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Intra-procedural bronchoscopy to prevent bronchial compression during pulmonary artery stent angioplasty

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Abstract

Background—Stenosis of the pulmonary arteries frequently occurs during staged palliation of hypoplastic left heart syndrome and variants, often necessitating stent angioplasty. A complication of stent angioplasty is compression of the ipsilateral main-stem bronchus. Following such a case, we re-evaluated our approach to PA stent angioplasty in these patients.

Methods—The incident case is described. A retrospective observational study of children and adults with superior(SCPC) and/or total cavopulmonary connection(TCPC) undergoing left pulmonary artery (LPA) stent angioplasty between 1/1/2005 and 5/1/2014 and subsequent chest CT was performed to assess the incidence of bronchial compression. The current strategy of employing bronchoscopy to assess bronchial compression during angioplasty is described with short-term results.

Results—65 children and adults underwent LPA stent angioplasty. Other than the incident case, none had symptomatic bronchial compression. Of the total study population, 12% had subsequent CT, of which 1 subject had moderate bronchial compression. To date, 7 subjects have undergone angioplasty of LPA stenosis and bronchoscopy. In one case, stent angioplasty was not performed because of baseline bronchial compression, exacerbated during angioplasty. In the rest of cases, mild-moderate compression was seen during angioplasty. Following stent angioplasty, the resultant compression was not worse than that seen on test angioplasty.

Conclusion—Bronchial compression is a rare complication of stent angioplasty of the pulmonary arteries in children and adults with SCPC/TCPC. Angioplasty of the region of interest with procedural bronchoscopy can help to identify patients at risk of this complication.

Keywords

cardiac catheterization; stents; Fontan; bronchus; airway

Introduction

Staged palliation of hypoplastic heart syndrome (HLHS) and anatomic variants is frequently complicated by stenosis or long segment narrowing of the pulmonary arteries. Though either pulmonary artery can be affected, the more common location is the pulmonary artery to the left of the superior cavopulmonary connection (SCPC) anastomosis[1]. This is comprised of both the anatomic proximal right pulmonary artery (RPA), often referred to as the central pulmonary artery (PA), and the anatomic left pulmonary artery (LPA). Staged palliation with systemic to PA shunt, SCPC, and eventual total cavopulmonary anastomosis (TCPC) can distort the PA geometry. The reconstructed aortic arch is frequently dilated and can directly compress the central PA and LPA. Narrowing due to external compression and/or distortion of PA's is usually unresponsive to balloon angioplasty, in which case stent angioplasty is necessary to restore normal caliber and appropriate distribution of pulmonary blood flow. However, stent angioplasty introduces an additional rigid structure into the fixed volume of the chest cavity, which can result in impingement on and narrowing of the left mainstem bronchus[2–4].

During an index procedure, stent angioplasty of the central PA and proximal LPA resulted in functional occlusion of the left mainstem bronchus, necessitating an airway stent to restore patency of the left bronchus and ventilation to the left lung. Subsequently, we have developed a strategy to prevent inadvertent bronchial compression. In the subset of patients in whom the risk of airway compression was identified during pre-procedural work up, bronchoscopy is performed in the catheterization laboratory at baseline and during test dilation of the pulmonary artery with a balloon of the diameter of the planned stent. We propose to describe the incident case, the prevalence of airway compression in our population, and the early outcomes of this novel approach.

Index Case

The subject is a 16 year old young man with HLHS, who underwent staged palliation culminating in a lateral tunnel fenestrated Fontan at 2 years of age. He had done well for many years but developed progressive cyanosis beginning at age 10. At the time of his referral for catheterization, he had a baseline oxygen saturation of 81% at rest. A cardiac magnetic resonance study (CMR) demonstrated maldistribution of pulmonary blood flow with 90% to the right, 10% to the left, and compression of the central PA by the dilated aortic root (Figure 1A). He was referred for catheterization for hemodynamic evaluation and possible intervention.

Hemodynamic evaluation demonstrated Fontan pressures between 14 and 17 mmHg with a 4 mmHg gradient between the Fontan baffle and LPA. Angiography demonstrated focal narrowing of the central PA and LPA (Figure 1B). Low-pressure balloon angioplasty with 16mm and 18mm diameter balloons was performed at the site of stenosis with no visible

waist on the balloon. A Palmaz XL stent was then deployed on an 18mm×4.5cm balloon-in-balloon (BIB) catheter. Post-intervention angiogram demonstrated resolution of narrowing, and on pressure pullback there was no residual gradient. The patient was observed overnight and discharged the next morning without significant symptoms and with an oxygen saturation while breathing air of 84%. He was readmitted to our institution the following evening after presenting to an outside hospital emergency department with chest pain and shortness of breath and pulse oximetry of 83%. Symptoms increased in severity when the patient was positioned in the left lateral decubitus position, and saturations decreased to 77%. Computed tomography angiogram (CTA) of the chest identified an area of marked narrowing of the left mainstem bronchus near the stent (Figure 2B). The patient underwent flexible bronchoscopy which demonstrated occlusion of the left mainstem bronchus (Figure 2C). Balloon dilation of the bronchus was performed with no effect. The left mainstem bronchus was stented with a 12mm Dumon silicone stent (Boston Medical Products, Westborough, MA) via rigid bronchoscopy (Figure 3). On emergence from anesthesia the patient described immediate symptom relief. His pulse oximetry was 92% and he was subsequently discharged. However, the next day, he was re-admitted because of progressive unremitting chest pain. The airway stent was removed, after which bronchoscopy demonstrated compression but not complete bronchial occlusion. The patient's chest pain resolved, and he was discharged with a saturation of 92%. A subsequent repeat chest CT demonstrated 1) no change in his LPA stent dimensions and 2) continued milder airway narrowing. He was re-admitted with fever and rigors 22 days after his initial procedure and was found to have methicillin sensitive *Staphylococcus aureus* bacteremia and was treated with intravenous antibiotics for six weeks without other sequelae. Since that time, he has been well without symptoms and with improved exercise tolerance. His last outpatient visit was nine months after his initial intervention, and, at that time, his saturation was 89% breathing air.

Methods

The index case motivated a review of cases in which children and adults who had undergone staged single-ventricle palliation and had subsequent stent angioplasty of the central PA and LPA. A retrospective observational study was approved by the Institutional Review Board of The Children's Hospital of Philadelphia, and a waiver of consent was granted. There are two parts to this study 1) a review of the prevalence of bronchial compression following central and/or LPA stent angioplasty in children and adults with SCPC and TCPC and 2) a description of the outcomes of procedural bronchoscopy to assess for compression of the main-stem bronchus prior to stent angioplasty in this population.

Prevalence of bronchial compression following stent angioplasty

Inclusion criteria were children and adults of all ages who had undergone SCPC or TCPC and subsequent central or LPA stent angioplasty at our institution from 1/1/2005 to 6/1/2014. Prospective subjects were identified through query of our institution's cardiac catheterization laboratory database. Subjects were included if they had undergone subsequent cross-sectional imaging of the chest in the study period, via either a computed tomogram (CT) or magnetic resonance imaging (CMR) study.

Measurements of the bronchi were made from digital images in the electronic medical record, which allow for coordinated, simultaneous review of axial, coronal, and sagittal projections. Measurements of the largest and smallest caliber of the left mainstem bronchus distal to the carina and proximal to the lobar bifurcation were performed in axial and coronal projections. To allow for comparison of measurements across subjects of different sizes, we chose to express narrowing as the ratio of narrowest region to maximal diameter. On review of the literature, no standard definitions of bronchial compression were found. We defined severity of narrowing as none or trivial 0.75–1, mild 0.5–0.75, moderate 0.25–0.5, severe 0–0.25. Measurements were made by two members of the study team (NR and MO). Intra-class correlation coefficients were calculated for measurement of the bronchus diameter to assess for inter-rater reliability. Inter-rater reliability was excellent with intra-class correlation coefficients >0.9 for each variable (Supplemental Table 1). Kappa statistic was calculated for classification of the degree of compression. Unadjusted Kappa was 0.995, demonstrating excellent inter-rater reliability.

Summary statistics were calculated and expressed as median and range or percent and count where appropriate. The Kruskal-Wallis test was used to assess for differences in the population that underwent CT, CMR, and no subsequent imaging.

Outcomes following procedural bronchoscopy

Following the incident case described, our approach to stent angioplasty of the PA's in this population was changed. Though no formal criteria have been developed, on a case by case basis the previous angiograms of patients are reviewed, as are pre-procedural and tomographic imaging (CT and increasingly CMR) studies. In the subset of patients, in whom the stenotic region is in proximity to the main-stem bronchus, the procedure is scheduled in conjunction with a plan for bronchoscopy by a pulmonologist. Catheterization was generally performed under general anesthesia with endotracheal intubation. Alternatively, if the case had previously been conducted under monitored sedation with a natural airway, elective conversion to general anesthesia was performed (1/7 cases) prior to bronchoscopy. If baseline hemodynamics and angiography confirmed significant PA stenosis meeting criteria for intervention, flexible bronchoscopy was performed to evaluate the airway prior to any intervention (Figure 3A). A long Mullins sheath was advanced over an appropriate guide-wire and positioned just proximal to the PA obstruction. Angioplasty of the stenosis was performed using a balloon of length and nominal diameter equal to that of the planned stent. Bronchoscopy was performed during the entire balloon inflation and deflation sequence to document the degree to which the bronchial lumen was compromised (Figure 3B). If the bronchi remained patent (at least 50% of its original cross-sectional area and large enough to accommodate passing the bronchoscope), stent angioplasty was performed. This was performed under bronchoscopic visualization, and inspection of the region was repeated after stent deployment (Figure 3C).

Cases where bronchoscopy was employed to provide risk-stratification for possible stent angioplasty in children and adults with either SCPC or TCPC between 2/1/2014 and 10/10/2014 are summarized. Cases were identified through a query of our institution's cardiac catheterization laboratory and eligibility was determined through chart review.

Demographic and procedural data were extracted and summarized using conventional descriptive statistics. This is a descriptive analysis so no further statistical testing was performed.

Results

Prevalence of bronchial compression

An initial query generated 65 cases of LPA stent angioplasty in patients with either a SCPC or TCPC over the study period (Table 1). Twenty-seven (42%) had subsequent cross-sectional imaging of the chest. Twelve percent of the total study population (n=8) had a subsequent chest CT. CMR were performed in a total of 22 subjects (of whom 3 also had CT). The bronchial diameter was not measurable on CMR studies following stent angioplasty, because stent artifact obscured the region of interest. As a result, these studies were excluded from analysis. Comparing the characteristics of subjects who underwent subsequent CT to those who had subsequent MRI and those with no subsequent cross-sectional imaging of the chest, the CT group was lighter and shorter than the other two groups ($p=0.02$, Table 1). The point estimate of age for the CT group was also lower than the other two groups, but this difference was not statistically significant ($p=0.07$).

The characteristics of the 8 subjects with subsequent CT of the chest are summarized in Table 1. They were median age of 1 year (Range: 0.4–9 years) at the time of stent angioplasty. Indications for the CT were: swelling of upper extremities or face (n=2), persistent consolidation or effusion contralateral to the PA stent, persistent fever, maldistribution of pulmonary blood flow on nuclear medicine lung perfusion scan, respiratory distress with stridor, and routine assessment of the aortic arch and PA's (n=1 for each). No subjects underwent CT for hypoxia, cough, or inability to wean from mechanical ventilator support. In this population, one subject (12.5%; 95% CI: 0.3–52.6%) had moderate narrowing of the left main-stem bronchus, 2 (25%; 95% CI: 3.2–65%) had mild narrowing, and the remainder had no narrowing. None of these subjects had clinical symptoms of chest pain or dyspnea.

Procedural bronchoscopy during catheterization

Using the method described, 7 children and adults underwent balloon angioplasty of the PA with procedural bronchoscopy (Table 2). There were no complications from bronchoscopy. Specifically, there was no decrease in oxygen saturation during procedural bronchoscopy. One subject (Case 6) had mild-moderate bronchial compression at baseline. With test balloon angioplasty using a balloon that was 100% of the anticipated goal stent diameter, the bronchus was 85–90% occluded. An attempt with a smaller balloon (~89% of the goal diameter of the stent) also resulted in significant compression (75%) of the bronchus, and as a result, the decision was made to not intervene.

For the remaining 6 cases (86% of cases) test balloon dilation resulted in mild bronchial compression. In each case, stent angioplasty was performed as described (Table 2). The degree of bronchial compression did not change following stent angioplasty. There were no procedural complications associated with either the catheterization or the bronchoscopy.

Interventions were performed with bare metal stents. In two cases, there was suspicion that to cover the region of stenosis, upper lobe branches of the LPA would be jailed. In these cases, open cell stents (EV3 LD Max stents in both cases) were used and in the same procedural the jailed branches were engaged and balloon dilation through the stent was performed to try to maintain the patency of the affected vessels.

The three youngest subjects (cases 3, 6, and 7) had central and LPA narrowing diagnosed prior to their elective Fontan operations, but at the request of their surgeon and primary cardiologist stent angioplasty was deferred until after the Fontan operation (to avoid having stent material near the anastomosis of the extracardiac conduit to the PA. In cases in which stent angioplasty was performed care was taken to perform angioplasty with balloons that not only matched the distal vessel diameter at the present time, but to a diameter that it was anticipated would be appropriate in an adult. This was done, because testing with bronchoscopy and angioplasty is not possible after stent angioplasty.

Discussion

Stent angioplasty is an important therapy that has demonstrated efficacy and safety in the treatment of PA stenosis resistant to conventional balloon angioplasty[5–9]. The radial force exerted by the stent supports the cross-sectional area of the vessel in the face of external compression and/or distortion of PA geometry, maintaining vessel patency. However, this also introduces a rigid structure into the fixed thoracic volume. The left mainstem bronchus is located between the neo-aortic root and central/left PA anteriorly and the descending aorta posteriorly. If a stent is deployed in this relatively fixed space, bronchial compression can result as demonstrated in our index case. In this retrospective study, we demonstrate that severe bronchial compression occurs, even if at this time a precise estimation of incidence is difficult. We also demonstrate that it can be anticipated and avoided through the use of procedural bronchoscopy during test balloon angioplasty.

Extrinsic compression of the left mainstem bronchus by an LPA stent was first reported in a subject with transposition of the great arteries who had undergone a Rastelli procedure[2]. It also has been reported in an infant with HLHS following a second stage operation to create a superior cavopulmonary connection[3]. Ferandos and colleagues reviewed a case series of 21 patients who underwent intravascular stents and subsequent CTA; 6 (29%) of patients had airway narrowing with 83% (5/6) having a history of aortic arch operations[4]. The patients in this series with bronchial compression were largely symptomatic (5/6), and 2 died. The study was limited to children who had stents and underwent CTA, and as such does not measure the risk in the larger population undergoing stents and does not allow for statistical inference to identify patient or procedural risk factors for bronchial compression. In the two cases we present, the mechanism for LPA stenosis is a dilated aortic arch. The course of the left mainstem bronchus is both posterior and inferior to the LPA in the space between the aortic arch anteriorly and the descending aorta posteriorly. Expansion of a stent within this fixed volume puts the bronchus at risk for compression.

In this study, the prevalence of moderate bronchial compression was low (12.5%) and given the small sample, confidence in this estimate is limited. At our institution, the proportion of

subjects undergoing CMR is much greater than that of subjects undergoing chest CT scans. Unfortunately with the MRI sequences in current use at our institution a stent creates significant artifact, which makes measurement of the diameter of the bronchus impossible. It is quite notable that 1/6 subjects who have been assessed using procedural bronchoscopy had severe bronchial compression with test balloon dilation, and would presumably have had severe compression if a stent was deployed. This suggests that the risk of compression is not trivial and that there is utility in screening patients prior to stent angioplasty. It remains unclear which patient population is at highest risk for bronchial compression. Our index case focused attention on HLHS patients. Reviewing tomographic images in this population we were struck by the effect of the alignment of dilated neo-aorta, pulmonary artery, bronchus, and descending aorta as a substrate for bronchial compression. However the previous reports make it clear that other anatomic lesions are also at risk[2–4]. There has been a single other incident of bronchial compression at our center during the study period in an adult with truncus arteriosus with deployment of bilateral PA stents, conduit stenting, and trans-catheter pulmonary valve placement. Future work will be required to optimally risk-stratify patients. Pre-procedure imaging with cross-sectional imaging by CTA or CMR is likely to be very helpful in identifying patients at risk for bronchial compression by stent angioplasty. Our results demonstrate that with assistance of procedural bronchoscopy during test angioplasty, immediate and dynamic assessment of the risk of bronchial compression is possible. In a case series of two patients, Ebrahim and colleagues a similar approach during stent angioplasty of the LPA (2 patients) and redilation of previously placed aortic stents (3 procedures in 2 patients)[10]. In this series, bronchoscopy was not technically challenging and not accompanied by any procedure-related adverse events, consistent with previously published series[11–13].

In patients identified as at risk for bronchial compression with test balloon inflation and procedural bronchoscopy, the care team must take into account the patient's clinical status as well as the relative degree of PA obstruction, maldistribution of pulmonary blood flow, and dilation of the aortic arch. Operative augmentation balloon angioplasty of the PA may have limited benefit if the etiology of the narrowing is external compression of the aorta. In this case, augmentation of the pulmonary artery with surgical plication of the dilated aorta, deployment of a stent at a diameter that incompletely relieves obstruction but does not compress the bronchus, and non-intervention have to be considered.

Radiation exposure is an important issue for all interventional cardiologists. The approach described has the potential to reduce radiation exposure significantly. We would advocate pre-procedural CMR, which can measure pulmonary artery flow splits, identify anatomic stenosis, and lay out the relationship of aorta, pulmonary artery, and bronchus with no radiation exposure. This is in lieu of CTA or rotational angiography whose use has been reported by other groups concerned with this complication[10]. Procedural bronchoscopy and test angioplasty has the potential to reduce the need for post-procedural CTA if a stent is deployed. Finally, novel CMR sequences with reduced stent artifact are in development and may allow for imaging without radiation.

In smaller patients, we describe performing test balloon inflations to a diameter sufficient for an adult and deploying stents at that larger diameter. This is to avoid having to perform

subsequent balloon angioplasty in these patients. Though other groups have reported using procedural bronchoscopy to further dilate stents in patients with coarctation [10], there is an inherent issue with this approach. As has been pointed out[14], once a stent has been deployed, there is no opportunity for a test balloon angioplasty. Balloon inflation dilates the metal stent, which will not recoil back to its previous diameter, and if there is bronchial compression, it is not reversible and there is no added benefit in visualizing it with bronchoscopy. Our approach was governed by the hypothesis that dilating the stent to adult size would be preferable. It is not possible to predict how the thoracic cavity and its contents will change with somatic growth and time, and it is possible that the risk of bronchial compression could either decrease or increase with time. It is also possible that dilation of stents beyond the caliber of the distal vessel could increase risk of in-stent stenosis or other adverse events. In the short follow-up of subjects in this study, there have been no adverse events in subjects with stents dilated to these larger once test inflation has demonstrated that there is not impingement on the ipsilateral bronchi.

The current series has several limitations. We have presented a small number of patients from a single center. The estimates of risk are inevitably imprecise. There is limited information at present regarding the baseline prevalence of bronchial narrowing in patients with TCP, a separate question that deserves attention.

Conclusions

PA stenosis is an important issue in the long-term treatment of patients with congenital heart disease. The geometry of anatomic structures in the chest of children with HLHS and variants is commonly distorted in a manner that may place them at greater risk of bronchial compression after PA stenting. Incorporating bronchoscopy in the procedural imaging during test pulmonary artery angioplasty provides a live view of the airway and can help determine the limits for stent deployment. It also has the potential to improve our understanding of the anatomic risk factors that predispose certain patients to airway compression.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

A) T2-weighted CMR with axial and coronal sections demonstrating the relative positions of (moving from anterior to posterior) the dilated neo-aortic root, pulmonary arteries, and left mainstem bronchus and descending aorta.

B) Power injection angiogram through a sidehole catheter in the RPA demonstrating thinning of the contrast column in the central PA and LPA, correlating with the previous CMR.

Figure 2.

A) Hand injection following stent angioplasty of the central PA and LPA demonstrating resolution of branch PA stenosis and straightening of the course of the PA.

B) CTA with axial and coronal sections demonstrating stenosis of the left mainstem bronchus compressed by both the dilated aorta and stented PA

C) Still-frame image from fiberoptic bronchoscopy of the left mainstem bronchus, demonstrating complete functional occlusion of the airway.

Figure 3.

A) CTA with axial section and coronal sections demonstrating resolution of the airway narrowing secondary to the stent in the bronchus (marked by white arrow).

Still-frame images from fiberoptic bronchoscopy of the left mainstem bronchus after deployment of the airway stent. B) Image taken at the proximal end of the stent demonstrating improved caliber of the bronchus the length of the stent. C) Image taken at the distal end of the stent, demonstrating normal caliber of the distal left main bronchus and the left upper lobe and left lower lobe bronchi.

Figure 4.
Simultaneous digital fluoroscopy and frame-captures from fiber-optic bronchoscopy
A) Prior to any intervention
B) During inflation of a 16mm by 3.5 cm balloon in balloon (BIB) catheter in the LPA, demonstrating airway with >50% of initial diameter
C) Following deployment of Palmaz XL stent deployed on 16mm by 3.5cm BIB, the airway has similar caliber to that during test inflation.

Table 1

Subjects with stent angioplasty of the LPA with subsequent computed tomography of the chest

	CT	CMR	No subsequent imaging	<i>p</i>
N	8	19	37	
Age (years)	1 (0.4–9)	3.7 (0.4–32)	6.0 (0.2–40.6)	0.07
Female sex % (n)	38% (3)	42% (8)	32% (12)	0.77
Weight (kg)	8.8 (4.6–23)	16.2 (4.8–67.5)	20.3 (5.0–77.9)	0.02
Height (cm)	71 (56–126)	95 (54–169)	114 (58–179)	0.02
Time from stent placement to CT (days)	113 (25 days–5 years, IQR: 51–703 days)			
Diameter of the bronchi (mm)				
<i>Maximal diameter (axial projection)</i>	4.7 (3.4–8.8)			
<i>Minimal diameter (axial projection)</i>	3.8 (1.8–6.1)			
<i>Ratio of minimal to maximal diameter in axial projection</i>	0.8 (0.4–0.9)			
<i>Maximal diameter (coronal projection)</i>	5.7 (3.9–10.4)			
<i>Minimal diameter (coronal projection)</i>	5.0 (2.0–9.5)			
<i>Ratio of minimal to maximal diameter in coronal projection</i>	0.9 (0.4–0.9)			
Bronchial compression % (n)				
<i>None-trivial</i>	62.5% (5)			
<i>Mild</i>	25% (2)			
<i>Moderate</i>	12.5% (1)			
<i>Severe</i>	0% (0)			

Table 2

Cases during which procedural bronchoscopy was used

Case	Age	Sex	Diagnosis	Balloon	Stent
1	24	M	HLHS (MS/AA) s/p fenestrated lateral tunnel dilated aortic root with previously demonstrated maldistribution of pulmonary blood flow and LPA stenosis on MRI	15mm×2cm Tyshak2 and 16mm×3.5cm BIB	Genesis 2910B on 16 mm ×3.5 cm BIB
2	13	F	TA (S,L,L) s/p fenestrated extracardiac Fontan known central and left PA stenosis with previous 12mm Genesis premount stent in central pulmonary artery	8mm×2cm, 9mm×4cm, and 10mm×4cm, and 12mm×4cm Atlas Atlas	EV3 LDMax on 12 mm × 3cm BIB
3	14	M	HLHS (MA/AA) s/p non-fenestrated extracardiac Fontan for routine catheterization	12mm×4cm ZMED 2	EV3 LDMax on 10 mm ×3.5 cm BIB
4	3	M	HLHS (MS/AS) s/p fenestrated extracardiac Fontan with distal LPA stenosis diagnosed prior to the Fontan operation	7mm×2cm Sterling and 10mm×2cm Sterling	Genesis 1910B on 7m m×2 cm Po werflex
5	20	F	IAA type B with LV hypoplasia s/p fenestrated lateral tunnel Fontan for hemodynamic evaluation prompted by increased fatigue and decrease in saturation	9mm×2cm ZMED2 and Tyshak2 10mm×3cm	Genesis 2910B on 9m m×3 cm ZMED 2
6	3	M	HLHS (MA/AS) VSD with central PA stenosis diagnosed on catheterization and MRI prior to extracardiac Fontan	9mm×3cm ZMED2 and 8mm×3cm ZMED2	N/A *
7	2	M	HLHS (MS/AS) with central PA stenosis on MRI prior to extracardiac fenestrated Fontan	8mm×2cm and 9mm×2cm ZMED2	Genesis 1910B on 9mm×3cm ZMED2

* There was baseline mild narrowing of the bronchus. During balloon dilation, there was complete or near-complete occlusion of the bronchus. Stent angioplasty was not performed

Abbreviations: AA: aortic atresia, AS: aortic stenosis, BIB: balloon in balloon catheter, HLHS: hypoplastic left heart syndrome, IAA: interrupted aortic arch, MA: mitral atresia, MS: mitral stenosis, TA: tricuspid atresia