Guideline
pediatric congenital heart disease

Single ventricular septal defect (VSD)

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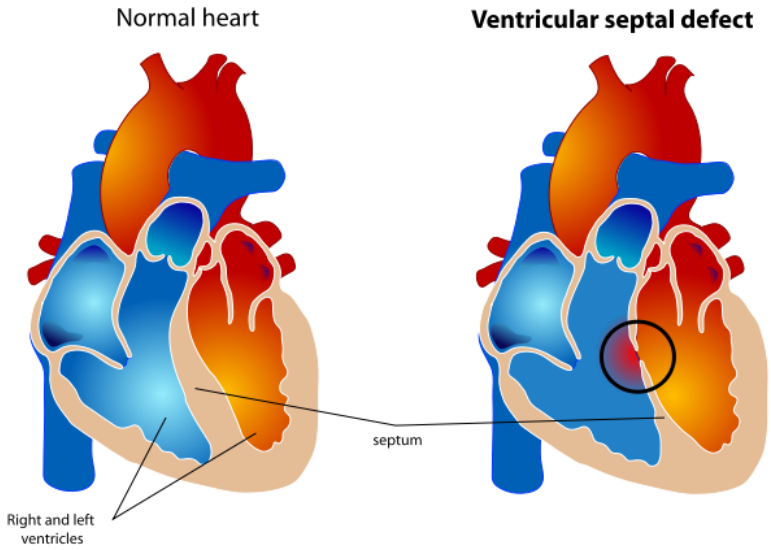


http://de.wikipedia.org

Consensus achieved in September 2010

Definition

- Connection between left and right ventricle
- Prevalence of congenital heart defects in Germany: 1.08 %
- thereof 49% isolated VSD
- thereof 2/3 small or muscular defects
- m:f = 1:1.3

Lindinger, A., G. Schwedler, and H.W. Hense, Prevalence of congenital heart defects in newborns in Germany: Results of the first registration year of the PAN Study (July 2006 to June 2007) Klin Padiatr; 222: 321-326

Classification

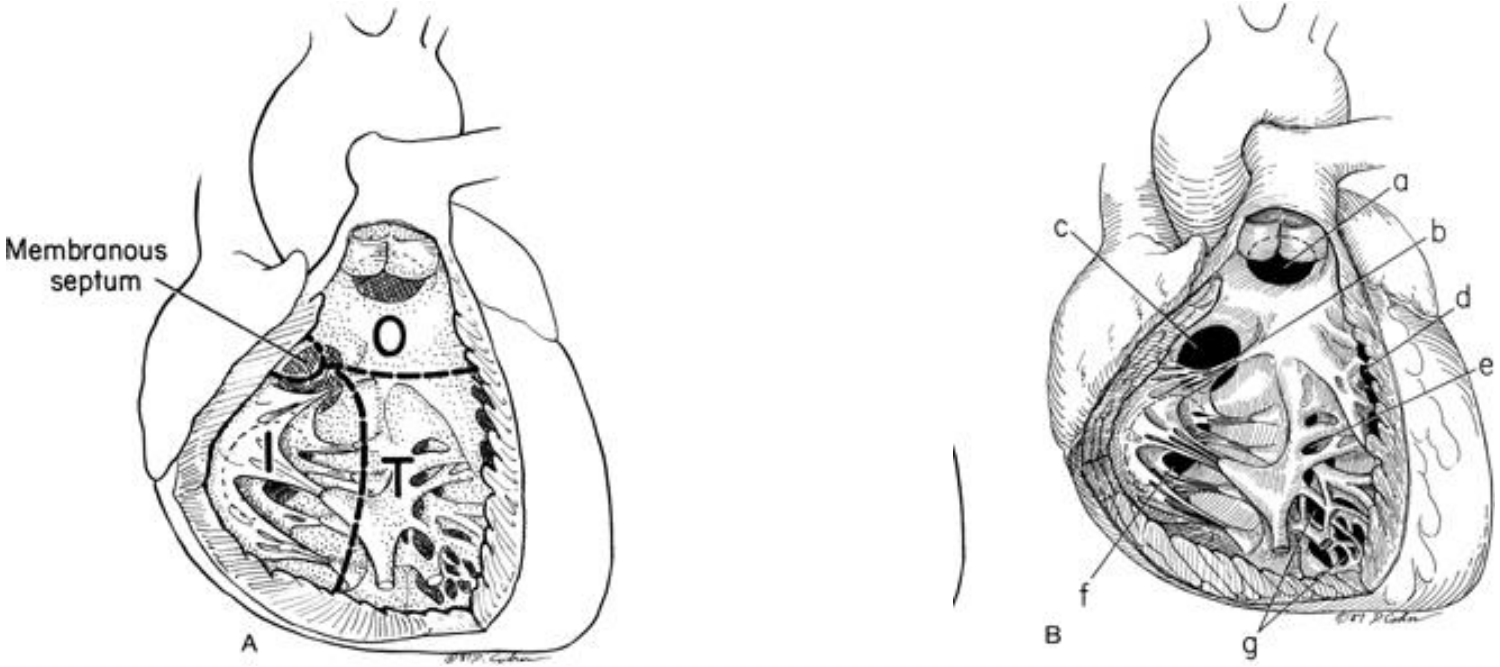


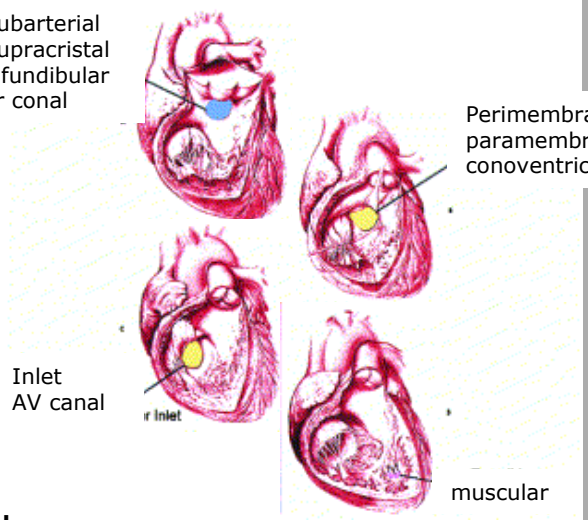
FIGURE 32.1 A: Ventricular septum viewed from right ventricular side is made up of four components: I, inlet component extends from tricuspid annulus to attachments of tricuspid valve; T, trabecular septum extends from inlet out to apex and up to smooth-walled outlet; O, outlet septum or infundibular septum, which extends up to pulmonary valve, and membranous septum.

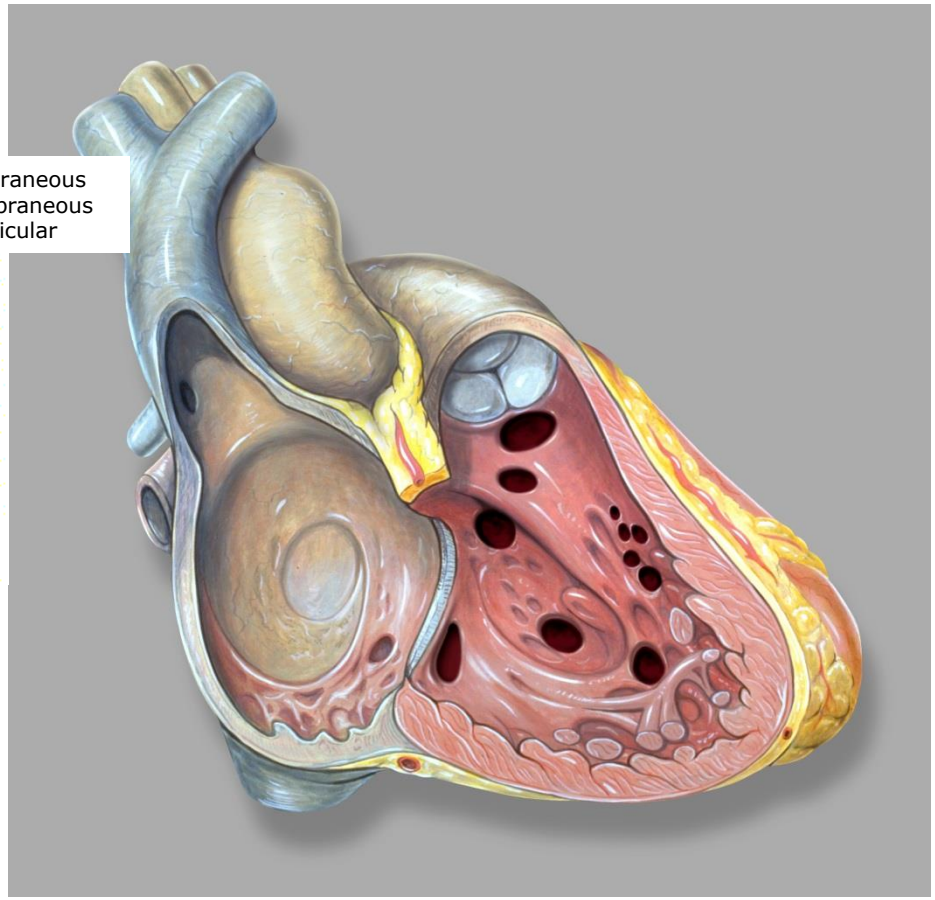
B: Anatomic position of defects: a, outlet defect; b, papillary muscle of the conus; c, perimembranous defect; d, marginal muscular defects; e, central muscular defects; f, inlet defect; g, apical muscular defects.

Moss Adams, 7th edition 2008

Classification

- Multiple VSD
- Type 1
- Type 2
- Type 3
- Type 4
- Gerbode type
- secondary VSD (e.g. after trauma, myocardial infarction)

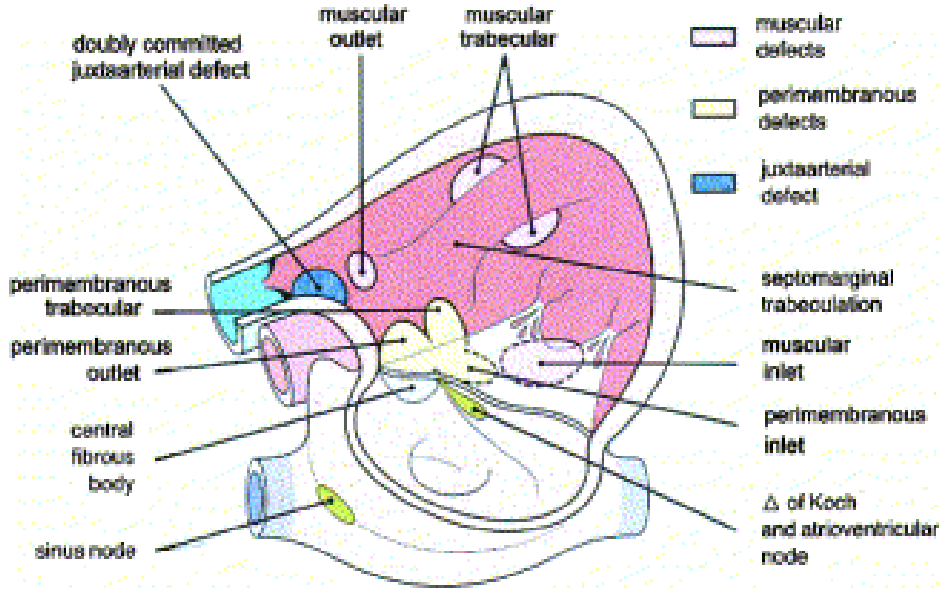




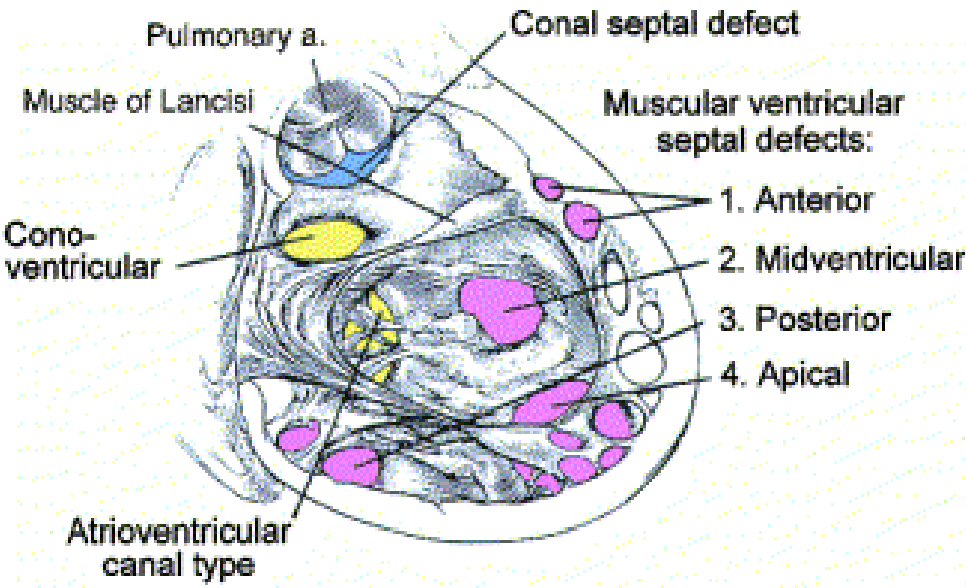
http://en.wikipedia.org/wiki/Ventricular_septal_defect

Jacobs, J.P., R.P. Burke, J.A. Quintessenza, and C. Mavroudis, Congenital Heart Surgery Nomenclature and Database Project: ventricular septal defect. Ann Thorac Surg, 2000; 69: S25-35

Classification



VSD nomenclature system advocated by Robert Anderson



VSD nomenclature system advocated by Van Praagh

Jacobs, J.P., R.P. Burke, J.A. Quintessenza, and C. Mavroudis, Congenital Heart Surgery Nomenclature and Database Project: ventricular septal defect. Ann Thorac Surg, 2000; 69: S25-35

Pathophysiology

- left-to-right-shunt,
  size related to diameter of defect and resistance ratio R_P:R_S
- non-restrictive VSD:
  magnitude of shunt depends on R_P:R_S only
- In case of pulmonary hypertension progressive increase of pulmonary vascular resistance with irreversible damage after six months is possible
- In case of restrictive VSD left ventricular dilation in long term follow-up was observed occasionally

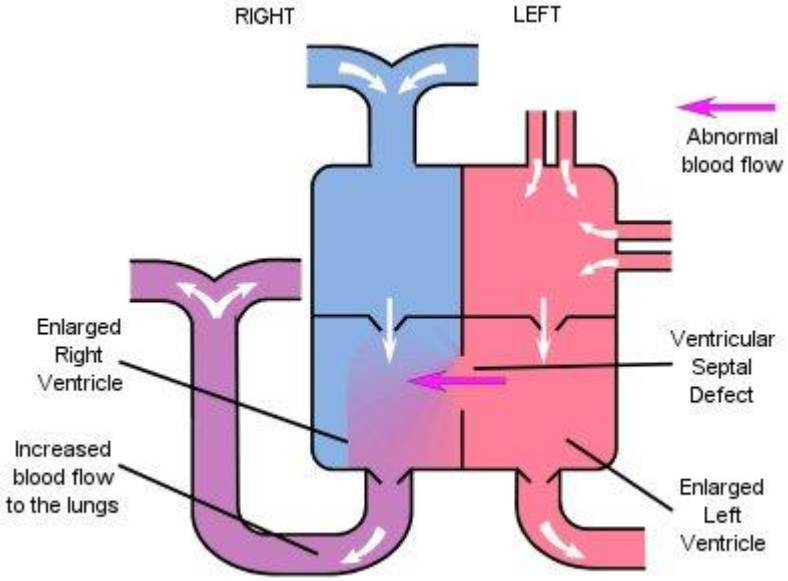


Diagram shows the heart looking at the patient

http://www.dhg.org.uk/information/ventricularseptaldefect.aspx

Clinical symptoms

- almost no symptoms in newborns due to elevated pulmonary resistance
- Systolic heart murmur (2-4/6°) occurs with the fall of pulmonary resistance
- Extension of left-to-right shunt might produce signs of congestive heart failure
- Heart murmur might become smaller (but 2. heart sound more pronounced) and congestive heart failure might improve if pulmonary resistance rises in large non-restrictive VSD due to PAH
- Pulmonary vascular remodelling in PAH might start to become irreversible even after 6 months of age
- right-to-left shunt (Eisenmenger´s syndrom) occurs after some years

Prognosis – natural history

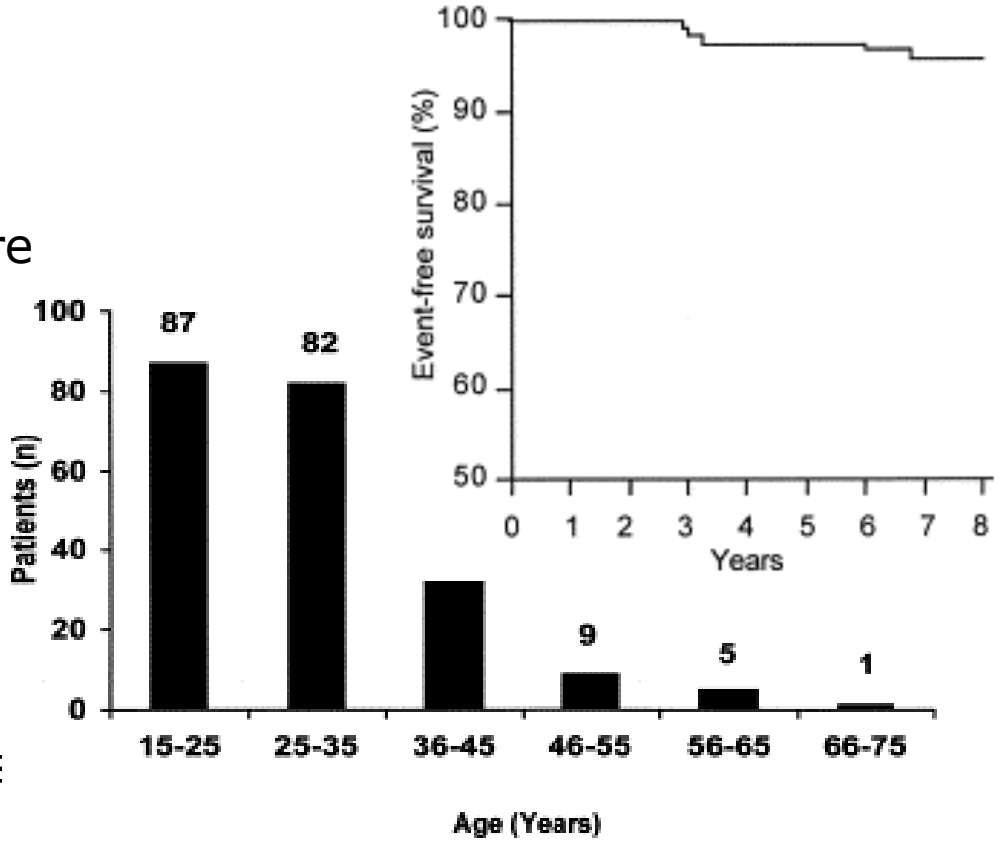
- Pulmonary arterial hypertension (PAH) with occurence of right-to-left-shunt (pulmonary vascular obstructive disease= Eisenmenger‘s syndrome)
- Spontaneous downsizing and closure of perimembranous and muscular VSD are frequent in the first years of life and even occure in adults with perimembranous VSD
- Normal life-span can be achieved with therapy in time

Soufflet, V., A. Van de Bruaene, E. Troost, M. Gewillig, P. Moons, M.C. Post, and W. Budts, Behavior of unrepaired perimembranous ventricular septal defect in young adults. Am J Cardiol, 2010; 105: 404-407

Roos-Hesselink, J.W., F.J. Meijboom, S.E. Spitaels, R. Van Domburg, E.H. Van Rijen, E.M. Utens, A.J. Bogers, and M.L. Simoons, Outcome of patients after surgical closure of ventricular septal defect at young age: longitudinal follow-up of 22-34 years. Eur Heart J, 2004; 25: 1057-1062

Prognosis – untreated restrictive VSD

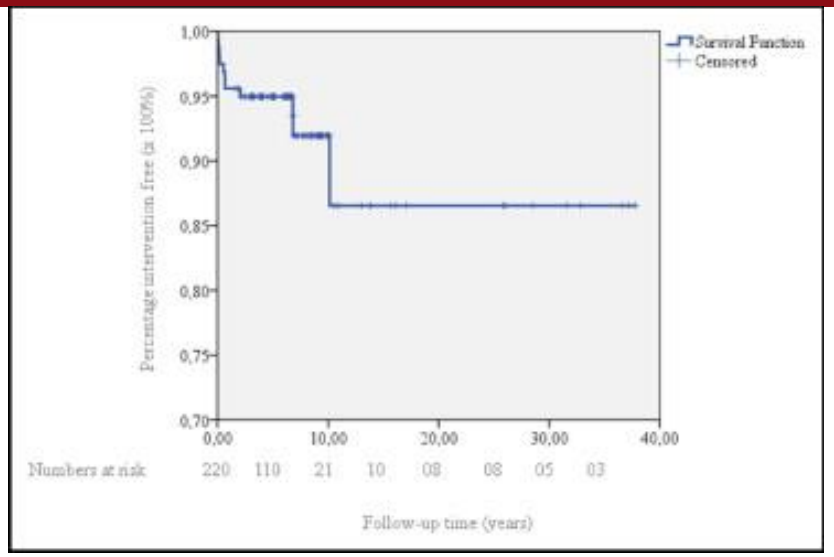
- Vienna, Austria, 2002
- 229 adult patients
- mean age 30±10 yrs.
- 6% spontaneous VSD closure
- 1.8% endocarditis (=4 pts., 2 AKE)
- 0.4% VSD closure for LV-enlargement
- event free survival 96±1.9% at 8 yrs.
- 10% borderline LV size
- 13% benign rythm disorders



Gabriel, H.M., M. Heger, P. Innerhofer, M. Zehetgruber, G. Mundigler, M. Wimmer, G. Maurer, and H. Baumgartner, Long-term outcome of patients with ventricular septal defect considered not to require surgical closure during childhood. J Am Coll Cardiol, 2002; 39: 1066-1071

Prognosis – untreated restrictive VSD

- Leuven, Belgium, 2010
- 220 adult patients
- mean age 18±7 yrs.
- follow-up 6 yrs.
- 4% spontaneous pmVSD closure
- 4% endocarditis
- 1% mortality (cardiomyopathy)
- 7% VSD closure for LV-enlargement
- 1 PM implantation
- 1 ICD implantation



Kaplan-Meier curve of event-free survival, with event defined as surgical or interventional VSD closure

Soufflet, V., A. Van de Bruaene, E. Troost, M. Gewillig, P. Moons, M.C. Post, and W. Budts, Behavior of unrepaired perimembranous ventricular septal defect in young adults. Am J Cardiol, 2010; 105: 404-407

Indication of therapeutic treatment

Closure of VSD if …

- Large VSD with pulmonary hypertension
- Clear volumetric overload of left atrium and ventricle in echocardiography[*1]
- Shunt ratio $Q_P:Q_S > 1.5$ [*1]
- Aortic valve insufficiency, particularly in infundibular VSD
- Prolapse of aortic valvular cusp into the VSD[*2]
- after endocarditis

[*1]) if no spontaneus decrease in size can be observed

[*2]) Jian-Jun, G., S. Xue-Gong, Z. Ru-Yuan, L. Min, G. Sheng-Lin, Z. Shi-Bing, and G. Qing-Yun, Ventricular septal defect closure in right coronary cusp prolapse and aortic regurgitation complicating VSD in the outlet septum: which treatment is most appropriate? Heart Lung Circ; 2006; 15:168-171

Time of treatment

In the first 6 months of life if

- large VSD with pulmonary hypertension
- signs of congestive heart failure are present

After infancy if

- Left ventricular overload is present (echo) and a trend to decrease VSD-size/ spontaneous closure is missing
- aortic valve insufficiency, particularly in infundibular VSD
- prolapse of aortic valvular cusp into the VSD
- after endocarditis

VSD with pulmonary hypertension >6 months

- testing of pulmonary vascular reactivity (Oxygen, nitric oxide, Prostacyclins by inhalation, …)
- Simple closure of VSD if…
- $R_P:R_S$ <0.2
- $R_P:R_S$ 0.2–0.3: closure with increased risk

Limsuwan, A. and P. Khowsathit, Assessment of pulmonary vasoreactivity in children with pulmonary hypertension. Curr Opin Pediatr, 2009; 21: 594-599

Engelfriet, P.M., M.G. Duffels, T. Moller, E. Boersma, J.G. Tijssen, E. Thaulow, M.A. Gatzoulis, and B.J. Mulder, Pulmonary arterial hypertension in adults born with a heart septal defect: the Euro Heart Survey on adult congenital heart disease. Heart, 2007; 93: 682-687

Roos-Hesselink, J.W., F.J. Meijboom, S.E. Spitaels, R. Van Domburg, E.H. Van Rijen, E.M. Utens, A.J. Bogers, and M.L. Simoons, Outcome of patients after surgical closure of ventricular septal defect at young age: longitudinal follow-up of 22-34 years. Eur Heart J, 2004; 25: 1057-1062

VSD with pulmonary hypertension >6 months

- R_P:R_S >0.3: individual therapy considering operative, interventional and medicamentous arrangements

Khan, I.U., I. Ahmed, W.A. Mufti, A. Rashid, A.A. Khan, S.A. Ahmed, and M. Imran, Ventricular septal defect in infants and children with increased pulmonary vascular resistance and pulmonary hypertension--surgical management: leaving an atrial level communication. J Ayub Med Coll Abbottabad, 2006; 18: 21-25

Kim, Y.H., J.J. Yu, T.J. Yun, Y. Lee, Y.B. Kim, H.S. Choi, W.K. Jhang, H.J. Shin, J.J. Park, D.M. Seo, J.K. Ko, and I.S. Park, Repair of atrial septal defect with eisenmenger syndrome after long-term sildenafil therapy. Ann Thorac Surg, 2010; 89: 1629-1630

Novick, W.M., N. Sandoval, V.V. Lazorhysynets, V. Castillo, A. Baskevitch, X. Mo, R.W. Reid, B. Marinovic, and T.G. Di Sessa, Flap valve double patch closure of ventricular septal defects in children with increased pulmonary vascular resistance. Ann Thorac Surg, 2005; 79: 21-28

Medicamentous treatment in VSD with pulmonary hypertension >6 months

- Oral Endothelin receptor antagonists (authorisation Bosentan from 2 years of age)
- Oral phosphodiesterase inhibitors (off-label use in children)
- Prostacyclines by inhalation
- Possibility of closure could be achieved in borderline cases
- Improvement of quality of life in Eisenmenger‘s syndrome with WHO stage III
- Evidence for improvement of prognosis of survival in Eisenmenger‘s syndrome

Gatzoulis, M.A., M. Beghetti, N. Galie, J. Granton, R.M. Berger, A. Lauer, E. Chiossi, and M. Landzberg, Longer-term bosentan therapy improves functional capacity in Eisenmenger syndrome: results of the BREATHE-5 open-label extension study. Int J Cardiol, 2008; 127: 27-32

Dimopoulos, K., R. Inuzuka, S. Goletto, G. Giannakoulas, L. Swan, S.J. Wort, and M.A. Gatzoulis, Improved survival among patients with Eisenmenger syndrome receiving advanced therapy for pulmonary arterial hypertension. Circulation, 2010; 121: 20-25

Technique of VSD treatment surgery – transcatheter intervention- hybrid

Surgery is the standard of treatment

- anticongestive medication should not delay surgery without reasons

technique

- routine: median sternotomy, total cardio-pulmonary-bypass with cardioplegia, transtricuspid patch-closure
- minimal invasive procedures are possible (partial inferior sternotomy, antero-lateral or mid-axillary thoracotomy)
- resection and re-fixation of the septal tricuspid valve might be indicated to visualize the cranial VSD border
- transaortic or transpulmonary access might be helpful to close subaortic or cono-truncal defects

Technique of VSD treatment surgery

- apical muscular defects need a (right-) ventriculotomy
- left-ventriculotomy is at risk for arrhythmias and left ventricular dysfunction
- palliative surgery/pulmonary banding today is indicated only in exceptional cases like swiss-cheese VSD or in contraindications for CPB

Prognosis – operated restrictive VSD short term perspective

- Chicago, 1993
- selection: >1yr., Q_P:Q_S<2
- 141 patients (Op 1980-1991)
- mean age at Op 6±5 yrs.
- mean Q_P:Q_S=1.6±0.3
- 3.5% prior endocarditis
- 45% aortic valve prolapse
- 18% aortic insufficiency
- 48% tricuspid valve pouch
- results:
- no ventriculotomy
- no death
- no permanent AV block
- no significant residual VSD

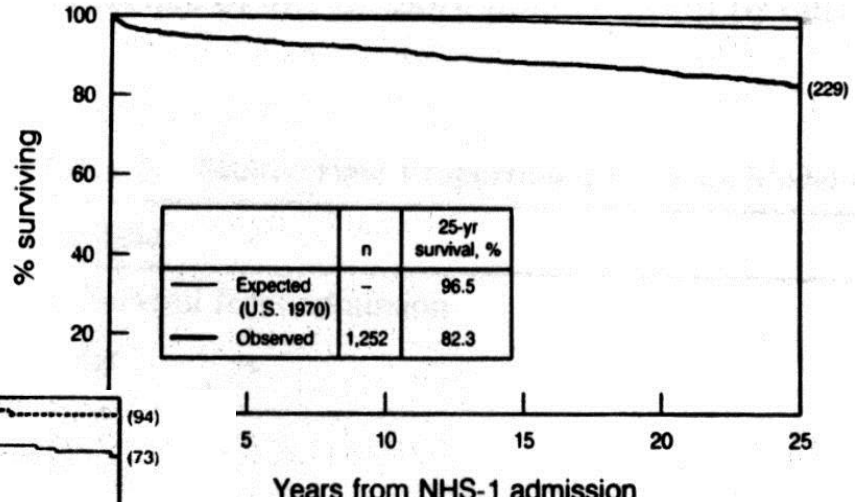
- Houston, Texas, 2010
- 215 patients (Op 2000-2006)
- age at Op 20d-18yrs.
- 80% perimebraneous VSD, 13% supracristal VSD, 3% inlet VSD, 4% muscular VSD
- results:
- 3 early and late deaths (prematuraty, syndroms)
- 16% small residual VSD
- No permanent AV-block
- 1% atrial rhythm
- 26% RBBB
- 2% mild, 0.5% moderate depressed LV-Fx
- 2 pts. moderate tricuspid regurgitation

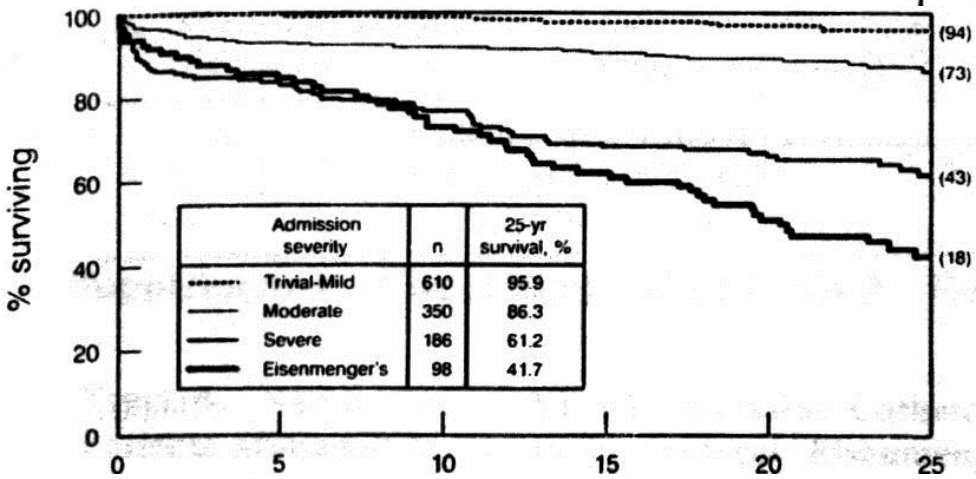
Backer, C.L., R.C. Winters, V.R. Zales, H. Takami, A.J. Muster, D.W. Benson, Jr., and C. Mavroudis, Restrictive ventricular septal defect: how small is too small to close? Ann Thorac Surg, 1993; 56: 1014-1018; discussion 1018-1019

Scully, B.B., D.L. Morales, F. Zafar, E.D. McKenzie, C.D. Fraser, Jr., and J.S. Heinle, Current expectations for surgical repair of isolated ventricular septal defects. Ann Thorac Surg; 2010; 89: 544-549; discussion 550-541

Prognosis – operated restrictive VSD short term perspective

- second natural history study, 1993
- 1099 patients (Op 1958-1969)
- 94% of small VSDs NYHA I
- higher-than-normal prevalence of serious arrhythmias and sudden death even in mild VSD





Kidd, L., D.J. Driscoll, W.M. Gersony, C.J. Hayes, J.F. Keane, W.M. O'Fallon, D.R. Pieroni, R.R. Wolfe, and W.H. Weidman, Second natural history study of congenital heart defects. Results of treatment of patients with ventricular septal defects. Circulation, 1993; 87: I38-51

Prognosis – operated restrictive VSD long term perspective

- Minneapolis, Minnesota, 1991
- 296 patients (Op 1954-1960)
- 20% late mortality 20% at 30 yrs.
  risk factors; age >5 yrs., PAH, cAV-block
- 22% late mortality in pts. with transient AV-block after surgery

- Göteborg, Sweden, 2000
- 277 patients (Op 1976-1996)
- decrease of early death to 0.6%
- no late death

TABLE III Ventricular Septal Defect After Surgery: Sudden and Unexpected Deaths (details in 5 patients)

Patient	Age at Death (yrs)	Postoperative Duration (yrs)	Postoperative Electro-cardiogram	Block
1	24	3	QRS = 0.18 sec	0
2	11	8	CRBBB	0
3	24	22	CRBBB	0
4	39	29	Normal	Transient
5	38	33	LAD + CRBBB	0

CRBBB = complete right bundle branch block; LAD = left-axis deviation; 0 = absent.

TABLE IV Ventricular Septal Defect After Surgery; Relation Between Pulmonary Vascular Resistance Before Surgery and Late Deaths

Pulmonary Vascular Resistance (mm Hg/L/min/m²)	No. of Patients	No. of Late Deaths
<3	44	2 (5%)
3–5	45	5 (11%)
5–7	46	8 (17%)
7–10	14	9 (44%)
>10	19	8 (42%)

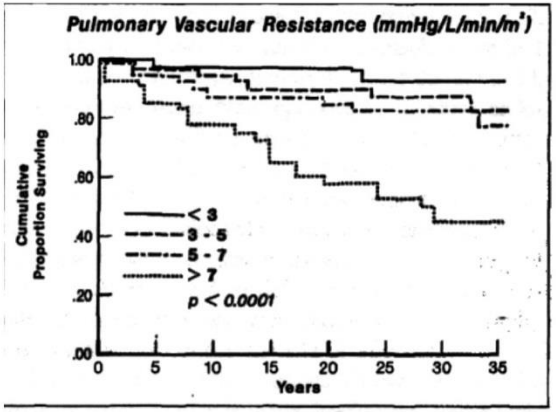


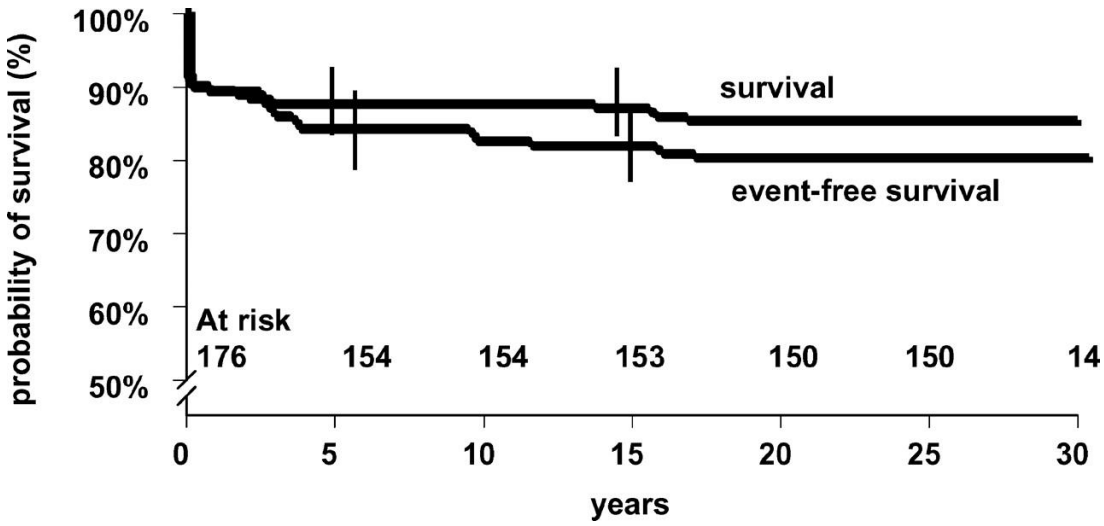
FIGURE 3. Ventricular septal defect after surgery. Life table analysis of 168 patients divided into categories according to level of pulmonary vascular resistance before surgery.

Moller, J.H., C. Patton, R.L. Varco, and C.W. Lillehei, Late results (30 to 35 years) after operative closure of isolated ventricular septal defect from 1954 to 1960. Am J Cardiol, 1991; 68: 1491-1497

Nygren, A., J. Sunnegardh, and H. Berggren, Preoperative evaluation and surgery in isolated ventricular septal defects: a 21 year perspective. Heart, 2000; 83: 198-204

Prognosis – operated restrictive VSD long term perspective

- Rotterdam, Netherlands
- 176 patients (Op 1968-1980)
- 4% late mortality (PAH)
- 6% re-operations
- 1% late cAV-block
- 4% sinus node disease, PM-implantation
- 1 AKE after endocarditis
- 92% NYHA I
- 4% PAH
- 16% aortic insufficiency



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Operative closure of VSD – outcome today

- Very low risk of mortality < 1% (besides pulmonary hypertension)
- Very low risk for…
  - residual shunt
  - atrioventricular block
  - aortic or tricuspid regurgitation

Andersen, H.O., M.R. de Leval, V.T. Tsang, M.J. Elliott, R.H. Anderson, and A.C. Cook, Is complete heart block after surgical closure of ventricular septum defects still an issue? Ann Thorac Surg, 2006; 82: 948-956

Scully, B.B., D.L. Morales, F. Zafar, E.D. McKenzie, C.D. Fraser, Jr., and J.S. Heinle, Current expectations for surgical repair of isolated ventricular septal defects. Ann Thorac Surg, 2010; 89: 544-549; discussion 550-541

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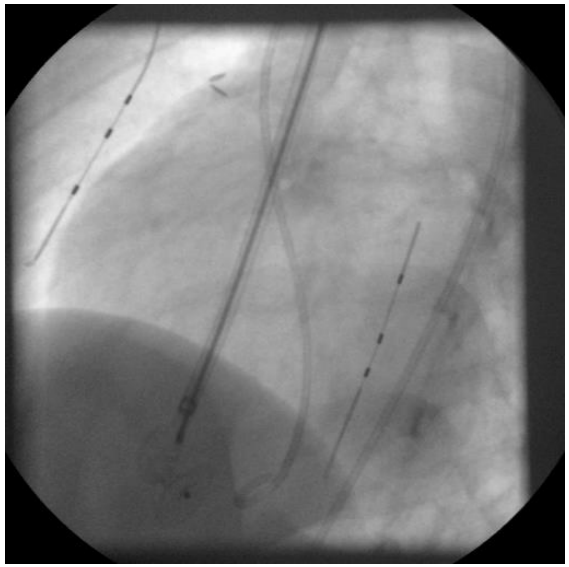
Technique of VSD treatment - transcatheter intervention

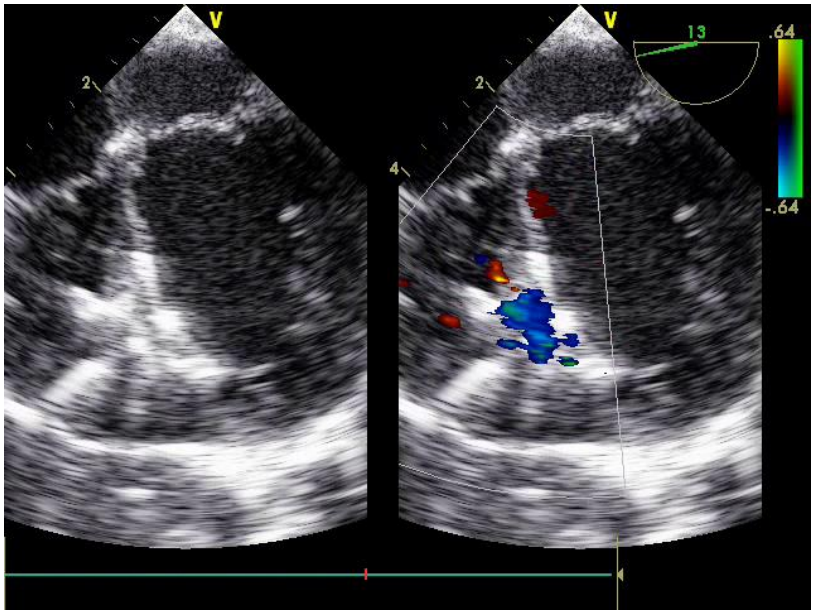
- Transcatheter closure of pmVSD and mVSD is possible in selected patients
- Transcatheter intervention should not be applied in infants with pmVSD (near to the conduction system) – introduction systems and current devices are too stiff and harmfull
- Self-expandable devices give most therapeutic options to close larger defects or defects near to the aortic valve
- the use of self expandable devices in pmVSD bears the risk for complete AV-block
- the risk for AV-block is less present in defects which are not localized near to the conduction system (muscular defects, septum aneurysms) or by the use of spiral coils



➢ **Planning of VSD device closure needs individual risk calculation and detailed information of the patient**

Technique of VSD treatment - hybrid procedure

- Alternative procedure mostly for infants with large muscular VSD
- Implantation of the device through the free right ventricular wall after thoracotomy
- TOE guiding
- Procedure is less invasive (beating heart without CPB)



Picture: courtesy of N. Haas, Bad Oeynhausen

Michel-Behnke et al. Device closure of ventricular septal defects by hybrid procedures – a multicenter retrospective study. Catheter Cardiovasc Intervention

Xing et al. Minimally invasive perventricular device closure of perimembraneous ventricular septal defect without cardiopulmonary bypass: multicenter experience and mid-term follow-up. J Thorac Cardiovasc Surg; 139: 1409-1415

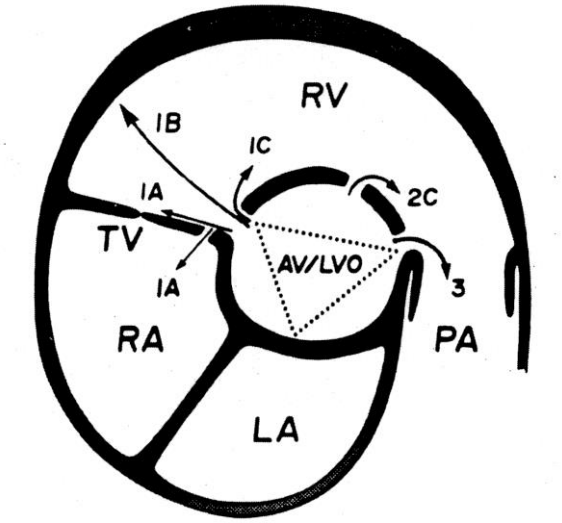
Diagnostics

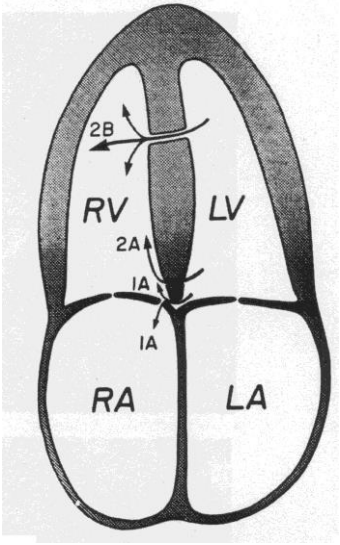
- Primary diagnostic performed by echocardiography
- localisation of defect
- Evaluation of hemodynamic effects, e.g. volumetric load of left atrium and left ventricle
- Evaluation of valvular function particularly in VSD with proximity to aortic valve
- Estimation of right ventricular and pulmonary vascular pressure
- Evidence/Exclusion of concomitant heart and vascular defects (22% of all patients with VSD show another significant cardiac defect[1])
- Estimation of prognosis and if necessary planning of therapy

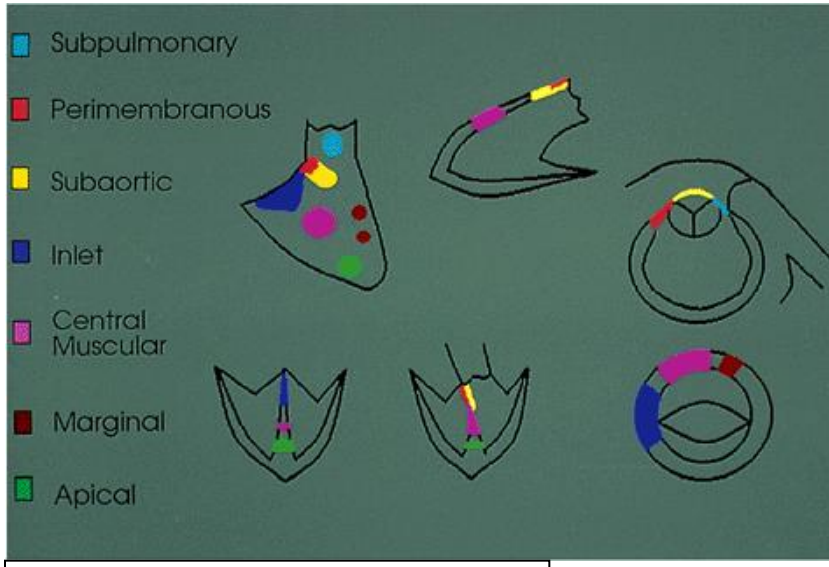
*1) Glen, S., J. Burns, and P. Bloomfield, Prevalence and development of additional cardiac abnormalities in 1448 patients with congenital ventricular septal defects. Heart, 2004; 90: 1321-1325

Description of localisation in echocardiography

- 1 perimembranous defects
  1A with inlet extension through leaflets of the tricuspid valve
  1B with trabecular extension towards the free wall
  1C with outflow extension towards the RV outflow tract
- 2 muscular defects
  2A muscular inlet
  2B trabecular
  2C high muscular defect
- 3 juxtaarterial doubly commited defect directed into the PA







Moss Adams, 7th edition 2008

Rahko, P.S., Doppler echocardiographic evaluation of ventricular septal defects in adults. Echocardiography, 1993; 10: 517-531

Apparative diagnostics

- Echocardiography – for routine only primary diagnostic
- ECG – basic diagnostic
- Chest X-ray – dispensable for diagnostic; preoperative
- Heart catheterisation - test of resistance in pulmonary vascular hypertension
  - interventional closure
- Pulse oxymetry – Exposure of right-to-left-shunt in pulmonary vascular hypertension
- Cardiac MRI – non-invasive measurement of shunt

Debl, K., B. Djavidani, S. Buchner, N. Heinicke, F. Poschenrieder, S. Feuerbach, G. Riegger, and A. Luchner, Quantification of left-to-right shunting in adult congenital heart disease: phase-contrast cine MRI compared with invasive oximetry. Br J Radiol, 2009; 82: 386-391

Korperich, H., J. Gieseke, P. Barth, R. Hoogeveen, H. Esdorn, A. Peterschroder, H. Meyer, and P. Beerbaum, Flow volume and shunt quantification in pediatric congenital heart disease by real-time magnetic resonance velocity mapping: a validation study. Circulation, 2004; 109: 1987-1993

Follow-up care in patients with VSD

Follow-up care in surgically closed VSD

- Till end of puberty by a pediatric cardiologist in long time intervals
- In case of no residual shunt, sinus rhythm with normal AV conduction, normal size and normal function of heart and good function of valves: no systematic follow-up care after adolescent years
- Endokarditis prophylaxis for the first 6 months after closure and therafter only if a residual shunt contacts patch material

Follow-up care in interventional closed VSD

- lifelong, time interval dependent on results

Follow-up care in untreated VSD

- perimembranous VSD: lifelong, time interval dependent on results
- muscular VSD: lifelong, time interval dependent on results

Unclear/borderline indications open questions/daily clinical decisions without evidence

- Adolescents/adults with borderline size of left ventricle
- High-energy beam directed on the tricuspid valve (elevated risk for endocarditis ?)
- large, „tottering“ septal aneurysm
- Small aortic regurgitation without prolapse of aortic valvular cusp
- Aortic valvular cusp might be involved in VSD anatomy without any aortic regurgitation
- Small muscular VSD close to the apex persistent in adulthood

VSD: compact pathophysiology and treatment

VSD size	PA mean pressure	PA resistance	Clinical symptoms	Treatment
large, no pressure restriction	elevated (>25 mmHg)	normal or slightly elevated (R_P:R_S<0,2)	loud systolic heart murmur, 2. heart sound regular, sometimes signs of congestive heart failure	<6 months surgical closure, consider previous test of vasoreagibility in older patients
		elevated (R_P:R_S=0.2-0.3)	soft systolic heart murmur, 2. heart sound pronounced, cynosis might occur	>6 months test of vasoreagibility, closure at elevated risk, consider anti-PAH medication
		severe elevated (R_P:R_S>0.3)		>6 months individual approach in selected patients, anti-PAH medication
medium	normal or slightly elevated	normal or slightly elevated	loud systolic heart murmur, 2. heart sound regular	>12 months closure if signs of left ventricular overload are present and spontaneous reduction of VSD size is missing
small, pressure restriction	normal	normal	loud systolic heart murmur, 2. heart sound regular	life-long follow-up by echo, closure if aortic regurgitation, left ventricular enlargement or endocarditis occurs