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REVIEW ARTICLE

Evaluation of Left to Right Shunts by the Pediatrician: How to Follow, When to Refer for Intervention?

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Abstract Left to right shunts are the most common congenital heart defects which may cause increased pulmonary blood flow leading to dilatation of cardiac chambers, congestive heart failure, pulmonary artery hypertension and eventually Eisenmenger's syndrome. Many children are, however, referred late for correction making them either high risk for intervention or inoperable. The device closure of atrial septal defect, ventricular septal defect and patent ductus arteriosus can literally cure the patient for life, without a scar on the chest. Hence, it is important for every pediatrician to know how to follow and when to refer the patients with left to right shunts for either device closure or surgical intervention, so that the patient can lead a near normal life.

Keywords Atrial septal defect · Ventricular septal defect · Patent ductus arteriosus · Device closure · Heart failure

Introduction

Left to right shunts are the most common congenital heart defects (CHD) which may cause increased pulmonary blood flow leading to dilatation of cardiac chambers, congestive heart failure (CHF), pulmonary artery hypertension (PAH) and eventually Eisenmenger's syndrome. In most patients, the volume of shunted blood determines the severity of symptoms. Many children are, however, referred late for correction making them either high risk for intervention or are inoperable. Therefore, it is important to recognize the defects in time and to know the ideal time for intervention in different types of left to right shunts, so that morbidity and mortality is drastically reduced.

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Background

Today we have X-ray, electrocardiography (ECG), CT angiogram, MRI and simple non-invasive, inexpensive 2-Dimensional transthoracic echocardiography (TTE) as the most versatile tools for evaluation of left to right shunts. Over the last few decades, with the advent, development, refinement of invasive, diagnostic and therapeutic modalities and catheter based interventions like device closure there has been a tremendous improvement in the management of left to right shunts.The device closure of atrial septal defect (ASD), ventricular septal defect (VSD) and patent ductus arteriosus (PDA) can literally cure the patient for life, without a scar on the chest. Hence it is important for every pediatrician to know when to follow and when to refer the patients with left to right shunts for either device closure or surgical intervention, so that the patient can lead a near normal life.

But the problems in our country are due to 1) Limited knowledge of natural history of individual conditions 2) Lack of awareness about the newer developments in the specialty 3) Lack of awareness about resources available within the country. The vast majority of children with CHDs receive no treatment and those who reach referral centers already have either pulmonary vascular obstructive disease, malnutrition or lower respiratory tract infection (LRTI), making the interventions difficult or impossible.

Classification

Depending on the relationship to tricuspid valve, the left to right shunts can be classified as:

(I) Pre-tricuspid Shunts: a) Atrial septal defect, b) Partial anomalous pulmonary venous connection (PAPVC), c) Ruptured sinus of Valsalva (RSOV) to right atrium, d) Coronary arteriovenous (AV) fistulae to right atrium, e) Gerbode defect (left ventricle to right atrial shunt).
(II) Post-tricuspid Shunts: a) Ventricular septal defect b) Patent ductus arteriosus, c) Aortopulmonary window d) Coronary AV fistula to right ventricle e) Pulmonary AV fistula, f) RSOV to right ventricle g) aorta - LV tunnel, h) aortopulmonary collaterals.

Pre-tricuspid Shunts

Atrial Septal Defects

The ASDs constitute 8 % to 13 % of all CHDs [1] and may be located at various sites in the septum and range in size from small to large. The ASDs may be classified as ostium secundum, ostium primum, sinus venosus or coronary sinus type of defects (Table 1). Large ASDs cause volume overload on the right sided cardiac structures resulting in dilation of the right atrium (RA) and right ventricle (RV). In most patients pulmonary artery pressure (PAP) is only slightly increased and pulmonary resistance remains in the normal range. In later age and adults, the RV which efficiently managed the volume overload in early childhood, eventually fails leading to heart failure.

In children, ASDs are usually asymptomatic and typically presents with a heart murmur and rarely fatigue and dyspnea. In infancy, only large ASDs or single atrium are associated with poor growth, recurrent LRTI and heart failure. Dyspnea on exertion occurs in 30 % of patients by the third decade and in more than 75 % of patients by the fifth decade of life [2]. Pulmonary hypertension usually takes 4 to 5 decades to develop, except in ostium primum defects which may develop PAH very early in life.

Clinically, wide split and fixed second sound with soft superficial grade 2–3/6 ejection systolic murmur (ESM) is the hallmark of ASD. The wide split and fixed second sound is due to prolonged RV ejection time and prolonged "hang out interval' due to increased capacitance of pulmonary circulation. Ostium primum defects will also have a pansystolic murmur of mitral regurgitation conducted towards the sternal border (instead of axilla). Only TTE can confirm the presence of an ASD, determine its size, numbers, type and permit calculation of shunt flow through it and identify any associated anomalies. Hence every suspected case of ASD, should be evaluated by TTE.

Why and When to Close the ASD? Despite the lack of symptoms at presentation, closure of the ASD is recommended before joining school, so as to (i) prevent development of pulmonary vascular obstructive disease (ii) reduce the risk of paradoxical emboli later in life, (iii) reduce probability for development of supraventricular arrhythmias and (iv) prevent symptoms during adolescence and adulthood [3].

Indications for Closure of ASD Among newborns with secundum ASD, the majority of defects close spontaneously before 1.5 y of age, with the exception of those larger than 8 mm in diameter [4, 5]. The child with small ostium secundum ASD should be followed up and evaluated once in 6–12 mo. The indications for intervention in ASDs are right ventricular volume overload by echocardiogram and a pulmonary to systemic blood flow ratio (Qp:Qs) >1.5 [3]. In patients with left to right shunting, if the pulmonary vascular resistance is less than two-thirds of the systemic vascular resistance, closure may be contemplated. If a bidirectional shunt is present, pulmonary vasodilators may be initiated, with reassessment in 6 mo [6]. Patients without left to right shunts or irreversible PAH are contraindicated to undergo closure [7]. The

Table 1 Types of ASDs and timing of interventions

Types of ASD	Anatomical location	Intervention
Ostium Secundum (75 %)	Mid portion of atrial septum - Fossa ovalis	Elective closure between 2 and 4 y with device (in suitable cases) or surgery. Early surgery only in symptomatic infants
Ostium Primum (15–20 %)	Lower portion of atrial septum often associated with a cleft in the AML	Early surgery in symptomatic infants (especially with MR). Elective surgical closure between 2 and 4 y
Sinus Venosus (5 %)	Region of junction of either SVC or IVC and RA	Elective surgical closure between 2 and 4 y. May be delayed upto 4–5 y
Coronary Sinus (rare)	Region of ostium of coronary sinus	Elective surgical closure between 2 and 4 y

AML Anterior mitral leaflet; *IVC* Inferior vena cava; *MR* Mitral regurgitation; *RA* Right atrium; *SVC* Superior vena cava

types of ASDs and their timings of interventions is given in Table 1 [8].

Other Pre-tricuspid Shunts

The other less common pre-tricuspid shunts like isolated PAPVC, RSOV to RA, coronary AV fistulae to RA, Gerbode defects can all be diagnosed precisely on TTE and can be referred for surgery depending on the condition. Small RSOV, coronary fistula to RA and Gerbode defects can be closed with device, thus avoiding surgery.

Post-tricuspid Shunts

Most of the large post-tricuspid left to right shunts have common symptoms like repeated LRTI, chest retractions, feeding difficulties, suck rest suck cycle, failure to thrive (FTT), excessive forehead sweating, precordial bulge and bilateral Harrison sulcus. Sometimes an asymptomatic child brought for fever or immunization may be detected to have a murmur. Therefore any child with these symptoms or murmur must be thoroughly examined and evaluated by the pediatricians. The magnitude of the shunt determines the clinical presentation and symptoms.

Ventricular Septal Defect

Isolated VSD is a very common CHD accounting for nearly 20 % of all cases of CHDs [9, 10]. They are classified anatomically into four types: Perimembranous (80 %), Muscular (5–20 %), Outlet (5–7 %) and Inlet defects (8 %). The VSDs are also classified as small, moderate and large, depending on their size and their presentation is given in Table 2.

Usually the small defects remain asymptomatic with high chances of spontaneous closure in muscular and perimembraneous VSDs. However they are prone for infective endocarditis (IE), aortic regurgitation (AR) especially in outlet defects due to Venturi effect causing aortic cusp prolapse. The AR is seen more in subpulmonic VSDs (52–78 %) than perimembranous VSDs (6 %). It is more between the ages of 5–10 y [11, 12]. Large defects can develop infundibular pulmonary stenosis (Gasul's effect), heart failure, PAH, endocarditis, or AR [13]. In nearly 3–7 % of moderate to large VSDs, Gasul's effect can develop [14, 15]. The majority of patients with large VSDs develop PAH by 2 y and Eisenmengerization occurs by teenage.

Hence timely detection and evaluation by pediatrician is very important. No pediatrician should give false hope of spontaneous closure without assessing the size, site and proper hemodynamic assessment. Otherwise parents take it for granted and when respiratory infections come down due to PAH, they think child is fine and when they bring the child with exertional dyspnea and fatigue, it will be too late for closure as the irreversible PAH would have already set in. It is criminal negligence by parents and pediatricians, if curable VSD becomes inoperable, due to Eisenmengerization.

How to Manage VSD? Unless the defect is clearly small and uncomplicated, the newborn should be reexamined at 1 and then 2 wk interval for first 4–6 wk to detect early signs of volume overload. Medical therapy includes prompt treatment with oral diuretics, prevention of anemia and respiratory infections. If congestive cardiac failure (CCF) is not severe, medical management is continued with the hope that spontaneous closure of the defect will occur.This trial should be limited to no longer than 6 mo. If the PAP is greater than half of the systemic systolic pressure the defect should be closed without delay. The timing of closure of VSDs in given in the algorithm in Fig. 1. Surgery is done in all large defects, inlet and outlet VSDs and in small VSDs with past history of endocarditis (Table 3). All mid muscular VSDs, apical VSDs and selected cases of moderate sized perimembranous VSDs with at least 4 mm of aortic rim can undergo nonsurgical

Table 2 Hemodynamic classification and clinical presentation of VSDs

	Small	Moderate	Large
Size (compared to aortic root)	<1/3	1/3–2/3	>2/3
Shunt - Qp/Qs	<1.5:1	>1.5–2.2:1	>2.2:1
LA/LV volume overload	Nil/minimal	+	++
PAP/PVR	Normal	↑	↑↑
Symptoms	Asymptomatic	Mild to moderate symptoms	Symptomatic
Signs	Grade 4/6, harsh long systolic, crescendo-decrescendo murmur, best heard along the LSB	Grade 3/6 long systolic decrescendo murmur in LSB with MDM in the mitral area	P2 is palpable and loud with a narrow split, left ventricular S3 may be present, short, soft decrescendo murmur in LSB

LSB Lower left sternal border; *MDM* Mid diastolic murmur; *PAP* Pulmonary artery pressure; *PVR* Pulmonary vascular resistance

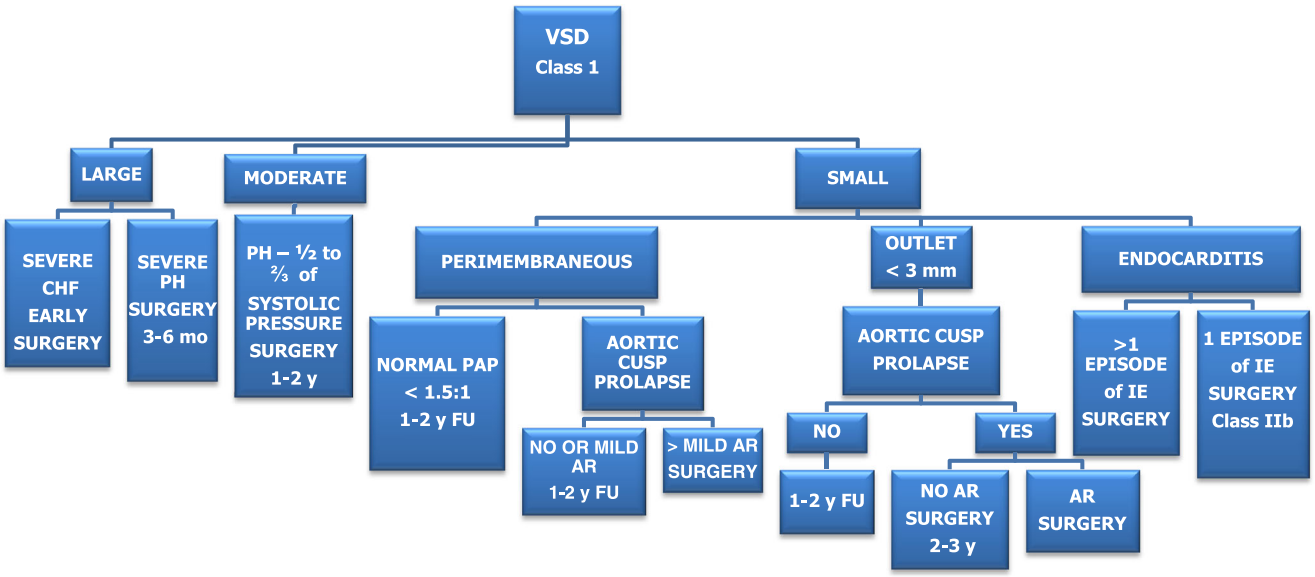

Fig. 1 Algorithm for timing of closure of ventricular septal defects [8]. *AR* Aortic regurgitation; *CHF* Congestive heart failure; *FU* Follow up; *IE* Infective endocarditis; *PH* Pulmonary hypertension; *PAP* Pulmonary artery pressure; *VSD* Ventricular septal defect

transcatheter device closure between 2 and 9 y of life. In young infants with muscular VSDs, hybrid surgery can be done.

Atrioventricular Septal Defect

Children with atrioventricular septal defect (AVSD) of the complete variety have large ostium primum ASD, inlet VSD, common atrioventricular valve, regurgitation of varying degrees and an early corrective surgery around 8 wk of life is needed. AVSD of the partial type usually has primum ASD without VSD. The timing of surgery is usually around 2–3 y as the ASD is usually very large. However, the management plan can vary if there is associated significant atrioventricular valve regurgitation which will lead to early CCF and necessitate early surgical intervention.

Patent Ductus Arteriosus

PDA is a common CHD (5–10 %) [16] and is defined as persistent patency in term infants even after three months [17]. It is seen more commonly in preterms due to incomplete ductal development and a dominant prostaglandin effect.The chambers that enlarge are the same as those in VSD, except for an enlarged aorta, at the level of the PDA (*i.e.*, enlarged ascending aorta and transverse arch), which also handles an increased amount of blood flow. If the PDA is large with PAH, right heart failure can occur. The patients with PDAs have a classical machinery continuous murmur. As PAH develops, the murmur decreases and P2 becomes loud.

Table 3 Indications for surgery in ventricular septal defects

Age	Indication
<6 mo	Uncontrolled congestive cardiac failure, failure to thrive
6–12 mo	Pulmonary hypertension, symptomatic
2–5 y	Qp/Qs >1.5 : 1, aortic regurgitation
> 5 y	Aortic regurgitation

Timing and Types of Intervention PDAs never close spontaneously except in the newborn period and in full terms it may close up to 3 mo of age [8]. The timing of the intervention should be determined by the clinical status. If the CCF persists in spite of appropriate medical management and/or there is no weight gain, immediate intervention should be offered. Though previously only surgical closure of PDA was being done, over the last three decades transcatheter closure has become the treatment of choice. Closure is not generally recommended in the so called "silent ductus" detected incidentally without typical auscultatory features [18].

In small PDAs, due to risk of IE, closure is indicated even without hemodynamic overload. In the medium and large PDAs, closure is recommended to prevent the development of CCF or PAH, apart from the IE risk. The PDA closure can be performed at any time and if symptomatic, early intervention is required either with surgery or non-surgically. In asymptomatic PDAs one can wait upto 6 to 12 mo of age for closure (Fig. 2) [8]. Small PDAs less than 3 mm can be closed with coils and large PDAs more than 3 mm can be closed with device like duct occluders and occasionally with vascular plugs.

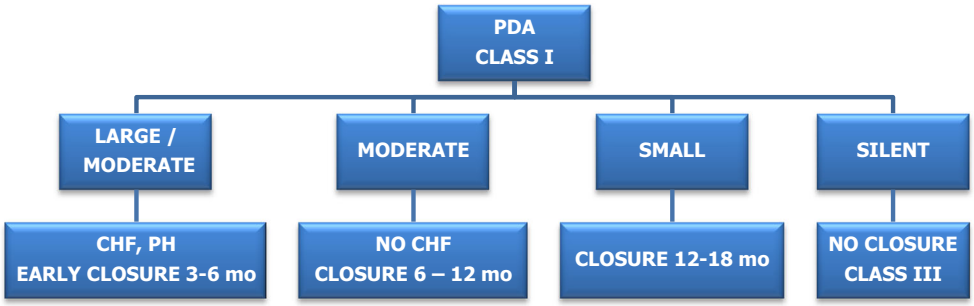

Fig. 2 Algorithm for timing of closure of patent ductus arteriosus [8]. *CHF* Congestive heart failure; *PH* Pulmonary hypertension; *PDA* Patent ductus arteriosus

Preterm Neonate with PDA

A hemodynamically significant PDA in preterms is diagnosed with various echocardiographic parameters and the important include: PDA diameter > 1.4 mm, left atrium to aorta ratio > 1.4 and diastolic reverse flow in the aorta,mesenteric,cerebral and renal arteries [19]. McNamara and Sehgal have proposed a staging system for the severity of PDA based on echocardiographic and clinical parameters [20].

Especially, premature neonate with PDAs can become very sick and develop CCF. As long as there is no renal dysfunction or thrombocytopenia, one can try medical therapy with indomethacin 0.2 mg/kg as an initial dose followed by two additional age adjusted doses given at 12 to 24 h intervals. Another drug ibuprofen, is usually given at 10 mg/kg stat followed by 2 doses of 5 mg/kg/dose × 2 doses at 24 h intervals [19, 21]. PDA closure is indicated in all premature neonates with symptoms and who are not responding to medical management.

Other Post-tricuspid Shunts

The other less common post tricuspid shunts like aortopulmonary window is clinically indistinguishable from PDA. These children develop PAH very early in life and need open heart surgery or device closure in suitable cases (Type II), hence they need to be referred as soon as diagnosis is made. The other very rare conditions like coronary AV fistula to RV, pulmonary AV fistula, RSOV to RV and aorta - LV tunnel, have to be referred for appropriate intervention at the earliest.

Conclusions

Children with left to right shunts are fortunately correctable at a low morbidity and mortality if operated at the appropriate time. In a country like ours, the common problem is late referral of some of these patients which results in they becoming inoperable or operable at high risk. It is therefore, important for every practicing pediatrician to evaluate these patients and send them to tertiary centers at the right time for further management. Small ostium secundum ASDs (<8 mm) must be followed up and large ASDs should be closed before joining school. Moderate to large VSDs need to be managed medically first. Infants with CCF and growth retardation need to be referred for surgery early in infancy. Moderate to large VSDs with dilated left atrium and left ventricle need to be referred for surgery/intervention. VSDs with aortic prolapse or AR is an indication for surgery. The results of device closure of mid muscular, apical VSDs and recently perimembranous VSDs using the Amplatzer membranous VSD device have been encouraging. All clinically detected PDAs need to be referred for coil/device closure to prevent IE and Eisenmenger's syndrome. Timely detection by pediatrician and appropriate management can literally cure most of the left to right shunts.

> We can say with some assurance that although children may be victims of fate, they will not be the victims of our neglect- John F Kennedy 1963.

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