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ORIGINAL ARTICLE

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Stenting the vertical neonatal ductus arteriosus via the percutaneous axillary approach

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Abstract

Background/Objective: Stenting the ductus arteriosus (DAS) has become an alternative to surgical systemic to pulmonary artery shunts in neonates with ductal-dependent pulmonary blood flow (PBF). Femoral approach for a vertical ductus can be difficult secondary to the acute angle and tortuous course, thus alternative access sites have been explored. Carotid access complications have been reported in 5%-10%. The extensive use of an axillary arterial approach in the United States has not been reported. The aim of this study is to describe our experience with DAS using the axillary approach.

Methods: We reviewed all patients with DAS with an axillary approach in neonates with ductal-dependent PBF (May 2017-May 2018) in our institution. Procedural reports, angiograms, and clinical records of all consecutive patients were reviewed. Procedural technique, procedural outcomes, adverse events, and post-hospital courses are reported.

Results: Seven consecutive patients who received DAS utilizing axillary approach. All patients had ductal-dependent PBF through a vertical, tortuous ductus. Five had pulmonary atresia or near atresia, one had compromised PBF due to dynamic subvalvar obstruction, and one had Tetralogy of Fallot with isolated left pulmonary artery. Axillary access with 3.3 or 4 French sheath was obtained using ultrasound guidance. Bare metal coronary stents were deployed successfully in all. Intra-procedure, one developed in stent thrombus requiring re-stenting. There were no procedural mortalities or major adverse events from axillary access. There is a steep learning curve. Hemostasis was achieved with manual compression. Two patients had reintervention at 6-8 weeks. All patients underwent successful planned surgeries.

Conclusions: This series suggests DAS in neonates utilizing an axillary approach is a feasible and effective alternative for establishing PBF. Axillary arterial approach may be preferred as there is no risk to neurological sequelae and very low risk of limb complications. Larger series are needed to validate this approach.

KEYWORDS

axillary access, cyanotic congenital heart disease, ductal stenting

1 | INTRODUCTION

Stenting the ductus arteriosus (DAS) has become an alternative to surgical systemic to pulmonary artery shunts in neonates with ductal-dependent pulmonary blood flow (PBF). The ductus arteriosus in severe cyanotic heart disease usually arises in a vertical orientation from the undersurface of the aortic arch and is frequently tortuous. Using a femoral approach for a vertical ductus can be difficult secondary to the acute angle and frequently tortuous course of the PDA, thus alternative access sites have been explored including the carotid artery. In recent reports, carotid complications have been reported in 5%-10% of pediatric patients including thrombus formation and pseudoaneurysms.[1,2] Although neurologic sequelae have not been associated with these complications, some centers are continuing to explore other access sites including the axillary artery. To our knowledge, the extensive use of an axillary arterial approach in the United States for DAS has not been reported. The aim of this study is to describe our experience with DAS using a percutaneous axillary approach.

2 | METHODS

The research plan was reviewed and approved by the University of California, San Diego Human Research Protections Program and Rady Children's Hospital Institutional Review Board. We retrospectively queried our institutional cardiac catheterization database to identify and include all patients who underwent DAS with an axillary approach in neonates with ductal-dependent PBF from May 2017-May 2018. Procedural reports, angiograms, and clinical records of patients were reviewed. Procedural technique, procedural outcomes, adverse events, and post-hospital course are reported.

2.1 | Statistical analysis

Continuous variables were summarized as mean (SD) or median (range) as appropriate. Categorical variables are represented by frequencies or percentages.

3 | RESULTS

3.1 | Pre-procedure

Patient diagnoses were established by echocardiography. Four patients (57%) had advanced imaging studies (CT/MRI) prior to the procedure. Each case was discussed in a multidisciplinary setting including cardiologists and cardiovascular surgeons prior to referring for DAS after a consensus was obtained (institutional clinical practice for all potential surgeries).

3.2 | Procedure

Prostaglandin infusions were not stopped prior to the procedure but titrated to the lowest dose required for ductal patency (0.01-0.02 mcg/kg/min). All procedures were done with general anesthesia. Initial arterial access was either obtained in the femoral (n = 4) or umbilical (n = 3) for an aortogram in the anteroposterior and lateral projections to evaluate the position, size, length, and morphology of the ductus arteriosus. The choice of left or right axillary access was determined based on arch sidedness and the relationship of the subclavian artery to the ductus arteriosus. Axillary access was obtained with ultrasound guidance (SonoSite, FujiFilm, Bothell, WA) to place a 3.3 or 4 French sheath (Figure 1). The patient's arm was abducted creating an angle slightly more than 90 degrees from the thorax to expose the axillary area. Towels were placed under the arm for support and to create stability during needle entry. Care was taken not to over-extend as it would create tension on the site and underlying vascular structures. Wire target (primary operator preference) using a 0.014" Balanced Middleweight Wire (Abbott Vascular, Santa Clara, CA) was used in three patients. Median time for axillary access was 12 minutes (range 7-23). Intravenous heparin (100 U/kg) with ACT maintained > 200 and routine prophylactic antibiotics were administered.

Next, the DA was engaged through the axillary sheath typically with a 0.014" Balanced Middleweight Wire (Abbott Vascular, Santa Clara, California) loaded inside a Renegade microcatheter (Boston Scientific, Marlborough, Massachusetts) which is inserted through a

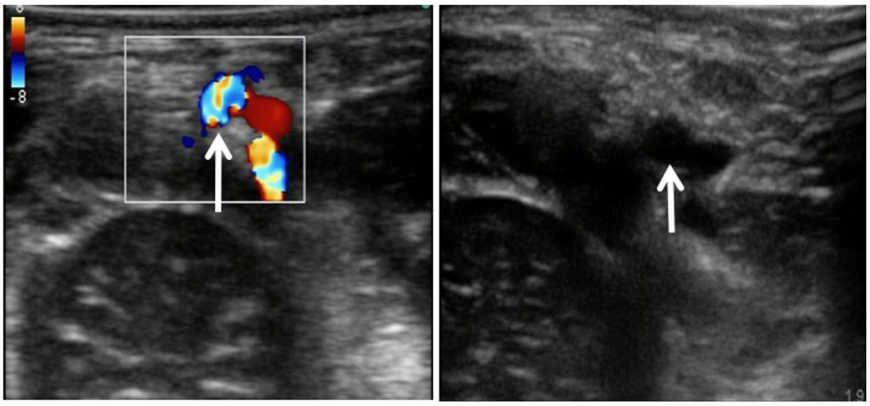

FIGURE 1 Color Doppler (left) and two-dimensional (right) images of the left axillary artery (arrow) during ultrasound guided access

4F angled Glide catheter (Terumo, Somerset, New Jersey). With this coaxial system, the wire is carefully guided across the DA and positioned into either the main pulmonary artery or branch pulmonary over which the microcatheter is advanced, the wire is exchanged for a stiffer coronary 0.014" Iron Man Wire (Abbott Vascular, Santa Clara, California) to straighten the DA. With this wire position, a bare metal Integrity coronary stent (Medtronic, Minneapolis, Minnesota) was delivered over the wire and implanted covering the entire length of the DA with 1-2 mm across the ductal-aortic and ductal-pulmonic junctions (Figure 2). The stent diameter was chosen based on patient weight and if there were any additional sources of PBF. As a general rule of thumb for single source PBF, we chose a 4 mm diameter stent for those > 3 kg, and 3.5 mm diameter for those < 3 kg. Prostaglandin infusions were stopped once the stent was in place. Hemostasis was achieved by manual compression.

3.3 | Post-procedure

Anticoagulation was started after hemostasis was ensured with intravenous heparin infusion of 10-15 units/kg/h. Therapy was transitioned to acetylsalicylic acid (3-5 mg/kg/day) and clopidogrel (2 mg/kg load, followed by 1 mg/kg/day) to maintain ductal patency.

During follow-up, patients were enrolled in our institutions home monitoring program and followed closely in clinic. Frequent clinical visits with echocardiograms were performed.

3.4 | Data results

Seven patients were taken to our catheterization laboratory in our institution for the purpose of DAS utilizing an axillary approach (Table 1). Six patients had left axillary access and one patient had right axillary access which corresponded to the arch sidedness. Median age at the time of the procedure was 8 days (range 6-23). Median weight was 3.2 kg (range 2.6-3.6). All patients were term. All patients had ductal-dependent PBF through a vertical and tortuous ductus. Five patients had pulmonary atresia or near atresia, one had compromised PBF due to dynamic subvalvar obstruction, and one had Tetralogy of Fallot (TOF) with an isolated left pulmonary artery (LPA). Bare metal coronary stents were deployed successfully in all cases with a median length of

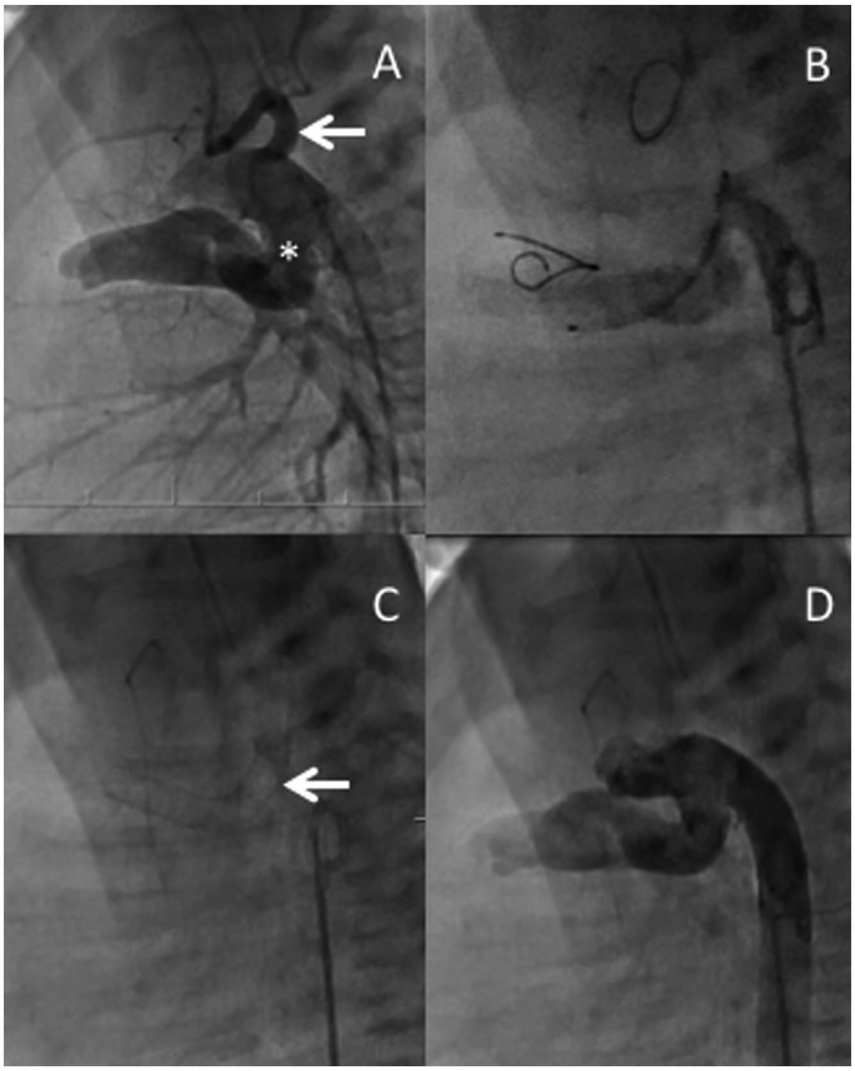

FIGURE 2 A, Pre-intervention aortogram showing the proximity of the left subclavian artery (arrow) to the PDA (*). B, Positioning of a coronary stent across the entire PDA length over a stiff 0.014" coronary guidewire. C, Stent deployed (arrow). D, Post-intervention aortogram, PDA stent is widely patent

TABLE 1 Patient demographics, procedure details, and outcomes

Patient	Age (days)	Gender	Weight (kg)	Diagnosis	CT/MRI	Access	Ultrasound access	Wire target	Stent wire anchor position	Stents (integrity)	Axillary access time (min)	Fluoro time (min)	Procedure time (min)	Other intervention	Related complications	Reinterventions	Surgery
1	9	M	3.2	Dextrocardia (abdominal and atrial situs solitus), L-looped ventricles with severely hypoplastic right-sided left ventricle, pulmonary atresia, bilateral superior vena cavae	MRI	Axillary: 4F (left) Other: 4F RFA	Yes	No	RPA	4 mm × 18 mm	7	39	160	None	None	Repeat stent angioplasty Integrity 4 mm × 22 mm (RFA access)	Bilateral bidirectional Glenn
2	6	M	3.1	TOF with discontinuous left pulmonary artery	CT	Axillary: 4F (left) Other: 4F LFV, UA	Yes	No	LPA	3.5 mm × 18 mm	8	34	168	Pulmonary balloon vavluoplasty	None	None	TOF repair LPA unifocalization
3	23	F	2.6	TOF with near pulmonary atresia Tracheal stenosis with complete tracheal rings Trisomy 21	CT	Axillary: 4F (left) Other: 4F RFA	Yes	Yes	MPA	3.5 mm × 18 mm	23	47	164	None	Intra-procedure stent thrombosis (thrombolytic and restenting with Integrity 4 mm × 15 mm from RFA)	None	TOF repair slide tracheoplasty
4	6	M	3.5	Pulmonary Atresia Intact ventricular septum RV dependent coronaries	None	Axillary: 4F (left) Other: UA	Yes	No	MPA	4 mm × 18 mm & 4 mm × 15 mm	17	17	66	None	Small left axillary pseudoaneurysm (no intervention)	None	Bidirectional Glenn
5	7	F	3.0	Pulmonary Atresia Intact ventricular septum RV dependent coronaries	None	Axillary: 4F (left) Other: UA	Yes	No	MPA	3.5 mm × 26 mm	12	13	99	None	None	Repeat stent angioplasty Integrity 4 mm × 22 mm (left axillary)	Bidirectional Glenn
6	15	M	3.5	Tricuspid atresia dynamic RVOT obstruction	None	Axillary: 3.3F (left) Other: 3.3F RFA	Yes	Yes	LPA	3.5 mm × 22 mm	14	11	115	None	None	None	Bidirectional Glenn
7	8	M	3.6	Heterotaxy pulmonary atresia discontinuous pulmonary arteries with bilateral ducti unbalanced atrioventricular canal	CT	Axillary: 4F (right) Other: 4F RFA	Yes	Yes	LPA/RPA	3.5 mm × 30 mm (L) 2.5 mm × 22 mm (R)	8	22	138	None	None	None	Pulmonary artery unifocalization Bidirectional Glenn

Abbreviations: LPA, left pulmonary artery; MPA, Main Pulmonary artery; RFA, Right femoral artery; RPA, Right pulmonary artery; RVOT, Right ventricular outflow tract; TOF, Tetralogy of Fallot; UA, Umblical artery

20 mm (18-30). No procedural mortalities or major adverse events from axillary access, although there is a steep learning curve. Hemostasis achieved with manual compression with good distal pulses. Two patients had reintervention at 6-8 weeks. All seven patients underwent successful subsequent planned surgical repair or palliation.

3.5 | Complications and reinterventions

Intra-procedure, one patient (patient #3) developed a thrombus in the stent which was treated with thrombolytics and re-stenting of the vessel. In this case, both femoral and axillary access was difficult. Once axillary access was obtained, the wire inadvertently crossed the DA causing spasm and desaturation. A bare metal coronary stent was urgently advanced across the DA and deployed, stabilizing the situation. However, desaturations started to occur again and the stented lumen was narrow due to thrombus. This was attributed to inadequate anticoagulation during the procedure with heparin. This patient was also found to have a retroperitoneal bleed from the femoral access which resolved with observation and an iliac artery thrombus occlusion requiring subcutaneous enoxaparin therapy. After re-stenting, the patient was stabilized for 3 months until she was large enough for her complex definitive repair including cardiac and tracheal surgery.

In the post-procedure period, two patients required reintervention (28%). Patient #1 had reintervention after being found to have lower oxygen saturations at 6 weeks of age. In the catheterization lab, it was noted that the stent had migrated toward the pulmonary side, and in retrospect the stent had not completely covered the aortic end during the initial procedure (this was not recognized at the time). The ductus arteriosus was restented which allowed for continued management until the bilateral bidirectional Glenn palliation. Patient #5 had reintervention at 8 weeks also after being noted to have lower oxygen saturations. In the catheterization lab she was found to have intimal proliferation causing in-stent stenosis. This was restented, and she subsequently underwent bidirectional Glenn palliation at the appropriate time.

4 | DISCUSSION

The evolution and utility of stenting the ductus arteriosus has progressed in the last 20 years. The initial reports from Gibbs in the 90s was disappointing to the point that he concluded "ductal stenting cannot be recommended."[3] Since then, the results are more encouraging due to the advancement of technology and techniques. The results are comparable if not better than surgical shunts.[4-13] DAS as an alternative to surgical shunts is becoming more widespread in its use especially in the United States and Europe. The vertical and tortuous ductus has been a risk factor for procedural failure especially with a femoral approach due to the acute angle of the wire course. Long femoral sheaths have also been found to be a major risk factor for femoral artery occlusion in this population.[14] This then led some centers to explore carotid access for these procedures as the ductus arteriosus would be more in line.

Carotid access in children has been used and has been shown to be feasible and safe. However, 5%-10% have some minor complications including thrombus and pseudoaneurysm formation although no neurologic sequelae has been reported. Due to the unknown long-term implications of this approach, there are centers exploring other arterial access options including the axillary artery.[15] In a recent report, Polat reports 100% procedure success with 10 patients in whom ductal stenting was performed in vertical tortuous ducti.[16] The axillary approach allows the operator to have similar access to the vertical ductus arteriosus when compared to the carotid artery through the subclavian artery without potential compromise to the brain. In our small experience, we did not have any major complications of poor limb perfusion from the axillary approach. All stenting attempts were successful though there is an initial learning curve. This learning curve is evident in increased procedure and fluoroscopy time in the initial patients (patients 1-3).

There are several key points that we would like to highlight from our experience. Firstly, thorough prior planning is paramount; we find three-dimensional gated, contrast enhanced cardiac CT useful. A CT allows for clear delineation of the relationship of the ductus arteriosus to the subclavian artery and left pulmonary artery. It is considered a contraindication if the left pulmonary artery arises from the ductus arteriosus. Secondly, due to the unpredictable and potential spastic response of the DA, once vascular access is obtained the operator should be ready to implant the stent urgently. Thirdly, wire position in the pulmonary artery tree should allow a relatively stiff wire to straighten out the DA to aid the delivery of the stent which should cover the entire length of the vessel. Fourthly, consideration should be given to having additional arterial access from either the femoral or umbilical sites. Smallest sheath size available should be placed if femoral artery is used, we used a 3.3F sheath. This access allows for an initial angiogram for accurate stent sizing as the guidewire from the axillary artery may cross the DA and cause spasm. It also allows for a wire target access to straighten out the subclavian and axillary artery if the axillary access by ultrasound is difficult. Although there was a femoral complication in patient 3, it was through this access site that we were able to cross the implanted stent after thrombosis for restenting. Lastly, stent thrombosis is a described complication in DA stenting. We suspect that our event was due to inadequate intraprocedural anticoagulation, though redundant intimal tissue cannot be excluded in a patient with Trisomy 21. Thoughtful anticoagulation and close follow-up strategies should be employed. Anticoagulation prior to the procedure may complicate bleeding during access. Our strategy is to anticoagulate after access and post-procedure.

Although bare metal stents were used in this series, we recognize that some centers have begun to used drug eluting stents to address the known issue of intimal proliferation.[12] We have since started to use these stents after this series. In addition, we have also trended toward smaller stents (ie, 3.5 mm for 3-4 kg, 3 mm for < 3 kg) due to pulmonary overcirculation. Future studies are needed to validate the safety and efficacy of this approach.

5 | CONCLUSION

This small series suggests DAS in neonates utilizing an axillary approach is a feasible and effective alternative for establishing PBF. Axillary arterial approach may be preferred as there is no risk to neurological sequelae and very low risk of limb complications. Larger series are needed to validate this approach.

CONFLICT OF INTEREST

The authors declare that they no conflicts of interest with the contents of this article.

AUTHOR CONTRIBUTIONS

Data collection, Data analysis and interpretation, drafting manuscript, critical revision of article, and approval of final article: Jesse Lee.
Concept and design of study, drafting manuscript, critical revision of article, and approval of final article: Kanishka Ratnayaka.
Concept and design of study, critical revision of article, and approval of final article: John Moore.
Data analysis and interpretation, drafting manuscript, critical revision of article, and approval of final article: Howaida El-Said.

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