large thrombotic infarct in the left middle cerebral artery. The neurological complication was considered unrelated to the stenting procedure as there was no difficulty during the stenting procedure and post procedure assessment showed good position and patency of the stent. At a mean follow-up period of fourteen months (range 12–26 months), there were no late deaths and none required reintervention. All patients had follow up echocardiograms and chest x-rays. Cardiac catheterization was performed in two patients and CT pulmonary angiography was performed in three patients during this period.

In addition to imaging studies, two patients underwent before discharge. The lung perfusion scans were done before and after the procedure in both the patients. The perfusion scans showed improved perfusion on the side of stented pulmonary artery and the findings correlated well with the imaging studies.

Among the remaining three survivors in whom follow up imaging studies could not be done early due to social reasons, we have confirmed the stent position, uniform expansion and flow by echocardiography and these patients are hemodynamically stable with normal RV pressure.

All survivors had increase in PA diameter with normal value Z score during follow up assessment. Patients who had redo conduit insertion had a significant improvement in RV systolic pressure following the procedure. The RV systolic pressure to systemic pressure ratio reduced significantly from a mean of 78 (54–98) mm Hg to a mean of 45 (28–52) mmHg. The reduction in RV systolic pressure may be partly due to the concomitant RV outflow tract surgeries.

5. Comments

Hybrid branch PA stenting is an option for PA reconstruction when (a) percutaneous transcatheter stenting is technically

Table 2 – Details of intraoperative stenting procedure ($n = 10$).

Patient	PA stented	Site of stenosis	Balloon diameter (mm) and type	Stent maximum expansion dimension and type	Number of stents	Difficulty or complications during stenting	Follow-up investigations
1	RPA	Severe proximal & entirely hypoplastic	Premounted	10/37 mm Chromaxx stent (BARD)#	1	Nil	Angiography
2	Both	Restenosis of previous stents	12/40 mm Z med Balloon $	12/29 mm (RPA) & 10/29 mm (LPA) Cordis Palmaz peripheral vascular stent*	2	Severe in-stent restenosis noted. Both stents were removed and fresh stents placed and it was a difficult stenting of the previously stented arteries. The stents were tied together posteriorly across the confluence to facilitate future transcatheter interventions. Expired in early postoperative period due to severe neurological complication.	Echocardiography & CXR
3	LPA	Proximal & mid segment	12/40 mm Z med Balloon $	12/29 mm Cordis Palmaz peripheral vascular stent*	1	No complications during stenting. Neurological complication – dense right hemiplegia in the immediate postoperative period despite reduced CPB time. Survived.	CT Angiography
4	LPA	Proximal & mid segment	Premounted	12/29 mm Cordis Palmaz peripheral vascular stent*	1	Nil	Echocardiography & CXR
5	LPA	Proximal and mid segment	14/30 mm BSC Diamond balloon##	12/27 mm Cordis Palmaz peripheral vascular stent*	1	Conduit was heavily calcified and fibrosed. Difficulty in accessing the branch PA opening as there were dense adhesions and the patient was very obese (98 kg). LPA opening was small and probe entered in oblique direction. RPA was good sized.	CT Angiography
6	LPA	Proximal & mid segment. Entirely small PA	Premounted	10/27 mm ev3 Visi pro stent**	1	Nil	Echocardiography & CXR
7	LPA	Proximal & mid segment	12/30 mm ev3 Balloon**	10/29 mm Cordis Palmaz peripheral vascular stent*	1	Nil	Angiography
8	LPA	Proximal and mid segment severe stenosis	Premounted	10/27 mm ev3 Visi pro stent**	1	Nil	Echocardiography & CXR
9	RPA	Proximal & mid segment	Premounted	8/27 mm ev3 Visi pro stent**	1	Nil	CT Angiography
10	LPA	Proximal stenosis & diffuse hypoplasia	Premounted	10/56 mm Biohonk dynamic stent***	1	No difficulty in stenting. Early postoperative death due to Severe RV dysfunction (Fibrous RV/Low cardiac output syndrome).	Echocardiography & CXR

– Bard Peripheral Vascular Inc, Tempe, AZ, USA, * – Cordis Cashel, Cashel, Co Tipperary, Ireland, ** – Medi mark Europe, SARL BR 2332,France, *** – Ackerstrasse 6,8180 Bulach, Switzerland, $ – Numed Inc, Hopkinton, NY, ## – Boston scientific corporation, Water town, MA RPA – Right pulmonary artery, LPA – Left pulmonary artery, CT – Computerized tomography, ECMO – Extracorporeal membrane oxygenation.

not feasible or difficult, (b) when concomitant surgery is needed and surgical PA plasty may be difficult or hazardous[1–4] or (c) when rescue needed following complications of percutaneous stenting such as stent migration, bleeding, dissection etc.[5,6] All patients in our group needed pulmonary artery reconstruction and concomitant redo cardiac surgery and hence transcatheter PA stenting was avoided as a separate invasive procedure. The primary aim of performing intraoperative stent implantation in this group was to reduce the complexity of surgical repair, to shorten cardiopulmonary bypass time and to reduce the risk of late restenosis that can occur after surgical plasty.

Intraoperative stenting has many advantages in patients with complex CHD undergoing redo cardiac surgeries besides reducing the number of invasive procedures. In addition, transcatheter stenting of stenosed branch PAs may be technically difficult in these patients due to one or more of the following factors: (a) absent or difficult vascular access, (b) severe right ventricular outflow/conduit obstruction, or tortuous and distorted branch pulmonary arteries, (c) presence of previously implanted prosthetic pulmonary or tricuspid valve, (d) marginal hemodynamics or ventricular dysfunction especially in the early postoperative period, which may not allow manipulation of large sheaths and splinting of the valves, (e) bilateral PA branch stenosis with closely placed ostia when the stent within one ostium may jail the other ostium, (f) adult CHD patients requiring large balloons and sheaths, (g) previously implanted stents with severe in-stent restenosis which are difficult to redilate, and (h) critically stenosed or completely occluded branch PAs which are hard to traverse with catheters and stent. These procedures can be safely performed as hybrid stenting in the operating room under cardiopulmonary bypass support.[2,3,7]

Surgical patch angioplasty may also be challenging in these patients and hybrid intraoperative stenting could be a better alternative approach for many reasons: (a) Dissection and access is complicated by adhesions, scarring, compression, bleeding and excessive collateral flow.[8] This directly leads to longer duration of surgery, prolonged CPB time and need for circulatory arrest. Hybrid intraoperative stenting on the other hand is much safer, quicker and easier to perform, effectively reducing the CPB time.[5,9] As the stent is placed with direct visualization extensive dissection is usually not needed. (b) Even anatomical sites that are difficult to access for patch angioplasty such as lobar branch stenosis, LPA stenosis in a redo surgical situation and RPA behind aorta, can be more easily managed by hybrid approach.[10] Eight out of ten patients in our study had LPA stenosis. (c) Sometimes the stenosis, especially in a redo situation is complex with severe fibrosis, calcification, hypoplasia and associated with dilatation or external compression. Hybrid stenting procedure may be a better option in these situations, especially in those with hypoplastic PA.[11,12] Use of stents will also allow serial dilatation of the small artery to a larger diameter.[9,16] Presence of fibrous scarring may be an advantage in hybrid stenting as it provides support during stent expansion.[5,10,13,14] Extensive dissection around the PA branch is in fact not advisable in hybrid stenting to prevent thinning and rupture of the artery. (d) Injury to the phrenic nerve, lymphatics and other vascular structures which can occur with dissection around PA branches in redo surgeries can be avoided in hybrid stenting. (e) Significant restenosis or complete occlusion following surgical angioplasty can occur in the early postoperative period in some patients, requiring percutaneous stent placement.[23,24] However transcatheter stenting may be hazardous in the early postoperative period with fresh suture lines.[15] (f) Autologous pericardium may not be available for patch angioplasty after multiple previous surgeries. (h) In cases of completely occluded or long segment PA stenosis where there is a long distance to reach the distal artery, reconstruction may be impossible with surgical patch angioplasty. Hybrid stenting may be the only possible treatment option in these situations.[17]

Complications associated with stenting can be better handled in the operating room while on CPB support than in the catheterization laboratory.[4,5,11,12,25–27] The various complications of hybrid stent implantation include (a) PA dissection or rupture, (b) stent migration, (c) incomplete expansion of stent, (d) stent thrombosis, (e) obstruction of smaller PA branches, (f) stent restenosis, (g) inhibition of PA growth, (h) transient pulmonary edema, (i) airway compression. Stent migration can be prevented by flaring the proximal end and suturing it to the pulmonary artery.[5] Inflation of balloon to the maximum recommended pressure, multiple inflations and redilating the proximal and distal end of the stent are the measures to ensure adequate stent expansion. Aspirin therapy is recommended postoperatively to prevent stent thrombosis. Careful review of preoperative angiograms, proper calibrated measurement, and careful selection of stent length and size should help to prevent potential entrapment of side branches. Over inflation of the balloon while deploying the stents should be avoided to prevent airway compression.

Ideally, intraoperative stenting should be performed in a hybrid suite with capability for biplane fluoroscopy and angiography. In our series, all the cases have been restricted to the proximal and mid portion stenting to avoid problems of stent malposition, dissection, jailing of side branches etc. When fluoroscopy is not available, post procedural visual inspection and gentle palpation of the pulmonary artery can be performed by the surgeons to assess correct deployment of the stent.[1] Operators however, should have a low threshold for performing exit angiography after the procedure.[10,12,18,19] The potential adverse long-term effect of a stent on future PA growth and making it less amenable to patch plasty at a later date in view of increased tissue friability are important concerns.[4,11] Cautious patient selection, use of re-expandable stents that can undergo repeat percutaneous dilatation if needed in the future to accompany growth of the patient will resolve these issues.[11,13,16,18]

The long-term concern is the need for re-intervention previously reported to be 26% within 15 months median follow up[4] and 25% within 2–24 months follow up.[12] Angtuaco et al[16] reported re-intervention rate as high as 49% with the longest follow up so far (mean of 7.6 years). They found age less than two years, weight less than 10 kg, and initial post-inflation stent diameter less than 10 mm in diameter as significant factors associated with a higher risk of re-intervention. In case of a 1.4 year old child in our study group (case No. 9 in Tables 1 and 2), we used an 8 × 27 mm ev3 Visi Pro premounted stent for RPA origin stenosis. The Right

pulmonary artery measured 3 mm at the stenosis and 6.4 mm distally in CT pulmonary angiography. Hence we chose to expand the stent to 8 mm diameter. Our first preference is to use a stent which can be expanded to a larger diameter in future if necessary, as the child grows. In this case we had to use a premounted Visi Pro stent due to non-availability of larger stents. Moreover bench testing has shown that an 8 mm Visi Pro stent can be expanded later, up to a diameter of 12 mm without damaging the stent.[28] The mean follow up period in our series is short similar to report by Coles et al[3] but there was no reintervention among the eight survivors. Further long term follow up of these patients is needed to comment on our incidence of reintervention.

We conclude that hybrid intraoperative stenting of branch pulmonary arteries is an effective method of pulmonary artery reconstruction and has many advantages in patients undergoing redo cardiac surgeries. The hybrid approach may result in reduced risk, less invasive procedures, and improved outcome. With meticulous preoperative planning it can be safely performed in the operating room without fluoroscopy.

Conflicts of interest

All authors have none to declare.

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