

Stent implantation into the patent ductus arteriosus in cyanotic congenital heart disease with duct-dependent or diminished pulmonary circulation

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We assessed the efficacy and safety of stent implantation into the ductus arteriosus in infants with cyanotic heart disease.

Ten patients with duct-dependent or diminished pulmonary circulation underwent cardiac catheterization with the aim of stent implantation. Coronary stents of 3.5-4 mm in diameter were used and successfully implanted in eight.

All patients in whom stent implantation was successful had adequate relief of their cyanosis and were discharged home. During a mean follow-up of 9.3 months (median 10 months), one patient had evidence of restenosis of the stent at five months. Re-dilatation of the stenosed stent was attempted but was unsuccessful and a modified left Blalock-Taussig shunt was placed surgically.

Stent implantation of ductus arteriosus in neonates and infants with a duct-dependent pulmonary circulation is an effective and safe palliative procedure. It may be an alternative to surgical systemic-pulmonary artery shunt in a select group of patients.

Key words: ductus arteriosus, stent implantation, cyanotic heart disease.

In neonates and infants with duct-dependent pulmonary circulation or diminished pulmonary blood flow, conventional emergency treatment consists of prostaglandin E1 (PGE1) infusion and subsequent creation of a surgical aorto-pulmonary shunt^{1,2}. Stent implantation of the arterial duct has been proposed as a non-surgical alternative to aorto-pulmonary shunt surgery^{3,4}. Results of early reports involving a small number of patients were not encouraging; however, more recent reports are promising⁵⁻⁸. We assessed the efficacy and safety of ductal stenting in infants with duct-dependent pulmonary circulation.

Material and Methods

Between July 2004 and August 2005, stent implantations into the patent ductus arteriosus (PDA) were attempted in 10 infants with duct-dependent or severely diminished pulmonary

circulation after parental consent was obtained. Diagnosis and clinical properties of patients are summarized in Table I. Cardiac catheterization was performed under deep sedation or general anesthesia. Right femoral artery and vein were cannulated with 4-5F sheath. Heparin bolus (100 IU/kg) was given after the introducer was inserted, and heparin drip (20 IU/kg/h) was continued for 24 hours in patients in whom stent was implanted successfully. Aortic arch angiography in 90° lateral positions in all and 40° right anterior-oblique position in some patients were obtained to show anatomy and size of the ducts. PGE1 infusion was stopped, in those patients taking PGE1 infusion before the stent implantation, in order to induce ductal constriction and to prevent displacement of stent into pulmonary artery. All procedures were performed transarterially (retrograde)

Table I. Main Diagnosis and Age of 10 Patients Who Underwent Catheterization for Stent Implantation

Case Number	Age (mo)	Main diagnosis
1	1.45	Infundibular PS and severe RV hypoplasia
2	3	PA with intact ventricular septum
3	4	DORV, PA with VSD
4	14	PA with intact ventricular septum
5	4	C-TGA, VSD and severe PS
6	11	PA with VSD
7	1	C-TGA, PA with VSD
8	1	Critical pulmonary stenosis, ductus arteriosus
9	1.5	PA with VSD
10	1	Single inlet RV, DORV, severe PS

PS: Pulmonary stenosis. RV: Right ventricle. PA: Pulmonary atresia. DORV: Double outlet right ventricle. VSD: Ventricular septal defect. C-TGA: Corrected transposition of great arteries.

except one. In a patient with pulmonary atresia and intact ventricular septum, the stent was implanted transvenously after transcatheter guide-wire perforation and balloon dilatation of the pulmonary valve had been performed one week before. A 0.014 inch floppy tipped extra-stiff guide-wire was placed either antegrade from the pulmonary artery into the descending aorta or retrograde from the aorta to pulmonary artery through the ductus. Standard coronary stents (OCCAM and EXOS PTCA stent) pre-mounted on low-profile balloon dilatation catheters were used and placed into the ductus over the guide-wire. In all patients, special care was given to align the pulmonary end of ductus and to use a single stent to cover the complete length of the duct when possible. Therefore, a stent length slightly longer than ductus length was used. The median ductus length was 13.5 mm, and the median stent length was 16 mm (Table II).

After stent implantation, control angiography was performed to determine stent position and to decide the necessity of additional stents (Figs. 1a, 1b, 1c). Cefazolin was given for 24 hours divided in three doses. All patients were discharged home on acetylsalicylic acid treatment (3 mg/kg/day).

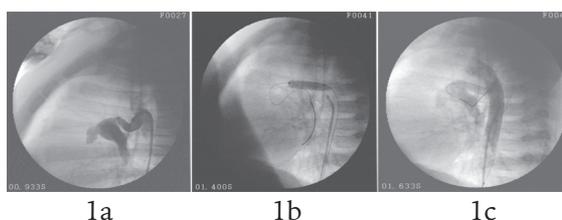


Fig. 1. (1a) 90° lateral aortic angiogram performed to determine ductus morphology and to measure ductus length; (1b) shows fully expanded stent in the patent ductus arteriosus, with the balloon and wire still in place; and (1c) is post-stent angiogram demonstrating final stent position after deployment and unrestricted blood flow to the pulmonary artery.

Table II. Stent Characteristics and Outcomes in 8 Patients with Successful Stent Implantation Intervention

Case Number	Method	Ductus Length (mm)	Stent Diameter (mm)	Stent Length (mm)	O ₂ Saturation ¹ (%)	O ₂ Saturation ² (%)	Follow-up Duration (month)	O ₂ Saturation ³ (%)
1	retrograde	8	3.5	11	55	82	12	80
2	antegrade	13	3.5	14	65	94	13	98
3	retrograde	12	4	16	60	92	5*	69
4	retrograde	14	4	16	42	86	12	83
5	retrograde	14	4	16	68	86	10	69
6	retrograde	20	4	20	62	84	10	71
7	retrograde	14	4	16	67	85	8	78
8	retrograde	12	3.5	13	65	85	4	98

¹: Before stent implantation. ²: After stent implantation. ³: During the last follow-up. *Surgical shunt after re-stenting.

Every patient was followed up regularly for clinical evaluation, measurement of pulse oximetry saturation and echocardiographic examination at the 1st, 3rd, and 6th months after the stent implantation.

The mean oxygen saturations before and after stent implantations were compared with paired t test, and $p < 0.05$ was accepted to be statistically significant.

Results

Results are summarized in Table II. Ductal stent implantations were successful in eight patients. In two patients with pulmonary atresia and intact ventricular septum, perforation and balloon dilatation of the atretic pulmonary valve were performed in addition to ductal stent implantation before or after. One of the patients, in whom intervention of the stent implantation was unsuccessful, had a vertical and tortuous PDA with a diagnosis of pulmonary atresia and ventricular septal defect (tetralogy of Fallot type; Case 9). We could not advance the stent-mounted balloon catheter through the PDA even though the guide-wire was manipulated in to the pulmonary artery in this patient. The other patient also had a vertical and tortuous PDA with severe narrowing at the pulmonary artery end (Case 10). During the attempts to cross the duct with a catheter over a guide-wire placed in to the pulmonary artery, spasm and complete obliteration of the ductus occurred. Even though intravenous PGE1 infusions were performed, neither reopened. Both patients had an emergency surgical aorto-pulmonary shunt; one patient survived and the other died.

The median age at the time of the interventions was 3.5 months (range 1-14 months). The body weight ranged from 3 to 9 kg, with a median of 5.4 kg. Aortic oxygen saturations increased from median 63.5% to median 85.5% after stent implantation. Mean arterial oxygen saturation before stent implantations was $60.5 \pm 8.5\%$ (42-68%) and increased to $86.7 \pm 4.1\%$ (82-94%). The mean difference before and after stent implantations was found to be $26.2 \pm 8.8\%$, which was statistically significant ($p < 0.0001$).

The mean catheterization time ranged between 30 to 75 minutes, with a median of 42 minutes. Median fluoroscopy time was 14 minutes.

Two patients were intubated and stayed on the ventilator for two days and were discharged to the pediatric floor on the third day. The median hospitalization time was five days. There were no procedure-related major complications. During a mean follow-up of 9.3 months, there was a significant reduction in pulse oxygen saturation in only one case. Re-dilatation of the stenosed stent was attempted in this patient. Since stent re-dilatation was not effective, re-stenting was performed, but stent kinking in the second stent occurred and a modified left Blalock-Taussig (BT) shunt was placed surgically. There was no significant decrease in oxygen saturations and all stents were patent without stenosis in the other patients (Table II).

Discussion

Neonates or infants with a duct-dependent pulmonary circulation or severely decreased pulmonary blood flow are usually treated by a surgical systemic to pulmonary artery shunt^{1,2}. Infusion of PGE1 has been life-saving in emergency conditions until the patient undergoes surgery, but it has disadvantages of peripheral vasodilatation, hypotension, hyperpyrexia and apnea². Compared with long-term PGE1 infusions, early duct stenting significantly shortens hospitalizations and reduces treatment costs⁹.

On the other hand, the disadvantages of surgical shunts are thoracotomy scar, adhesion and complications such as chylothorax, and phrenic and vagal nerve injury^{6,7,9-11}. Surgically created shunts may also cause distortion and stenosis of the shunted pulmonary artery or differential growth of the pulmonary arteries. Many of those disadvantages of the shunt operation can be avoided by securing pulmonary blood flow by stent implantation into the arterial duct. Stenting also enables equalized pulmonary blood flow, which may induce pulmonary arterial growth without causing distortion or stenosis^{6,10,11}.

The stenting procedure is well tolerated in premature and small infants^{6,7,9}. Without stent implantation, such patients would require prolonged PGE1 infusion or would be operated with high mortality and morbidity¹¹. Ductal stenting in such patients not only relieves cyanosis adequately but also induces growth of the pulmonary vasculature.

Animal studies and previous reports showed optimum stent length must be a few millimeters longer than ductal length. The full length of the ductus is to be covered with stent, but at least the pulmonary side of the ductus must be covered since unstented segments of the PDA have a propensity for constriction^{6,9}. In all patients, special care was given to align the pulmonary end of the ductus and to use a single stent to cover the complete length of the duct. A stent length slightly longer than ductus length was used in our cases. The median ductus length was 13.5 mm, and the median stent length was 16 mm.

Modified BT shunts of 3 to 5 mm in diameter are usually preferred by surgeons in neonates and infants. It has been reported that many neonates with stent diameter of 4.0 mm initially had excessive pulmonary flow. Since the PDA diameter is usually smaller than the modified BT shunts, it is reasonable to use a stent of 3.5 mm or less for neonates and 4 mm or greater for infants^{7,8}. However, when smaller stents are used, the risk of intimal proliferation and narrowing of the stent may be increased. In three patients, 3.5 mm, and in five patients, 4 mm stents were implanted. Only one of our cases (Case 2) needed treatment for increased pulmonary blood flow. This patient was three months old and diagnosed with pulmonary atresia and intact ventricular septum. After the initial guide-wire perforation and balloon valvuloplasty of the pulmonary valve, the patient continued to require PGE1 perfusion, and although a 3.5 mm stent was placed into the PDA, since the right ventricle compliance improved, the antegrade flow increased and the patient needed anti-congestive treatment.

The absolute contraindication to stenting of the ductus is the presence of branch pulmonary artery stenosis⁷. In a certain group of patients, constricted ductus arteriosus may cause branch pulmonary artery stenosis at the site of its insertion. Before the stent implantation, all patients should be evaluated for branch pulmonary artery stenosis. None of our cases had such a problem.

The structure of the ductus arteriosus is unique when compared to other vascular structures. The media layer of the ductus is composed primarily of muscular fiber and the intimal layer is thicker than other vessels¹². These

properties of the ductus theoretically may cause fatal ductal spasm. Even after initial successful stent implantation, intimal proliferation may cause early ductal stenosis¹². Although acute ductal obstruction and major complications leading to death are rare, intimal proliferation and slowly progressive stent stenosis are the major limiting factors^{6,12}. In such patients, it is still possible to re-dilate and/or implant a second stent into the narrowed ductus^{6,13}. Drug eluting stents or covered stents also have been proposed for preventing restenosis in adults. Studies evaluating efficacy of ductal stenting using such stents have not yet been done. Only one of our cases presented decreasing oxygen saturations at five months, which we considered as due to intimal proliferation.

Our experience with a limited number of patients suggests that PDA stenting is a safe and effective procedure to secure pulmonary blood flow. With improved stent design and extended experience in implantation techniques, stenting of the ductus arteriosus in duct-dependent pulmonary circulation could be an attractive alternative, in a select group of patients, to the gold standard surgical creation of an aorto-pulmonary shunt.

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