Multidetector-Row CT Evaluation of Tortuous Ductus Arteriosus for Stent Implantation in Neonates with Duct-Dependent Pulmonary Circulation: Preliminary Experience in 4 Cases

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Purpose: This study describes the preliminary experience of multidetector-row CT (MDCT) assessment of tortuous patent ductus arteriosus (PDA) for stent implantation in neonates with duct-dependent pulmonary circulation.

Methods: Seven neonates with pulmonary atresia and PDA initially diagnosed with echocardiography who were scheduled for MDCT for evaluation for stent implantation were reviewed. The PDA size measured on MDCT and catheter angiography, stent size and outcomes were studied. The patients’ ages at stent implantation and hospitalization duration were compared with those in 14 patients with Blalock-Taussig surgical palliation.

Results: After MDCT, three patients were excluded from stent implantation; therefore, 4 neonates (1 girl, 3 boys; mean age, 12.8 days; range, 10-15 days) were included in the study. All four PDA appeared elongated and tortuous originating from the inferior surface of the aortic arch. The length of the tortuous PDA measured on angiography (mean, 13.8 mm; range 10.8 mm-15.8 mm) tended to be shorter than those measured on MDCT (mean, 15.0 mm; range 11.1 mm-17.1 mm). One PDA stent selected based on angiographic measurements was not adequate for total PDA coverage while the other three stents selected based on MDCT led to successful maintenance of pulmonary flow. Compared with patients underwent Blalock-Taussig shunt, patients underwent stent implantation were significantly younger (mean age 34.9 vs. 12.8 days, P = 0.018) and the hospital stay was significantly shorter (mean 63.5 vs. 20.0 days, P = 0.022). Follow-up MDCT clearly demonstrated the stent-related stenoses facilitating subsequent interventional treatment.

Conclusion: MDCT may be a considerable alternative method for assessing tortuous PDA in neonates with duct-dependent pulmonary circulation for stent implantation and is also useful for demonstrating stent-related complications.

Key Words: Ductus arteriosus • Multidetector-row computed tomography • Stent implantation

INTRODUCTION

For neonates with duct-dependent congenital heart diseases, maintenance of a patent ductus arteriosus (PDA) for pulmonary circulation is crucial. Conventional palliative treatment in neonates with duct-dependent pulmonary circulation usually relies on prostaglandin E1 for some days and followed by surgical establishment of aortopulmonary shunt if total repair cannot be accomplished.1,2 However, shunt-related complications such as
infection, phrenic and vagal nerve palsy, shunt stenosis or occlusion and surgical adhesion may add complexity to subsequent surgery.1-4 On the other hand, reliable non-surgical palliation of duct-dependent pulmonary circulation with adequate flow for several months to attain adequate pulmonary artery growth is beneficial for corrective surgery.2,5,6 With recent advancement in transcatheter delivery method and flexible low-profile pre-mounted stent, complete stenting of PDA has been reported to be a safe and effective alternative to surgical aortopulmonary shunt.5-8 Nevertheless, most of the cases with successful stenting were of short, straight or slightly curved ductal configuration.5,6 In contrast, detailed anatomic assessment and accurate determination of length and width of tortuous PDA on angiography may be problematic and may lead to failure of stent implantation.7,8 Given its superb spatial and temporal resolution and short scanning time, multidetector-row CT (MDCT) has been described as is a good tool for morphologic evaluation of congenital heart diseases, coronary aneurysm, coronary arteriovenous fistula or even concurrent septal defect and heart tumor.9-13 However, the role of MDCT in the comprehensive assessment of tortuous PDA has not been fully addressed. This study reports our preliminary experience of MDCT assessment of tortuous PDA for stent implantation in neonates with duct-dependent pulmonary circulation.

MATERIALS AND METHOD

Patients

Between 2007 June to 2009 April, seven neonates with ductal-dependent pulmonary circulations and PDA seen on transthoracic echocardiography who were considered potential candidates for transcatheter insertion of a PDA stent were enrolled. The inclusion criteria for subsequent MDCT were as follows: (1) neonate with duct-dependent pulmonary circulation, (2) a tortuous and elongated PDA suspected on echocardiography, and (3) progressive deterioration of O2 saturation that require urgent interventional or surgical treatment. Exclusion criteria were as follows: (1) known renal function impairment, (2) concurrent congenital diseases that required early correction (transposition of the great artery, severe coarctation of the aorta, interruption of the aortic arch), (3) concurrent infection. In addition, in order to compare the age the patients underwent PDA stent or surgical palliation, and hospitalization duration, patients who underwent Blalock-Taussig shunt for pulmonary circulation between January 1999 to 2009 were also enrolled. The study was approved by the institutional review board of this hospital and consents for thoracic MDCT were obtained from the patients’ parents.

MDCT examination

Thoracic MDCT was performed with a 64-MDCT scanner (Aquilion, Toshiba Medical Systems Corporation, Tochigi-ken, Japan) within 2 days of PDA stent implantation. Intravenous access was established by inserting a 22-gauge intravenous cannula into a peripheral vein. The patients were sedated with oral choral hydrate (75 mg/kg, maximal dose 2000 mg). If not successful, intravenous ketamine (1 mg/kg) were administered. No beta-blocker was given. The examination was limited to the 2 cm above the arch and the heart, and other parts of the body were appropriately protected. The scanning parameters of included tube voltage, 80 kV size; tube current adjustment from 30 mAs; pitch, 0.25 with ECG gating; scanner rotation, 0.4 second; slice thickness, 1 mm; reconstruction interval, 0.5 mm and field of view, 24 cm. Before scanning, a test bolus of normal saline was injected via a mechanical power injector (Stellant; Medrad, Pittsburgh, PA, USA) at a rate of 0.7 ml/sec, to ensure that there was no rupture or leakage in the cannulated vein. Nonionic iso-osmolar contrast material (Iodixanol, 320 mgI/mL; Visipaque, GE Healthcare) was given at a dosage of 2 ml/kg at the same rate as the saline test bolus with subsequent saline flushing. Automatic triggering was applied by putting a circular region of interest at the ascending aorta at a threshold level of 100 HU. After the examination, the raw data were immediately transferred to a workstation (Vitrea 2, Vital Images Inc, MN) for post-processing. In addition to axial images, post-processing was performed with interactive real-time multiplanar or curved reconstructions, 2-dimensional composite sub-volume and 3-dimensional projection angiograms to best depict particular anatomic features of interest. By using data segmentation methods, unnecessary overlapping structures were removed so that the extracardiac thoracic great arteries and veins were clearly shown. Despite the tortuosity of the PDA,
the length of the PDA was defined as the maximal distance between the center of the aorto ductal junction to the center of ductopulmonary junction measured along an obliquely reconstructed plane with inclusion of this two points. The narrowest width of the PDA was also measured.

**PDA stent implantation**

Prophylactic antibiotic (cefazolin, 25 mg/kg) was administered every 6 hours on the day before the procedure. The procedure was performed under deep sedation with intravenous injection of ketamine (1 mg/kg). After local anesthesia, vascular access was obtained via the right femoral artery using a 5 Fr. sheath. Intravenous heparin (100 U/kg) was administered at the beginning of the procedure then a dosage of 25 IU/kg/hr continuously for 48 hrs. Prostaglandin-E-1 infusion was discontinued shortly after the beginning of the catheterization to impose constriction of the duct. Angiography of the aorta in lateral, 40-degree right anterior oblique and cranio-caudal tilting (to avoid superimposition of the PDA and great vessels) projections were done to delineate ductal anatomy. The maximal length and the width of the PDA were measured with the digital calipers. The origin of the PDA was identified and catheterized. Subsequently, two 0.014-inch guide-wires (Rinato, Asahi Intecc Co., and Runthrough, Terumo Co.) was inserted and anchored to the distal pulmonary artery to assist engagement of the long delivery sheath and the stent. A pre-mounted coronary stent (Liberte Monorail coronary stent, Boston Scientific; Multo-Link Mini Vision coronary stent, Abbott Vascular; or Driver coronary stent, Medtronic) was implanted in the PDA through the long delivery sheath and after deployment of the stent, balloon dilatation of the stent was performed. Attempts were made to cover the entire length of the PDA. After PDA stent implantation, oxygen saturation was evaluated and immediate echocardiographic assessment to confirm adequate flow through the PDA stent was attained. All patients were under close observation after the procedure and aspirin (5 mg/kg/day) was administered for 6 months after discharge. All patients were follow-up weekly in the first month and if stable 2-4 weeks thereafter. Follow-up thoracic MDCT was performed if echocardiography revealed impaired flow through the PDA stent or suspicious stent complications.

**Data collection and analysis**

Data on patients’ age, sex, body-weight, days of hospital stay, PDA size measured on MDCT and catheter angiography, stent size, changes in O2 saturation before and after PDA stenting and outcomes were collected. The age of the patients underwent PDA stent or surgical palliation and hospitalization duration between the patients treated by PDA stenting and Blalock-Taussig shunt were compared by using the Student’s t-test. P values smaller than 0.05 were considered statistically significant.

**RESULTS**

Thoracic MDCT was successfully accomplished in 7 neonates with tortuous PDA and none had any complications after the examination. Their heart rates ranged from 138-152 beats/min, averaged 144 beats/min. One patient was dead to sudden cardiac arrest 4 hours before scheduled PDA stent implantation and the parent of one patient refused further intervention after brain anomaly was suspected on echo evaluation. Another patient was excluded for MDCT revealed extreme tortuosity with multiple loops of the PDA (Figure 1) rendering high risk for stent implantation. Therefore, a total of 4 neonates (1 girl, 3 boys; mean age, 12.8 days; range, 10-15 days) were included in this study (Table 1). The calculated effective radiation dose was 1.4 mSv to 1.7 mSv (averaged 1.5 mSv). On the other hand, there were 17 patient underwent Blalock-Taussig shunt for palliation but three of them were dead within 2 days after operation and the other 14 patients (mean age, 63.5 days; range, 16-65 days) were included in this study. Compared with patients underwent Blalock-Taussig shunt, patients underwent PDA stent implantation were significantly younger (mean age 34.9 vs. 12.8 days, p = 0.018).

All 4 PDA appeared tortuous and elongated on MDCT and coronary angiography and were originated from the inferior surface of the aortic arch. The length of the tortuous PDA measured on angiography (mean, 13.8 mm; range 10.8 mm-15.8 mm) tended to be shorter than those measured on MDCT (mean, 15.0 mm, range 11.1 mm-17.1 mm). In patient 1, MDCT clearly demonstrated the tortuous duct (Figures 2A-C) while catheter angiogram showed partial obliteration due to overlapping...
Figure 1. A 9-day-old neonate with ventricular septal defect, pulmonary atresia and patent ductus arteriosus. (A) and (B) contrast-enhanced subvolume coronal oblique CT images show an elongated, extremely tortuous ductus arteriosus (white and black arrows) originating from the inferior part of the aortic arch with an initial hair-pin loop which twists to the left and then turns superoanteriorly to the right to join the pulmonary confluence of the right and left pulmonary arteries (open arrows). (C) Contrast-enhanced volume-rendered CT image in right posterior oblique view with segmentation of the descending aorta offers three-dimensional demonstration of the extremely tortuous duct (arrows) and the pulmonary arteries (open arrows).

Table 1. Clinical summary of 4 neonates with tortuous patent ductus arteriosus

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ductal-dependent condition</td>
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<td>PA, VSD</td>
<td>PA, VSD, PDA</td>
<td>PA, ASD, VSD</td>
</tr>
<tr>
<td>Age (days)</td>
<td>12</td>
<td>14</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Sex</td>
<td>female</td>
<td>male</td>
<td>male</td>
<td>male</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>2.2</td>
<td>3.0</td>
<td>2.8</td>
<td>2.7</td>
</tr>
<tr>
<td>PDA size (mm) on MDCT (length/diameter)</td>
<td>16.7/5.3</td>
<td>17.1/4.5</td>
<td>15.1/4.9</td>
<td>11.1/4.7</td>
</tr>
<tr>
<td>PDA size (mm) on angiography (length/diameter)</td>
<td>15.3/4.9</td>
<td>15.8/3.9</td>
<td>13.3/4.1</td>
<td>10.8/4.2</td>
</tr>
<tr>
<td>Stent size (mm) (length/diameter)</td>
<td>16.0/5.0</td>
<td>18.0/4.0</td>
<td>16/4.5</td>
<td>12/4.5</td>
</tr>
<tr>
<td>O2 saturation (%) before and after stenting</td>
<td>75 → 90</td>
<td>68 → 91</td>
<td>76 → 92</td>
<td>73 → 92</td>
</tr>
<tr>
<td>Stable duration after initial stenting (days)</td>
<td>1</td>
<td>180</td>
<td>95</td>
<td>93</td>
</tr>
<tr>
<td>Outcome</td>
<td>Palliative shunt at day 2</td>
<td>Balloon dilatation at day 182 and total correction at day 325</td>
<td>Stable after second stent implantation at day 96 and under follow-up</td>
<td>Stable and under follow-up</td>
</tr>
</tbody>
</table>

PA, pulmonary atresia; ASD, atrial septal defect; VSD, ventricular septal defect.
aorta (Figure 2D) but the stent selection was based on angiographic measurements. The patient appeared well initially after stent implantation with improvement of O2 saturation (from 75% to 90%). However, rapid clinical deterioration on day 2 with O2 saturation dropped down to 58%. Emergency surgery revealed inadequate PDA coverage by the stent with pulmonary stenosis just beyond the stent and palliative Blalock-Taussig shunt was performed.

On the other hand, the selection of stent length in the other three patients was based on MDCT measurement. Patient 2 recovered well and remained stable. However, at day 180 echocardiographic follow-up, decreased flow through the PDA stent was noted and follow-up MDCT revealed a stenosis just beyond the stent (Figure 3). Subsequent balloon dilatation was successfully accomplished and the patient eventually underwent total correction at day 325 with adequate pulmonary arterial growth. Patient 3 was stable until day 90 echocardiographic follow-up revealed decreased flow through the PDA stent and follow-up MDCT revealed a stenosis at aortic side (Figure 4). Subsequent implantation of an-

![Figure 2](image.png)

**Figure 2.** A 10-day-old neonate with ventricular septal defect and pulmonary atresia. (A) and (B) Contrast-enhanced subvolume coronal oblique (A) and axial oblique (B) CT images show an elongated, tortuous ductus arteriosus (arrows) originating from the inferior part of the aortic arch with a sigmoid course and connects to the superior surface of the proximal left pulmonary artery. (C) Contrast-enhanced volume-rendered CT image in right posterior oblique view offers three-dimensional demonstration of the tortuous duct (large arrows) connecting to the superior surface of the proximal left pulmonary artery (small arrow) and patent right pulmonary artery (open arrow). (D) Oblique catheter aortogram shows proximal part of the tortuous duct (arrows) while distal part is partially obliterated due to superimposed aorta (open arrow).
other stent was successfully accomplished. The patient remained stable. Both patients 3 and 4 were still under observation with satisfactory condition. Compared with patients underwent Blalock-Taussig shunt, the hospital stay in patients underwent PDA stent implantation was significantly shorter (mean 63.5 vs. 20.0 days, p = 0.022).

DISCUSSION

Maintenance of patency of the ductus arteriosus is crucial in newborns and neonates with critical stenosis or atresia of the right ventricular outflow tract. Although primary repair in the neonatal or early infancy is recent trend in the management of complex congenital heart diseases, Blalock-Taussig shunt remains an indispensable surgical palliation of duct-dependent cyanotic disease.1-4 However, in small newborn with low body weight and small pulmonary artery, a shunt operation is of high surgical risk.1,2,5 In addition, surgical adhesion, distortion of the shunted pulmonary artery and different aspects of the ductus arteriosus. Contrast-enhanced volume-rendered image in right posterior oblique view shows the stent within the ductus arteriosus (large arrow) and focal stenosis at the pulmonary side (small arrow) which was subsequently managed with balloon dilatation.

Figure 3. A 180-day-old boy with ventricular septal defect and pulmonary atresia post stent implantation with straightening of the tortuous ductus arteriosus. Contrast-enhanced volume-rendered image in right posterior oblique view shows the stent within the ductus arteriosus (large arrow) and focal stenosis at the pulmonary side (small arrow) which was subsequently managed with balloon dilatation.

Figure 4. A 94-day-old with ventricular septal defect and pulmonary atresia post stent implantation with straightening of the ductus arteriosus. (A) Contrast-enhanced volume-rendered CT image in left posterior oblique view with segmentation the descending aorta shows the stent within the ductus arteriosus (large arrow) and stenosis at the aortoductal orifice (small arrows). (B) Contrast-enhanced subvolume coronal oblique CT image shows part of the stent within the ductus arteriosus (large arrow) and stenosis at the aortoductal orifice (small arrow) which was subsequently managed with by second stent placement.
tial growth of the pulmonary arteries may pose difficult in corrective repair. With advancement in coronary stent development, low-profile, flexure premounted stents with good scaffolding are available and have been used for PDA stenting. Promising results have been reported in complete coverage of straight or mildly curved PDAs with effective non-surgical palliation of duct-dependent congenital heart diseases. On the other hand, the PDA in neonates with pulmonary atresia is characterized by complex tortuosity, usually takes a sigmoid course, and with stenosis at the pulmonary artery site or middle part. Such a complex tortuous morphology may easily lead to failure when attempting ductal stent implantation and thus requires special attention, especially in the measurement of PDA size and the selection of appropriate stent.

Conventionally, the measurement of the length and width of the PDA relies on catheter angiography. Aortograms in lateral and 40-degree right anterior oblique projections are commonly used as a road map for measurement and deployment of the stents. Such angiographic projections are adequate for PDA with a straight or mildly curved course, mostly originating from the upper portion of the descending aorta. For tortuous PDA, craniocaudal tilting of the X-ray tube with individual angulations to avoid superimposition of the PDA and the great vessels for better delineation of the duct has also been suggested. Consistent with prior reports, in the present study, all 4 patients with pulmonary atresia harbored an elongated PDA originating from the inferior part of the aortic arch and exhibited a complex tortuous course with focal stenosis. However, despite various positioning and X-ray tube angulations, we found that complete evasion of overlapping of the tortuous PDA with the great vessels on angiogram could hardly be accomplished. In additional to radiation, more contrast material had to use for each trial while the maximal dose allowable for newborn and neonate was limited due to low body weight. Furthermore, based on two-dimensional angiographic images, an accurate measurement of the whole PDA with complex tortuosity could be difficult leading to underestimation of PDA length and as in patient 1, ductal stenosis ascribing to incomplete PDA stent coverage might occur within hours and days leading to rapid clinical deterioration.

With advances in the spiral CT armamentarium, MDCT technology offers isotropic volume data, and high spatial and time resolution, allowing imaging of the heart, coronary artery and great vessels in details within several seconds. In the present study, two- and three-dimensional display in various perspectives would give a clear morphologic overview of the complex tortuosity of PDA to the pediatric cardiologist. MDCT demonstration of the PDA origin and sharp angulation from the inferior surface of the aortic is beneficial for treatment planning for catheterization of the orifice of such PDA via a retrograde approach can be very difficult. Alwi et al. have reported that by cutting the tip of a pigtail catheter, engagement of such a sharply angulated orifice would easily be attained, and in three of our patients, rapid catheterization was achieved by using this method. In the remaining case, an antegrade technique via the ventricular septal defect into the ascending aorta with subsequent catheterization of the pulmonary artery through the PDA was applied. Besides, since MDCT demonstrated that the PDA were elongated and tortuous, double guide-wire method was deliberately applied providing adequate support for advancement of the catheter through the PDA and subsequent deployment of the PDA stent. Our results also show the ductal length measured on angiography tended to be shorter than those measured on MDCT. One PDA stent selected based on angiographic measurements was not adequate for total PDA coverage while the other three stents selected based on MDCT led to successful maintenance of pulmonary flow. In our experience, MDCT may be supplementary to catheter angiography, allowing the cardiologist to double-check the PDA length and to better judge the appropriate PDA stent size. On other hand, as in one of our patients, MDCT also helpful for identifying inappropriate candidates for stent by revealing extreme tortuosity with multiple loops of the PDA.

In order to impose slight ductal constriction and facilitate stable stent positioning, prostaglandin E1 infusion was stopped shortly after the catheterization procedure. Therefore, the minimal PDA diameter acquired during angiography was generally a little smaller than that measured on MDCT. The PDA stent was selected with the diameter a bit larger than the minimal diameter and among our cases, the stent diameters were 4-5 mm and with further constriction of the PDA, firm adherence to the ductal wall was achieved. A final stent diameter of...
4.5 mm is sufficient to guarantee adequate flow to induce growth of the pulmonary artery while the chance of overflow or hyperperfusion is low.6,8

Despite initial successful palliation of duct-dependent pulmonary circulation by PDA stenting, in-stent neointimal proliferation or thrombosis may lead to restenosis ranging from mild to marked luminal obstruction in 70-80% of cases.5,8 Depending on the oxygen saturation, clinical status and growth, recatheterization after 3-6 months has been recommended.5 However, catheterization is still an invasive procedure and our study suggests that MDCT is a helpful non-invasive tool for follow-up the PDA stent. Among two of our cases, MDCT revealed stenosis at the pulmonary side in one and mild distal stent migration leading to stenosis at the aortoductal orifice in another one which were successfully managed with balloon angioplasty and placement of a second stent respectively.

Our study had limitations. First, since MDCT is currently not the primary screening tool for PDA and only those neonates with pulmonary atresia and suspicious tortuous PDA and a planned stent implantation were included, the sample size was small. However, our preliminary experience demonstrated that MDCT assessment of tortuous PDA is helpful so that stent implantation could successfully be accomplished in neonates in a significantly younger age compared with those patients underwent Blalock-Taussig shunt, resulting in a significantly shorter hospital stay. Second, MDCT scanning has the inherent shortcoming of radiation exposure. With use of low kV and low tube current adjustment, systemic protection of non-scanned organs and minimal acquisition whenever possible, the radiation dose was minimized following the “as low as reasonably achievable” principle.9-11 In addition, with a good pre-procedural MDCT assessment of the PDA, the catheterization and intervention time could be shortened and thus radiation dose might be reduced. Third, the use of contrast material is inevitable in MDCT but none of our patients had any complications from the iso-osmolar contrast medium used in our study.

In summary, MDCT may be a considerable alternative method for assessing tortuous PDA in neonates with duct-dependent pulmonary circulation for stent implantation and is also useful for demonstrating stent-related complications.

REFERENCES


