

VENTRICULAR SEPTAL DEFECTS

Definition and Classification

The ventricular septum can be divided into 2 morphological components, the membranous septum and the muscular septum. The **membranous septum** is small and located at the base of the heart between the inlet and outlet components of the muscular septum, behind the septal leaflet of the tricuspid valve and below the right and noncoronary cusps of the aortic valve. The much more extensive **muscular septum** interposes for its greater part between the apical components of the ventricles. Its inferior component separates the inlet of the right from the outlet of the left ventricle.¹

According to the International Society for Nomenclature of Paediatric and Congenital Heart Disease Classification Scheme for Ventricular Septal Defect Defects,² VSDs can be classified as:

Perimembranous central VSD (Figure 1).

Inlet VSD without a common AV junction (with or without AV septal malalignment) (Figure 2).

Trabecular muscular VSD (midesepal, apical, postero-inferior), anterosuperior, multiple) (Figure 3).

Outlet VSD (with or without malaligned outlet septum, doubly committed juxta-arterial with anteriorly or posteriorly malaligned fibrous outlet septum) (Figure 4).

Defects that involve the **membranous** septum are the most common VSD (70-80%) and may be associated with progressive AR due to prolapse of an aortic cusp. Common synonyms for central perimembranous defects include membranous, perimembranous, paramembranous, conoventricular without conal septal malalignment, and type 2 VSDs. Less frequently used terms include infracristal and subaortic VSDs.² **Inlet** defects open into the RV inlet and extend along the septal leaflet of the tricuspid valve. They are located below the medial papillary muscle, postero-inferior limb of the septal band, and anterosseptal commissure of the tricuspid valve.² **Outlet** defects open into the RV outlet between the limbs of the septal band.² Trabecular **muscular** defects have exclusively muscular borders and are located within the apical muscular component of the ventricular septum. Muscular VSDs may be multiple and can be acquired after a septal myocardial infarction.^{3,4}

Epidemiology

VSD is the most common congenital heart defect after the bicuspid aortic valve, occurring in 40% of all children with congenital heart disease and with an estimated prevalence of 5% in newborn babies.^{3,4} With paternal VSD, the recurrence risk in an offspring is 2%. Maternal

VSDs have a recurrence risk of 6% to 10%.^{3,4} No direct genetic testing at this time for VSD exists.

Aetiology

The origins of VSD are not known, and as in most cases of ACHD, are most probably multifactorial. Initial reports about the teratogenic effects of selective serotonin uptake inhibitors in this respect, have not been verified.⁵ A locus on chromosome 10p15 has been associated with familial ventricular aneurysms and VSDs,⁶ and mutations in the transcription factors TBX5 and GATA4 have been identified in familial cases of VSD.⁷ **Associated disorders** are tetralogy of Fallot, AV canal, aortic coarctation, and, rarely, double-outlet right ventricle in which the VSD is subaortic, subpulmonary (Taussig-Bing anomaly), or noncommitted (remote from the outlets).^{8,9}

Pathophysiology

The shunt volume in a VSD depends on the size of the defect and the pulmonary vascular resistance.¹⁰ Without pulmonary hypertension or obstruction to the right ventricle, the direction of shunt is left to right with decreased LV output and compensatory intravascular volume overload. Thus, pulmonary artery, left atrial, and left ventricular volume overload develop. Moderate or large VSDs result in the transmission of LV pressure to pulmonary vascular bed with increased shear forces. This combination of high volume and pressure contributes to the development of irreversible pulmonary vascular disease.¹⁰ VSD is the most common cause of pulmonary hypertension. Eventually, the elevated pulmonary vascular resistance becomes irreversible and leads to reversal of shunt and cyanosis, and Eisenmenger syndrome develops. In the setting of elevated pulmonary vascular resistance or right ventricular obstruction resulting from muscle bundles or pulmonary stenosis, the shunt volume is limited and may be right to left, depending on the difference in pressures.

Spontaneous Closure. Muscular or membranous VSDs can undergo spontaneous closure usually at the first years of life. Up to 90% of such defects close spontaneously by one year of age.¹¹

Presentation

Adults with small defects and normal pulmonary artery pressure are generally asymptomatic. Patients with large defects who survive to adulthood usually have left ventricular failure or pulmonary hypertension with associated RV failure.¹² according to the 2025 ACC/AHA GL on ACHD, the spectrum of isolated VSDs in adults includes:

Pressure- and volume-restrictive VSDs: small restrictive defects, with a high-pressure gradient (>64 mm Hg) between the left and right ventricles and a small left-to-right shunt.

Pressure-restrictive, but not volume-restrictive, VSDs: moderate-size restrictive defects ($Q_p:Q_s \geq 1.5$ but < 2) that may have developed PAH (ie, pulmonary vascular disease), LV dilatation, or both.

Large nonrestrictive defects that, in the absence of RVOT obstruction, are typically associated with Eisenmenger syndrome in adults

Previously closed defects with patch leaks and PAH and/or LV dilatation.

Physical Examination

Physical signs depend on the size of VSD.

Holosystolic (pansystolic) murmur with or without a **thrill** with moderate or large defects. The grade of murmur depends on the velocity of flow. ***Very small or large defects*** with no shunt and defects with Eisenmenger physiology and right-to-left shunt may not have a VSD murmur. ***Muscular*** defects can be heard along the lower left sternal border and may vary in intensity as the defect size changes with muscular contraction throughout systole. ***Infundibular*** defects close to the pulmonary valve can be heard best at the left upper sternal border.

Short, **mid-diastolic apical rumble** (increased mitral flow) may be heard.

Decrescendo murmur in the presence of AR.

Cyanosis with **clubbing** and **peripheral oedema** due to right-sided heart failure gradually appear.

Investigations

ECG is normal in small VSDs. With large defects there is LA and LV hypertrophy. When pulmonary hypertension develops there is right axis deviation and RV hypertrophy.

Chest radiography is normal with small VSDs. With large defects there is “shunt vascularity”, ie well visualized small pulmonary arteries in the periphery of both lungs. When pulmonary hypertension develops there is marked enlargement of the proximal PAS, rapid tapering of the peripheral arteries (pruning), and oligemic lung fields.

Transthoracic or **transesophageal echocardiography** with color flow mapping are used for quantification of the shunt, assessment of pulmonary artery pressure, distortion of the aortic valve, and obstruction of the right ventricular outflow tract (double chamber RV). ***Three-dimensional echocardiography*** is useful for defects that are difficult to evaluate by 2-dimensional imaging. Recommendations on follow-up are provided in Table 1.

Cardiac magnetic resonance is very useful with complex associated lesions.

Cardiac catheterization is no longer necessary. However, it can be used to determine Q_p/Q_s by oximetry, and pulmonary artery pressure and resistance in case of anticipated closure. It

can also assess response to pulmonary vasodilators that can guide therapy, and evaluate coexistent AR, dual chamber RV or multiple VSDs.

Therapy

Medical

Adult patients with small VSD without evidence of left ventricular volume overload or AR do not require intervention,¹³ but abnormalities of the right ventricular structure that are related to reduced exercise capacity may develop.¹⁴ These patients as well as patients who had VSD repair need surveillance for AR (perimembranous and infundibular VSDs) and endocarditis. Endocarditis a lifelong risk in unoperated patients, being six times higher than in the normal population but is primarily associated with the associated valve disease rather than the VSD itself.¹³ Routine **endocarditis prophylaxis**, however, is not recommended any more for unrepaired VSDs. Patients with unrepaired VSDs are advised on dental hygiene and the physician should be alert of suspicious symptoms (see Chapter 1 and on endocarditis).

Patients with VSD have lower survival compared with the general population. Mortality is increased over 2.5-fold in patients with unrepaired defect (Eisenmenger syndrome excluded) and over 1.5-fold in patients with surgically closed defect (excluding surgical mortality).¹⁵

Indications for closure

Indications are presented in Tables 2 and 3 and Figures 5 and 6. Main indications are:

- Qp/Qs>1.5 and LV volume overload
- Progressive AR

Contraindications for closure

- Irreversible pulmonary arterial hypertension, ie PA pressure > 2/3 systemic pressure or PVR > 2/3 SVR at baseline or after oxygen or vasodilation.

Surgical Closure

Peri-operative mortality for VSD closure is 0.7 (0-1.1)%.¹⁶ Survival up to 40 years after successful surgical VSD closure is slightly lower than in the general population, and follow-up for the identification of LV or RV dysfunction may be advisable. Aortic cross-clamp time and, most probably, post-operative arrhythmia are unfavourable prognostic signs.¹⁷ In adults with inoperable VSDs with progressive/severe pulmonary vascular disease, pulmonary vasodilator therapy may be considered.

Catheter Closure

Currently, defect-specific devices are in the investigational stage and have been used both for congenital and post-MI VSD. They may interfere with AV or TV and carry a higher risk for AV block than surgical closure. Recent experience with closure of perimembranous VSDs

indicates a <1% risk of complete AV block which is comparable to that after surgical closure.¹⁸⁻²⁰

Pregnancy

Small or repaired VSDs without left heart dilatation or ventricular dysfunction have a low-risk of complications during pregnancy (mWHOI and II) (Table 4).²¹ Women with large shunts and pulmonary arterial hypertension may have arrhythmias, LV dysfunction and progression of pulmonary hypertension, and pregnancy is contraindicated in Eisenmenger syndrome. Combinations of epoprostenol and sildenafil may improve outcome in pregnant women with severe pulmonary hypertension who choose to continue pregnancy (see also General Principles).² The estimated recurrence rate in the offspring is 2-10% (Table 1.2).⁹

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