Percutaneous Closure of Ventricular Septal Defects in 116 Patients
Experience with different devices

*Khalfan S. Al Senaidi,1 Salim Al Maskary,2 Eapen Thomas,2 Boris Dimitrov,2 Abdullah Al Farqani2

ABSTRACT: Objectives: This study aimed to review the experience with percutaneous closure of ventricular septal defects (VSDs) at the National Heart Center (NHC) in Muscat, Oman. Methods: This retrospective study was conducted from November 2008 to December 2017. Patients' electronic medical records were reviewed to identify their clinical, imaging and interventional data before and after the procedure and on the last follow-up. Results: A total of 116 patients, the majority of which were female (58%), underwent 118 percutaneous procedures for VSD closure at a median age of 3.5 years (range: 0.25–33 years) and a median weight of 12 kg (range: 3.5–78 kg). The mean diameter of the VSDs as determined by transoesophageal echocardiography was 5.6 ± 1.9 mm (n = 105). The commonest type of VSD was perimembranous (n = 75, 63.5%). Devices were successfully placed during 111 (94.1%) procedures in 109 (94.0%) patients, with the commonest device being a Amplatzer™ duct occluder I (St. Jude Medical, Little Canada, Minnesota, USA; n = 39, 35.1%). There was no mortality. Early major cardiac complications occurred in six patients (5.5%) with device embolisation being the commonest (n = 4, 3.7%). The median follow-up period was 19 months (range: 1–84 months) in 89 (81.7%) of the patients. One patient (0.9%) required a permanent pacemaker for a complete heart block. Conclusion: This study has demonstrated a good rate of VSD closure with low morbidity and no mortality using the percutaneous approach with different devices. Long-term follow-up is needed to specifically evaluate the function of adjacent structures and the long-term effects on conduction systems.

Keywords: Ventricular Septal Defect; Percutaneous Coronary Intervention; Amplatzer Occluder Device; Vascular Closure Device; Heart Block; Oman.

Advances in Knowledge
- The results of this study revealed that percutaneous closure of ventricular septal defects (VSDs) can be performed safely with limited complications.
- This study may serve as a reference point for future research on this subject.

Application to Patient Care
- This study provides evidence that percutaneous VSD closure is safe and effective with low risk of complete heart block.
Ventricular septal defect (VSD) is the most common type of congenital heart disease with an incidence of 3–3.5 per 1,000 live births; almost 80% of these VSDs are perimembranous.1–3 Closure is indicated when the VSD is haemodynamically significant to prevent future complications, including ventricular dysfunction, arrhythmias and pulmonary arterial hypertension.4 Surgical approaches traditionally have been the mainstay of therapy in closing VSDs.2,3,5,6 Surgical approaches, however, have been associated with morbidity and mortality, patient discomfort, sternotomy and scarring.5–8 The transcatheter approach gained cardiologists’ special interest over the last decade due to its encouraging results.9–12 This study aimed to review experiences with percutaneous VSD closure at the National Heart Center (NHC) of Oman.

Methods
This retrospective study included all patients who underwent percutaneous VSD device closure at the NHC from November 2008 to December 2017. Medical records were reviewed for clinical evaluation data and findings from electrocardiograms, thoracic electrocardiograms (TTEs) and transeosophageal echocardiograms (TEEs) before and after the intervention and on the last follow-up. The catheterisation database was reviewed to identify patients who underwent attempted transcatheter VSD closure. Angiograms and cardiac catheterisation reports were analysed to determine haemodynamics and procedural characteristics. All cardiac catheterisations were done under general anaesthesia by a transfemoral approach under TEE guidance. Follow-ups were done at one, three and six months post-procedure and then yearly. A successful procedure was defined as one in which a stable device was successfully positioned across the defect with no complications to adjacent structures and no significant residual shunt. Adverse events and complications were assessed intraoperatively, before discharge and on subsequent follow-up visits. Technical details of the procedure were followed according to a previously established protocol.13

Statistical Package for the Social Sciences (SPSS), Version 25.0 (IBM, Corp., Armonk, New York, USA) was used to analyse the data, which were described as mean ± standard deviation. Median and range were used to describe continuous variables and categorical data were expressed as frequencies with percentages. An association analysis of procedure results and risk factors was done. Dependent outcome variables were analysed to determine whether procedures were successful, the incidence of total early complications and the occurrence of device embolisation. Independent variables included in the analysis were patients’ age at the procedure, weight and gender. Also included in the analysis was the defect diameter as measured on TTE and whether patients were diagnosed with ventricular septal aneurysm. Univariate analysis was performed using binary logistic regression. Multivariable analysis to study risk factors for the occurrence of dependent variables was performed using multiple logistic regression. Odds ratios (OR) and their 95% confidence intervals were calculated for the independent variables. Differences were considered statistically significant at P < 0.05.

The study was approved by The Royal Hospital’s Institutional Review Board.

Results
A total of 116 patients, of which 67 (58%) were female, underwent 118 percutaneous procedures (two patients underwent two device placements) for VSD closure at a median age of 3.54 years (range: 0.25–33 years) and had a median weight of 12 kg (range: 3.5–78 kg) [Table 1]. Nine patients were over 18 years of age with a mean age of 24.5 ± 3.4 years and a mean weight of 66 ± 8 kg. Perimembranous VSD was commonest (n = 75; 63.5%).

Devices were successfully placed in 109 (94.0%) patients during 111 (94.1%) procedures. The mean diameter of the defects from the right ventricular side was 5.7 ± 2.1 mm (n = 109) as determined by TTE and 5.6 ± 1.9 mm (n = 105) as determined by TEE [Table 2]. Mild tricuspid valve regurgitation was present prior to closure in 34 (31.2%) patients and was determined to be moderate in three (2.8%) cases. Aortic valve regurgitation was mild in three (2.8%) patients. In total, 56 (51.4%) cases had aneurysmal tissues from the right ventricle side. Procedures were abandoned in seven patients (five males and two females) at a median age of 1.7 years (range: 0.58–22 years) and a median weight of eight kg (range: 4–60 kg). Abandonment was due to various reasons including haemodynamic instability and hypotension in three patients, worsening aortic regurgitation in one patient, improper orientation and compaction of the device across the defects in two patients and incidental finding of an interrupted inferior vena cava in one patient. In this last patient, the procedure was attempted via a jugular venous approach, which was unsuccessful.

Analysis of risk factors using univariate analysis revealed that only a larger diameter of the VSD, as determined by TTE, was a significant predictor of procedure failure; successful procedures involved VSDs with a mean diameter of five mm (range: 2.5–
Percutaneous Closure of Ventricular Septal Defects in 116 Patients
Experience with different devices

14 mm) while unsuccessful procedures had a mean diameter of eight mm (range: 5–14 mm; \( P < 0.01 \)). Multivariable analysis also showed that a larger VSD diameter was a significant predictor for procedure failure (OR: 1.60, 95% CI: 1.11–2.30, \( P = 0.01 \)) [Table 3].

All closures were performed through a transfemoral approach. Arterio-venous looping was done in 104 (93.7%) procedures, whereas in six (5.4%) procedures the closure was done by a retrograde approach from the femoral artery. In one patient (0.9%), the device was deployed directly from a right ventricular approach. The most common devices used were the Amplatzer™ duct occluder I (St. Jude Medical, Little Canada, Minnesota, USA; ADOI) in 39 (35.1%) procedures and the Amplatzer™ duct occluder II (St. Jude Medical; ADOII) in 26 (23.4%) [Table 2].

The mean duration of stay in hospital was 2.0 ± 1.6 days. No procedure-related deaths were recorded. Immediate complete closure was achieved in 52 (46.8%) procedures, which increased to 69 (62.2%) at day one post-procedure and to 79 out of 89 patients (88.8%) at last follow-up.

Procedure or device-related complications occurred in 10 (9.2%) patients. Of these cases, early major cardiac complications within 12 hours of the procedure occurred in six patients (5.5%); device embolisation occurred in four patients (3.7%). Severe tricuspid valve regurgitation occurred in one patient (0.9%); the sixth patient in the series developed severe tricuspid valve stenosis (0.9%). Five patients required surgical retrieval of devices (4.6%). In one patient, the device was retrieved by a snare

Table 1: Characteristics of the study population (N = 118 procedures)*

| Characteristic          | Total procedures | Unsuccessful procedures | \( P \) value |
|-------------------------|------------------|-------------------------|--------------|
| Median age in years     | 3.54 (0.25–33)   | 1.7 (0.58–22)           | 0.48         |
| Median weight in kg     | 12 (3.5–78)      | 8 (4–60)                | 0.49         |
| Gender                  |                  |                         | 0.13         |
| Male                    | 49               | 5                       |              |
| Female                  | 67               | 2                       |              |
| Age in years            |                  |                         |              |
| ≤1                      | 20 (16.9)        | 2 (1.7)                 |              |
| 1–13                    | 81 (68.6)        | 4 (3.4)                 |              |
| 13–18                   | 8 (6.8)          | 0 (0)                   |              |
| ≥18                     | 9 (7.6)          | 1 (0.8)                 |              |
| VSD Type                |                  |                         |              |
| Perimembranous          | 75 (63.5)        | 6 (5.1)                 |              |
| High muscular           | 23 (19.5)        | 0 (0)                   |              |
| Mid muscular            | 9 (7.6)          | 0 (0)                   |              |
| Residual post-surgery   | 7 (5.9)          | 0 (0)                   |              |
| Inlet                   | 3 (2.7)          | 1 (0.8)                 |              |
| Residual post-device    | 1 (0.8)          | 0 (0)                   |              |

Table 2: Procedural data and devices used for percutaneous closure of ventricular septal defects (N = 111 procedures)*

| Variable                          | n (%) | Mean ± SD |
|-----------------------------------|-------|-----------|
| Procedure                         |       |           |
| VSD diameter (RV) via TTE in mm   | 109 (98.2) | 5.7 ± 2.1 |
| VSD diameter (LV) via TEE in mm   | 46 (41.4)  | 8.6 ± 2.5 |
| VSD diameter (RV) via TEE in mm   | 105 (94.6) | 5.6 ± 1.9 |
| VSD diameter via angiogram in mm  | 103 (92.8) | 5.7 ± 2   |
| MPA pressure in mmHg              | 79 (71.2)  | 21 ± 8    |
| LVEDp in mmHg                     | 93 (83.8)  | 10 ± 3.5  |
| Qp:Qs                             | 87 (78.4)  | 2 ± 1.1   |
| VSD Device                        |       |           |
| ADOI                              | 39 (35.1)  |           |
| ADOII                             | 26 (23.4)  |           |
| AMVSD                             | 16 (14.4)  |           |
| APMVSD                            | 14 (12.6)  |           |
| Pfm Coil                          | 8 (7.2)    |           |
| CDO                               | 7 (6.3)    |           |
| ASO                               | 1 (1.0)    |           |
| Device size (LV) in mm            |        | 8.7 ± 2.5 |
| Device size (RV) in mm            |        | 6.7 ± 2.2 |

SD = standard deviation; VSD = ventricular septal defect; RV = right ventricle; TTE = transthoracic echocardiography; LV = left ventricle; TEE = transoesophageal echocardiography; MPA = main pulmonary artery; LVEDp = left ventricular end diastolic pressure; Op = pulmonary flow; Qs = systemic flow; ADO = Amplatzer™ duct occluder (St. Jude Medical, Little Canada, Minnesota, USA); AMVSD = Amplatzer™ muscular ventricular septal defect occluder (St. Jude Medical); APMVSD = Amplatzer™ perimembranous ventricular septal defect occluder (St. Jude Medical); CDO = cocoon duct occlude; ASO = Amplatzer™ atrial septal occlude (St. Jude Medical).

*Procedures were carried out in 109 patients. Procedures were abandoned in seven patients due to hemodynamic instability and hypotension in three patients, worsening aortic regurgitation in one patient, improper orientation and compaction of the device across the defects in two patients and incidental finding of an interrupted inferior vena cava in one patient (procedure was attempted via a jugular venous approach but was unsuccessful).
Table 3: Univariate and multivariate analysis of risk factors for successful percutaneous closure of ventricular septal defect (N = 118)

| Variable                        | Univariate | Multivariate |
|---------------------------------|------------|--------------|
|                                 | Procedure success | P value | OR 95% CI | P value |
|                                 | Yes | No |                  |                |
| Median age in years (range)     | 4 (0.25–33) | 1.7 (0.58–21.6) | 0.48 | 1.01 | 0.67–1.52 | 0.10 |
| Age less than one year          | 0.41 | 1.72 | 0.17–17.70 | 0.65 |
| Median weight in kg (range)     | 13 (3.5–78) | 8 (4–60) | 0.49 | 1.02 | 0.86–1.22 | 0.81 |
| Weight less than 10 kg          | 0.26 | 6.33 | 0.38–105.1 | 0.20 |
| Gender                          | 0.13 | 0.30 | 0.05–1.80 | 0.19 |
| VSD aneurysm present            | 0.28 | 0.68 | 0.10–4.68 | 0.69 |
| Median VSD size via TTE in mm (range) | 5 (2.5–14) | 8 (5–14) | <0.01 | 1.60 | 1.11–2.30 | 0.01 |

OR = odds ratio; CI = confidence interval; VSD = ventricular septal defect; TTE = transthoracic electrocardiogram.

Table 4: Details of early complications after percutaneous closure of ventricular septal defect

| No. | Age in months | Gender | Weight in kg | VSD type | VSD size in mm | Device type (size) | Adverse event | Outcome                          |
|-----|---------------|--------|--------------|----------|----------------|-------------------|---------------|-----------------------------------|
| 1   | 20            | M      | 8.9          | PMVSD    | 9              | ADOI (10/8)       | Embolisation   | Surgical retrieval                |
| 2   | 6             | M      | 12           | PMVSD    | 9              | ADOI (12/10)      | Embolisation   | Surgical retrieval                |
| 3   | 14            | F      | 7.4          | PMVSD    | 6              | APMVSD (8)        | Embolisation   | Catheter retrieval; same device used |
| 4   | 13            | M      | 11.2         | PMVSD    | 4              | Pfm coil (8/6)    | Embolisation   | Catheter retrieval                |
| 5   | 5             | F      | 3.5          | PMVSD    | 4              | ADOI (5/4)        | Severe TR and severe residual shunt | Surgical removal and repair |
| 6   | 36            | F      | 11.7         | MM       | 11             | AMVSD (12)        | Severe TS      | Surgical removal                  |
| 7   | 11            | M      | 5.3          | PMVSD    | 5              | PFM coil (10/6)   | Haemolysis and severe residual shunt | Second device placed (ADOII) |
| 8   | 10            | F      | 5.7          | PMVSD    | 7.5            | APMVSD (10)       | Haemolysis     | Improved                          |
| 9   | 6             | F      | 4.2          | HM       | 9              | AMVSD (12)        | Transient second-degree block | Improved but CHB 21 months later |
| 10  | 12            | M      | 39           | HM       | 7              | ADOI (12/10)      | Urinary bladder-injury | Required surgical exploration of urinary bladder |

VSD = ventricular septal defect; PMVSD = perimembranous ventricular septal defect; ADO = Amplatzer™ duct occluder (St. Jude Medical, Little Canada, Minnesota, USA); APMVSD = Amplatzer™ membranous ventricular septal defect occlude (St. Jude Medical); TR = tricuspid regurgitation; MM = mid-muscular ventricular septal defect; AMVSD = Amplatzer™ muscular ventricular septal defect occlude (St. Jude Medical); TS = Tricuspid stenosis; HM = high muscular ventricular septal defect; CHB = complete heart block.
Table 5: Univariate and multivariate analysis of risk factors for early complications of percutaneous closures of ventricular septal defects (N = 111)

| Variable                        | Early complications | Univariate P value | Multivariate OR  | 95% CI | Multivariate P value |
|---------------------------------|---------------------|--------------------|------------------|--------|-----------------------|
| Median age in years (range)     | 1.38 (0.33–13.67)   | 0.11               | 0.91             | 0.58–1.42 | 0.67                 |
| Age less than one year old      | Yes 4               | 0.06               | 0.39             | 0.06–2.73 | 0.35 |
|                                 | No 6                |                     |                  |        |                       |
| Median weight in kg (range)     | 8.15 (3.5–39)       | 0.14               | 1.01             | 0.85–1.18 | 0.96 |
| Weight less than 10 kg          | Yes 6               | 0.10               | 1.54             | 0.17–13.87 | 0.70 |
|                                 | No 4                |                     |                  |        |                       |
| Gender                          | Male 5              | 0.53               | 0.66             | 0.14–3.03 | 0.59 |
|                                 | Female 5            |                     |                  |        |                       |
| VSD aneurysm present            | Yes 6               | 0.53               | 2.31             | 0.45–11.84 | 0.32 |
|                                 | No 4                |                     |                  |        |                       |
| Median VSD size via TTE in mm   | 6 (3.6–12)          | 0.17               | 1.29             | 0.95–1.75 | 0.11 |
| (range)                         |                     |                     |                  |        |                       |

OR = odds ratio; CI = confidence interval; VSD = ventricular septal defect; TTE = transthoracic electrocardiogram.

Table 6: Univariate and multivariate analysis of risk factors for device embolisation (N = 111)

| Variable                        | Embolisation present | Univariate P value | Multivariate OR  | 95% CI | Multivariate P value |
|---------------------------------|----------------------|--------------------|------------------|--------|-----------------------|
| Median age in years (range)     | 1.71 (1.08–4.17)     | 0.23               | 0.05             | 0.01–5.29 | 0.21 |
| Age less than one year old      | Yes 0               | 0.100              | 1.38             | 0.18–14.70 | 0.100 |
|                                 | No 4                |                     |                  |        |                       |
| Median weight in kg (range)     | 10.05 (7.4–12)      | 0.30               | 0.61             | 0.11–3.37 | 0.57 |
| Weight less than 10 kg          | Yes 2               | 0.54               | 0.16             | 0.00–184.29 | 0.61 |
|                                 | No 2                |                     |                  |        |                       |
| Gender                          | Male 3              | 0.19               | 0.17             | 0.03–9.48 | 0.40 |
|                                 | Female 1            |                     |                  |        |                       |
| VSD aneurysm present            | Yes 3               | 0.34               | 11.18            | 0.19–647.12 | 0.24 |
|                                 | No 1                |                     |                  |        |                       |
| Median VSD size via TTE in mm   | 6 (3.6–12)          | 0.23               | 1.42             | 0.77–2.66 | 0.26 |
| (range)                         |                     |                     |                  |        |                       |
catheter. An early significant residual shunt occurred in two (1.8%) patients. Pre-existing mild tricuspid valve regurgitation did not change post-procedure. However, moderate regurgitation was detected in two (1.8%) patients. Early aortic valve regurgitation was mild in two (2%) patients, although the condition was pre-existing; another patient also had an early mild aortic valve regurgitation before the procedure which improved. Complete heart block (CHB) was detected in only one patient (0.9%), a symptomatic six-month-old girl weighing 4.2 kg with an 11-mm long anterior muscular VSD. A 12-mm Amplatzer™ (St. Jude Medical) muscular VSD (AMVSD) occluder was used. However, after releasing the device, a transient 2:1 atrioventricular block was noted. The block improved and the patient was discharged two days later. She presented 21 months later with a recurrence of CHB with a heart rate of 56 beats/minute for which a permanent pacemaker was placed. Her follow-ups prior to the presentation were completely normal [Table 4]. Follow-up was possible in 89 (81.7%) patients with a median follow-up period of 19 months (range: 1–84 months). All patients improved clinically.

The assessment of risk factors for the occurrence of early complications and device embolisation using univariate and multivariate logistic regression analyses showed no statistically significant association with independent predictors [Tables 5 and 6].

Discussion

Percutaneous closure of VSDs has gained popularity in the last few years. The procedure has many advantages, but it is not without challenges. In this study, different types of VSDs were closed, but the perimembranous type was the most common (63.5%). The reported success rate of the procedure in the literature is high; Butera et al. and Holzer et al. reported successful closure rates of approximately 96% and 93%, respectively. The current study found a comparable successful closure rate of 94.1%.

The percutaneous approach for VSD closure is challenging in small patients and there are no clear guidelines about the best approaches to use or what devices to select. Choosing the correct procedure to use in addressing VSDs depends on many factors. Infants with low body weight are often referred for surgery. Diab et al. reported a series of infants less than one year of age; the smallest infant undergoing a purely percutaneous approach was 3.8 kg. Narin et al. reported successful percutaneous closure in 12 infants less than 12 months of age using this approach in infants as small as three kg, although one patient in their series developed CHB six months post-procedure. In the current study, the youngest patient was a symptomatic male aged three months old and weighing 3.5 kg. This patient had a large (eight mm) residual mid muscular post-surgical VSD closed using a 10 mm AMVSD occluder uneventfully. The researchers have observed a trend of early complications in younger patients; however, the number of complications among these younger patients was not statistically significant (P = 0.06). Holzer et al. reported that patients “with a weight below 10 kg had a significantly higher incidence of adverse events than patients with a weight above 10 kg (58.3% versus 25.0%, P = 0.0285).” Therefore, interventionists should be extremely careful in smaller infants in selecting the types of devices and sizes to use when dealing with VSDs. Moreover, current devices should be improved to reduce complications in this group.

Appropriate device selection is of fundamental importance to achieve safe closure when dealing with VSDs. The current researchers primarily select devices based on VSD morphology with preferences for ductal devices for VSDs in membranous/upper muscular locations and muscular VSD devices for muscular VSDs. ADOII, with its softer profile, should be used for VSDs close to the aortic valve. It has been observed that 51.4% of the defects had aneurysmal tissues from the right ventricle. In the majority of cases, the researchers aim to deploy the device within the aneurysm if it is large enough to avoid encroaching on the aortic valve. Furthermore, the researchers use devices with a smaller right ventricular disc such as duct occluders to avoid entrapment of the tricuspid valve. However, the number of fenestrations and the strength of the aneurysm are limiting factors. The current study, though, did not show the presence of an aneurysm to be a predictor for procedure success or for the occurrence of complications.

Early complications were observed in 10 (9.2%) patients but fortunately, no deaths occurred. Six (5.5%) patients required surgical removal of the devices and repair of the defects with no sequelae. In the current study, there was a relatively small number of patients with large defects. The rate of early complications was comparable to other published literature. Butera et al. reported 13 early significant complications in 12 patients (11.5%); two of these complications were related to device embolisation. In the current study, no variables were observed which predicted early complications in the analysis model, but valvular regurgitation or stenosis were found to be more concerning complications with device closures.

Tricuspid, mitral and aortic valve impingement have also been described in the literature. Holzer et al. reported an early new or increasing tricuspid and
Percutaneous Closure of Ventricular Septal Defects in 116 Patients
Experience with different devices

Conclusion

This study has demonstrated a good closure rate of VSDs with low morbidity and no mortality using the percutaneous approach with different devices. Long-term follow-up is needed to specifically evaluate the function of adjacent structures and the long-term effects of devices on the conduction system.

CONFLICT OF INTEREST
The authors declare no conflicts of interest.

FUNDING
No funding was received for this study.

ACKNOWLEDGMENT
The authors would like to thank Dr Hashim Javad and Dr Hussain Al Safar for reviewing this manuscript.

References

1. Hoffman JL, Kaplan S. The incidence of congenital heart disease. J Am Coll Cardiol 2002; 39:1890–900. https://doi.org/10.1016/S0735-1097(02)01886-7.

2. Warnes CA, Williams RG, Bashore TM, Child JS, Connolly HM, Dearani JA, et al. ACC/AHA 2008 guidelines for the management of adults with congenital heart disease: A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (writing committee to develop guidelines). Circulation 2008; 118:e718–833. https://doi.org/10.1016/j.jacc.2008.10.001.

3. Baumgartner H, Bonhoeffer P, De Groot NM, de Haan F, Deenfield JE, Galie N, et al. ESC Guidelines for the management of grown-up congenital heart disease (new version 2010). Eur Heart J 2010; 31:2915–57. https://doi.org/10.1093/eurheartj/ehq249.

4. Kriis D, Driscoll DJ, Gersony WM, Hayes CJ, Keane JE, Fallon WM, et al. Second natural history study of congenital heart defects. Results of treatment of patients with ventricular septal defects. Circulation 1995; 87:138–51.

5. Mono JL, Alexiou C, Salmon AP, Keeton BR. Reoperations and survival after primary repair of congenital heart defects in children. J Thorac Cardiovasc Surg 2003; 126:511–20. https://doi.org/10.1016/s0022-5223(03)00115-6.

6. Bol-Rap G, Weerheim J, Kappetein AP, Witsenburg M, Rogers AJ. Follow-up after surgical closure of congenital ventricular septal defect. Eur J Cardiothorac Surg 2003; 24:511–15. https://doi.org/10.1016/s0107-7904(03)00430-5.

7. Andersen HØ, de Leval MR, Tsang YT, Elliott MJ, Anderson RH, Cook AC. Is complete heart block after surgical closure of ventricular septum defects still an issue? Ann Thorac Surg 2006; 82:948–56. https://doi.org/10.1016/j.athoracsur.2006.04.030.

8. Nygren A, Sunnegårdh J, Berggren H. Preoperative evaluation and surgery in isolated ventricular septal defects: A 21 year perspective. Heart 2000; 83:198–204. https://doi.org/10.1136/heart.83.2.198.

9. Lock JE, Block PC, McKay RG, Bain DS, Keane JF. Transcatheter closure of ventricular septal defects. Circulation 1988; 78:361–8. https://doi.org/10.1161/01.cir.78.2.361.

10. Bass IL, Kalar GS, Arora R, Masura I, Gavora P, Thanopoulos BD, et al. Initial human experience with the Amplatzer perimembranous ventricular septal occluder device. Catheter Cardiovasc Interv 2003; 58:238–45. https://doi.org/10.1002/ccd.10406.

11. Walavalkar V, Majra S, Pujar S, Ramachandra P, Siddaiah S, Sprock E, et al. Percutaneous device closure of congenital isolated ventricular septal defects: A single-center retrospective database study amongst 412 cases. Pediatr Cardiol 2020; 41:591–8. https://doi.org/10.1007/s00246-020-02315-0.
12. Bentham JR, Gujral A, Adwani S, Archer N, Wilson N. Does the technique of interventional closure of perimembranous ventricular septal defect reduce the incidence of heart block? Cardiol Young 2011; 21:271–80. https://doi.org/10.1017/S10479511110002039.

13. Diab KA, Cao QL, Hijazi ZM. Device closure of congenital ventricular septal defects. Congenit Heart Dis 2007; 2:92–103. https://doi.org/10.1111/j.1747-0803.2007.00080.x.

14. Butera G, Chessa M, Carminati M. Percutaneous closure of ventricular septal defects. Cardiol Young 2007; 17:243–53. https://doi.org/10.1017/S1047951107000431.

15. Holzer R, de Giovanni J, Walsh KP, Tometzki A, Goh T, Hakim F, et al. Transcatheter closure of perimembranous ventricular septal defects using the amplatz membranous VSD occluder: Immediate and midterm results of an international registry. Catheter Cardiovasc Interv 2006; 68:620–8. https://doi.org/10.1002/ccd.20659.

16. Diab KA, Cao QL, Mora BN, Hijazi ZM. Device closure of muscular ventricular septal defects in infants less than one year of age using the Amplatzer devices: Feasibility and outcome. Catheter Cardiovasc Interv 2007; 70:90–7. https://doi.org/10.1002/ccd.21142.

17. Narin N, Pamukcu O, Tuncay A, Baykan A, Sunkak S, Tasci O, et al. Percutaneous ventricular septal defect closure in patients under 1 year of age. Pediatr Cardiol 2018; 39:1009–15. https://doi.org/10.1007/s00246-018-1852-5.

18. Santhanam H, Yang L, Chen Z, Tai BC, Rajaor DD, Quek SC. A meta-analysis of transcatheter device closure of perimembranous ventricular septal defect. Int J Cardiol 2018; 254:75–83. https://doi.org/10.1016/j.ijcard.2017.12.011.

19. Butera G, Carminati M, Chessa M, Piazza L, Micheletti A, Negura DG, et al. Transcatheter closure of perimembranous ventricular septal defects: Early and long-term results. J Am Coll Cardiol 2007; 50:1189–95. https://doi.org/10.1016/j.jacc.2007.03.068.

20. Arora R, Trehan V, Kumar A, Kalra GS, Nigam M. Transcatheter closure of congenital ventricular septal defects: Experience with various devices. J Interv Cardiol 2003; 16:83–91. https://doi.org/10.1046/j.1540-8183.2003.08006.x.