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STATE-OF-THE-ART PAPER

Pediatric Cardiac Interventions

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The field of pediatric cardiac interventions has witnessed a dramatic increase in the number and type of procedures performed. We review the most common procedures performed in the catheter laboratory. Lesions are divided according to their physiological characteristics into left-to-right shunting lesions (atrial septal defect, patent ductus arteriosus, ventricular septal defect), right-to-left shunting lesions (pulmonary stenosis, pulmonary atresia/intact ventricular septum), right heart obstructive lesions (peripheral arterial pulmonic stenosis, right ventricular outflow tract obstruction), and left heart obstructive lesions (aortic valve stenosis, coarctation of the aorta). In addition, a miscellaneous group of lesions is discussed. (J Am Coll Cardiol Intv 2008;1:603–11) © 2008 by the American College of Cardiology Foundation

In the past 2 to 3 decades, the field of pediatric interventional cardiology has experienced significant growth. Technological innovations have greatly advanced treatment of cardiovascular disease in both children and adults with congenital heart disease (CHD). Interventional therapy has become an acceptable alternative treatment for many CHD, including closure of atrial defects, muscular ventricular septal defects (VSDs), patent ductus arteriosus (PDA), dilation of stenotic valves (aortic and pulmonary), and dilation of stenotic vessels (branch pulmonary arteries, coarctation of the aorta [COA]). In some cases where the percutaneous approach is difficult or the patient still requires repair of other associated cardiac anomalies, a hybrid approach can be implemented with its obvious advantages to the patient.

In this article, we will review the advances and state-of-the-art in interventional therapy for CHD. For the best understanding of the various lesions that can be treated in the catheterization laboratory, we will attempt to divide the lesions based on their physiological characteristics.

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Left-to-Right Shunting Lesions

Atrial level shunts, such as atrial septal defect (ASD) and patent foramen ovale, are common congenital cardiac defects. Because patent foramen ovale is quite common and there is still controversy about closure in patients who sustain a cryptogenic stroke, we elected not to discuss it in this article.

Atrial septal defects account for approximately 19% of all CHD (1). With the advances in diagnostic tools for CHD, the incidence of many of the defects has increased compared with reports from the past (2).

Patients with ASDs are usually asymptomatic in the first 2 decades of life. Usually, if the Q_p/Q_s ratio is more than 1.5:1, such patients may experience symptoms of shortness of breath and fatigue (3). As shunting continues, there are risks of development of right ventricular volume overload and later dysfunction, progressive pulmonary vascular disease, and atrial arrhythmias. In addition, these patients are at risk of development of paradoxical embolus (3–5). In 1974, King and Mills (6) performed the first successful transcatheter closure of a secundum ASD. After that, a number of different devices were developed with variable degrees of success (7–11). The currently approved devices by the U.S. Food and Drug Administration for clinical use are the Amplatzer septal occluder (ASO) (AGA Medical, Plymouth, Minnesota),

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and the Helex septal occluder (W. L. Gore and Associates, Flagstaff, Arizona).

The ASO provides good closure rates (97%) with similar or lower complication rates than open-heart surgery (12,13).

The Helex septal occluder consists of an expanded polytetrafluoroethylene patch material with hydrophilic coating, supported by a nickel-titanium (nitinol) superelastic wire frame in the shape of a coil. This device is not suitable for defects larger than 18 mm (14).

Various modifications of the ASO have been reported, including fenestrated ASO and the cribriform ASO for multifenestrated ASDs or ASDs with septal aneurysms (15,16). We prefer the use of intracardiac echocardiography to guide closure of ASD, even in smaller children (17). Figure 1 demonstrates steps of closure of a large ASD using ASO under intracardiac echocardiography guidance.

Ventricular septal defects are considered the most common cardiac abnormalities found in children, accounting for approximately 30% of all defects (1,18). Ventricular septal defects could be classified into 4 major categories according to Soto et al. (19) with the perimembranous category being the most common representing type followed by the muscular defects. A VSD can rarely be iatrogenic secondary to traumatic injury to the chest and in 0.2% of patients following ventricular septal rupture associated with myocardial infarction. Large VSDs are unlikely to close spontaneously, and patients with such defects will present with signs and symptoms of congestive heart failure and failure to thrive. All VSDs can be repaired surgically with the exception of the apical defects and Swiss cheese–type of VSD. The latter consists of multiple apical muscular VSDs due perhaps to excessive resorption of myocardial tissue during formation of the muscular part of the interventricular septum. The overall risk for VSD repair is less than 5%. Mortality and morbidity rates increase with multiple VSDs, pulmonary hypertension, residual VSD, and complex associated anomalies. Complete heart block immediately after surgery occurs in less than 1% of patients. Late-onset complete heart block is occasionally a problem, especially in patients who have a post-operative complete right bundle branch block with a left anterior hemiblock (20,21).

Abbreviations and Acronyms

ADO = Amplatzer duct occluder

AS = aortic valve stenosis

ASD = atrial septal defect

ASO = Amplatzer septal occluder

CHD = congenital heart disease

COA = coarctation of the aorta

PDA = patent ductus arteriosus

PS = pulmonary stenosis

VSD = ventricular septal defect

Since the first successful percutaneous VSD device closure in 1987 by Lock et al. (22), there have been several reports of transcatheter closure of the VSD using different devices (23–28). The Amplatzer muscular occluder device (AGA Medical) was specifically designed for the ventricular septum. It is made of 0.004- to 0.005-inch nitinol wire. Holzer et al. (29) reported on the use of this device in a U.S. registry. Their data were prospectively collected from 83 procedures involving 75 patients who underwent an attempt of percutaneous and/or perventricular device closure of hemodynamically significant muscular VSDs. The device was implanted successfully in 86.7% procedures. Complete closure was achieved in 47.2% at 24 h, which increased to 69.6% at 6 months and to 92.3% at 12 months follow-up. Figure 2 shows a patient's muscular VSD after closure with a device.

In smaller patients (less than 5 kg) and patients with abnormal septal planes (e.g., double outlet right ventricle, transposition of the great vessels) or patients with other associated cardiac defects requiring repair, the hybrid approach has been advocated as an alternative to conventional surgery on cardiopulmonary bypass (30).

Percutaneous transcatheter closure of perimembranous VSDs using the Amplatzer membranous VSD occluder (AGA Medical) has recently become available as well. This device has a unique design with a left ventricular desk that is asymmetric (31). However, the complication rate using this device is more than that of the surgical closure, especially the incidence of complete heart block (32,33). Due to the high incidence of complete heart block, clinical trials in the U.S. using this device have been terminated.

Patent ductus arteriosus is the presence of the normal fetal structure commonly connecting between the left pulmonary artery and the descending aorta beyond 2 to 3 weeks of life and represents 5% to 10% of all CHD, excluding those in premature infants (34).

In infants beyond the neonatal period, device and or coil closure has been advocated since the 1980s (4).

The Amplatzer duct occluder (ADO) is currently the most commonly used device with a low rate of procedure- or device-related complications (35). Figure 3 demonstrates closure in a child with PDA.

Modifications of the ADO device have taken place to overcome certain technical difficulties. The angled ADO was developed to overcome the protrusion of the original device in the aortic lumen of smaller children causing partial aortic obstruction (36,37). However, the manufacturer never pursued this device. Another modification to the original device is the ADO-II (AGA Medical), which has a cylindrical waist with retention disks on either end to secure it in the PDA. This device is currently under clinical trials in the U.S.

The Nit-Occlud PDA system (Pfm Medical, Oceanside, California) was used by Celiker et al. (38) in 2005 to close moderate-size PDA.

Coronary arteriovenous fistulae can originate from all major epicardial coronary arteries, and drainage usually occurs to the coronary sinus, right atrium, right ventricle, or pulmonary artery. These collaterals can become markedly