

Transcatheter Versus Surgical Closure of Perimembranous Ventricular Septal Defects in Children

A Randomized Controlled Trial



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Objectives	The objective of this study was to evaluate the safety and efficacy of the surgical versus transcatheter approach to correct perimembranous ventricular septal defects (pmVSDs) in a prospective, randomized, controlled clinical trial.
Background	pmVSD is a common congenital heart disease in children. Surgical closure of pmVSD is a well-established therapy but requires open-heart surgery with cardiopulmonary bypass. Although the transcatheter approach is associated with significant incidence of complete atrioventricular block, it may provide a less invasive alternative. Critical comparison of the safety and efficacy of the 2 interventions necessitates a prospective, randomized, controlled trial.
Methods	Between January 2009 and July 2010, 229 children with pmVSD were randomly assigned to surgical or transcatheter intervention. Clinical, laboratory, procedural, and follow-up data over a 2-year period were compared.
Results	Neither group had mortality or major complications. However, statistical analysis of the 2 groups demonstrated significant differences ($p < 0.001$) in minor adverse events (32 vs. 7), quantity of blood transfused, duration of the procedure, median hospital stay, median intensive care unit stay, median hospitalization cost, and median blood loss. During a median follow-up of 2 years, the left ventricular end-diastolic dimension of both groups returned to normal and there was no difference in closure rate, adverse events, and complications between groups.
Conclusions	Transcatheter device closure and surgical repair are effective interventions with excellent midterm results for treating pmVSD in children. Transcatheter device closure has a lower incidence of myocardial injury, less blood transfused, faster recovery, shorter hospital stay, and lower medical expenses. (Transcatheter Closure Versus Surgery of Perimembranous Ventricular Septal Defects; NCT00890799) (J Am Coll Cardiol 2014;63:1159–68) © 2014 by the American College of Cardiology Foundation

Ventricular septal defect (VSD) is the most common type of congenital heart disease, in which perimembranous ventricular septal defect (pmVSD) is 1 of the most common

subtypes (1–3). Treatment of pmVSD has improved dramatically over the last 50 years (4–6). Although open-heart surgery is considered a standard treatment for pmVSD, catheter-based intervention is a promising alternative (7–9). Transcatheter device closure of pmVSD is not currently approved in the United States because of an unacceptably high rate of post-procedural and late-onset heart block (2.9% to 5.7%) (5,7,10). Nevertheless, this procedure is widely used in developing countries such as China and India, with a low mortality and morbidity rate using modified nitinol shape-memory alloy devices (11,12). Nonetheless, data comparing the clinical outcomes of the 2 procedures are minimal (13). In 2009, we performed retrospective studies to examine the early results and

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Abbreviations and Acronyms

ALT = alanine aminotransferase
AST = aspartate aminotransferase
BUN = blood urea nitrogen
CK-MB = creatine kinase-MB
cTnI = cardiac troponin I
pmVSD = perimembranous ventricular septal defect
TTE = transthoracic echocardiography/echocardiographic
VSD = ventricular septal defect

complications of percutaneous compared with surgical closure of VSDs (14-16). On the basis of these preliminary findings, we designed a randomized, controlled trial to prospectively compare the safety and efficacy of the 2 interventions for pmVSD in children.

Methods

Patients. Between January 2009 and July 2010, 465 children age 3 to 12 years with pmVSD from 3 major medical centers in northwest China (Xijing Hospital, Xi'an; Xi'an Children's Hospital, Xi'an; and Hanzhong

Central Hospital, Hanzhong) were enrolled in the study. After clinical and transthoracic echocardiographic (TTE) assessment for eligibility, 236 patients were excluded from the study and the other 229 were randomly allocated to either the surgical or transcatheter group (Fig. 1). See details in the [Online Appendix](#).

Echocardiography. A comprehensive TTE study, which included M-mode, 2-dimensional, continuous-wave, pulsed-wave, and color-flow Doppler echocardiography, was performed prior to operation or intervention and at each follow-up visit (Fig. 2) (see [Online Videos 1, 2, 3, and 4](#) of echocardiography screening and follow-up of transcatheter pmVSD closure). See details in the [Online Appendix](#).

Catheterization. Each patient underwent catheterization before surgery or transcatheter intervention. Catheterization was done in the catheterization laboratory with the patients under conscious sedation and local anesthesia. Hemodynamic parameters, including pulmonary arterial, aortic, atrial, and ventricular pressures, were recorded, and oximetric values were measured in the cardiac chambers and vessels, based on which pulmonary-to-systemic flow ratio (Qp/Qs) was calculated.

Occluding device. The Shanghai pmVSD occluder (Lepu Medical Technology Co., Ltd., Beijing, China) (Fig. 3) was used in this study (11,15). See details in the [Online Appendix](#).

Transcatheter device implantation. Transcatheter intervention was described in previous reports (15,16) (see [Online Videos 5, 6, 7, 8, 9, 10, 11, and 12](#) of transcatheter pmVSD closure of different kinds of pmVSD). See details in the [Online Appendix](#).

Surgical procedure. The surgical closure was performed with the patient under general anesthesia the second day after catheterization. The chest was opened through a standard median sternotomy. Depending on the size of the pmVSD, direct-suture, Dacron, or pericardium patch was used to repair the defect. All patients were transferred to the intensive care unit for further treatment. See details in the [Online Appendix](#).

Follow-up protocol. All patients were followed up for 2 years. Each patient underwent serial follow-up at 3 days, 3 months, 6 months, 1 year, and 2 years following intervention or surgery. See details in the [Online Appendix](#).

Laboratory tests. The biochemical assays included measurement of levels of aspartate aminotransferase (AST), alanine aminotransferase (ALT), blood urea nitrogen (BUN), creatinine, cardiac troponin I (cTnI), and creatine kinase-MB (CK-MB) at the induction of anesthesia and 1, 3, 6, 12, 24, and 72 h after pmVSD occluder deployment/aorta cross-clamp removal. See details in the [Online Appendix](#).

Statistical analysis. See details in the [Online Appendix](#).

Results

Trial profile. The sample size needed for this study was calculated, assuming the largest difference between treatment groups. With a significance level of 0.05 and a power of 80%, we calculated the needed number of events to be 35 in each group. We also determined that a minimum of 43 patients in each group was necessary to conduct the present study.

The patients were followed up until June 2012, with a median follow-up of 2 years (2 to 40 months). During this period, 29 patients withdrew from the study. A total of 101 patients in the transcatheter group and 99 patients in the surgery group completed follow-up examinations. The trial profile is shown in [Figure 1](#). The 2 groups were well matched for baseline characteristics ([Table 1](#)).

Baseline characteristics. The 2 groups had comparable baseline characteristics ([Table 1](#)) with regard to age, sex, weight, clinical manifestations, echocardiographic data, and invasive data. Twenty-five patients in the surgery group and 28 in the transcatheter group had Qp/Qs values below 1.5:1. Among them, 17 patients in the surgery group and 21 in the transcatheter group had no left ventricular enlargement (Z-score <+2). These patients were enrolled mainly because they had symptoms such as refractory pneumonia, congestive heart failure, delayed growth, exercise intolerance, frequent colds, or unyielding parental requests. The average age at closure was 5.8 ± 2.4 years and 5.5 ± 2.6 years, respectively ($p = 0.398$). Most patients (56.6% in the surgery group and 65.3% in the transcatheter group; $p = 0.531$) were treated because of hemodynamic changes. The mean defect size was 5.9 ± 5.3 mm and 5.2 ± 6.1 mm in the surgical and transcatheter groups, respectively ($p = 0.866$).

Transcatheter versus surgical treatment. The operative characteristics and outcomes in patients according to treatment are summarized in [Table 1](#). In both groups, no mortality, stroke, or neurological deficit was observed. According to ventriculographic examination of the left ventricle, pmVSD was classified as tubular ($n = 24$), window-like ($n = 5$), aneurysmal ($n = 33$), or infundibular ($n = 37$) in the surgery group, a distribution that was comparable to

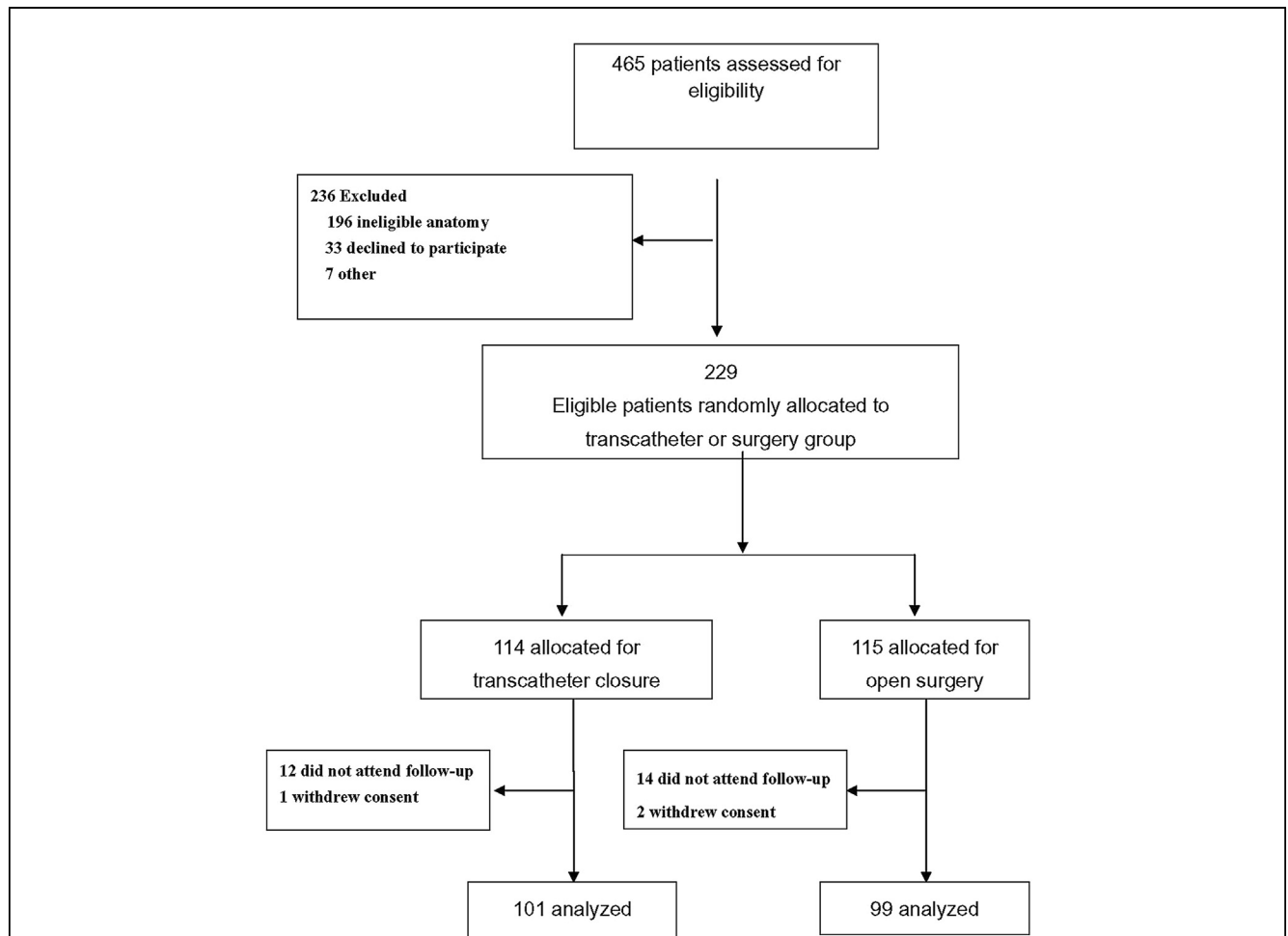


Figure 1 Trial Design and Profile

A total of 465 children with perimembranous ventricular septal defect (pmVSD) were enrolled, and 236 patients were excluded after assessment for eligibility. A total of 229 were randomly allocated to the surgical or transcatheter group, and 29 patients withdrew from the study. A total of 101 patients in the transcatheter group and 99 patients in the surgery group completed follow-up examinations.

that in the transcatheter group. The average procedural time in the surgery group was 180.5 ± 66.1 min, with an average cardiac arrest time of 24.2 ± 15.4 min and an average cardiopulmonary bypass time of 55.1 ± 32.0 min. In the group receiving surgery, 75 patients were repaired with a Dacron or pericardium patch and 24 patients with primary closure. One major adverse event occurred in the surgery group (i.e., bleeding occurred following operation in a 7-year-old girl that required thoracic re-exploration). Several minor adverse events were reported. Blood loss that required blood transfusion occurred in 23 patients. Prior to discharge, 2 patients experienced a residual shunt through the rim of the VSD patch, as demonstrated by color-flow Doppler mapping. Furthermore, 2 patients developed new or increased tricuspid valvular regurgitation <2 grades and were followed without further intervention. Other minor adverse events in the surgery group included 3 right bundle-branch blocks and 1 partial left bundle-branch block (Table 2). Two

patients were found to display a prolonged PR interval (>0.02 s) after surgical closure and before discharge.

In the transcatheter group, device deployment was successful in all patients. The mean defect size measured by TTE was 5.2 ± 6.1 mm, and the mean size of the occluder was 7.4 mm. The Shanghai pmVSD device was used for all patients. The mean fluoroscopy time was 8.2 ± 3.4 min, and the total procedural time was 38.2 ± 24.6 min. A mean of 42.7 ± 6.6 ml of contrast was used. Based on ventriculographic results (12,16), pmVSD was classified as tubular ($n = 27$), window-like ($n = 2$), aneurysmal ($n = 26$), or infundibular ($n = 46$). The transcatheter procedure failed with the first occluder in 3 patients, but a second device was deployed successfully in all of them. No major adverse event was observed in the transcatheter group, and none of the patients required a transfusion as a result of blood loss. There were 7 minor adverse events, including 1 hematoma of the groin, 1 right bundle-branch block, 2 junctional

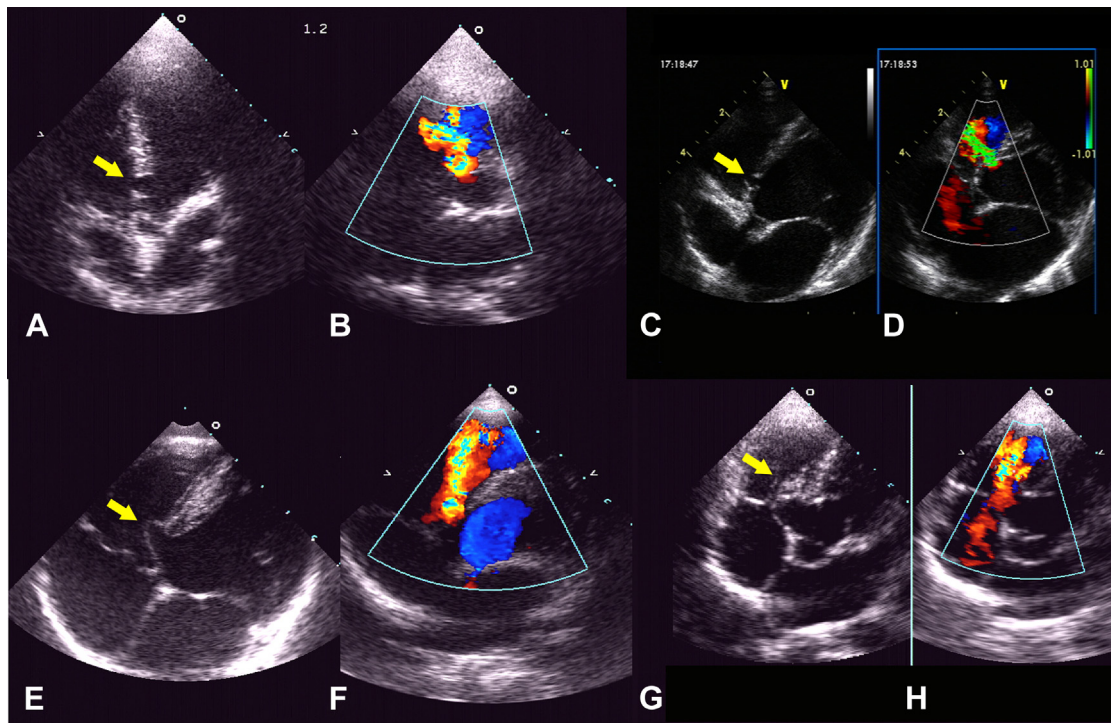


Figure 2 TTE Images Showing 4 Types of pmVSD

(A) Two-dimensional image of a window-shaped perimembranous ventricular septal defect (pmVSD). (B) Color-flow Doppler image showing left-to-right shunt through pmVSD (same patient as in A). (C) Two-dimensional image of a tubular-shaped pmVSD. (D) Color-flow Doppler image showing left-to-right shunt through pmVSD (same patient as in C). (E) Two-dimensional image of an infundibular-shaped pmVSD. (F) Color-flow Doppler image showing left-to-right shunt through pmVSD (same patient as in E). (G) Two-dimensional image of an aneurysmal-shaped pmVSD. (H) Color-flow Doppler image showing left-to-right shunt through pmVSD (same patient as in G). Yellow arrows indicate pmVSD. TTE = transthoracic echocardiography/echocardiographic. See [Online Videos 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12](#).

rhythms, 1 partial left bundle-branch block, 1 residual shunt before discharge, and 1 new case of mild tricuspid valve regurgitation. Five patients had a prolonged PR interval (>0.02 s) following transcatheter closure before discharge, which was not significantly different than that of the surgery group ($p = 0.260$). All of the patients were asymptomatic and did not require further treatment.

Overall, there were 32 minor adverse events in the surgery group (32.3%) and 7 in the transcatheter group (6.9%). The Fisher exact test showed a significant difference in minor adverse events between the 2 groups ($p < 0.001$).

Laboratory data. The levels of ALT in the surgery group began to increase 1 h after removal of the aortic cross-clamp

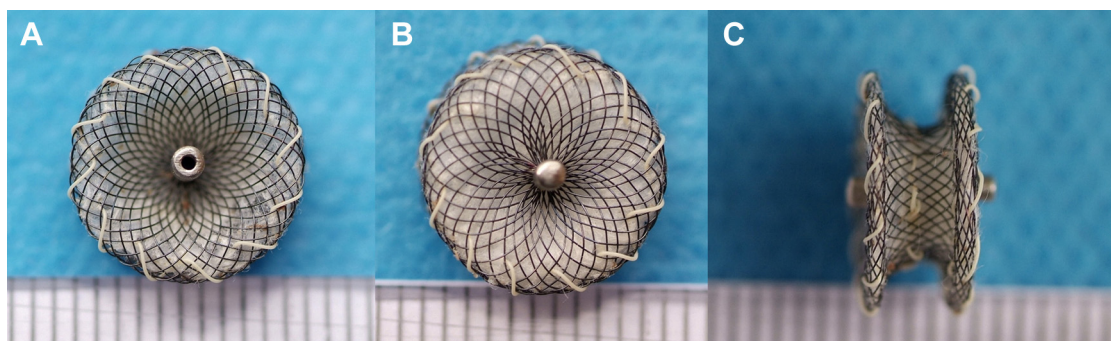


Figure 3 Shanghai pmVSD Occluder

(A) Front view. (B) Back view. (C) Lateral view. pmVSD = perimembranous ventricular septal defect.

Table 1 Baseline Characteristics, Laboratory Data, Procedural Details, and Clinical Outcomes at 2-Year Follow-Up

	Surgery Group	Transcatheter Group	p Value
Sample size	99	101	
Age, yrs	5.8 ± 2.4	5.5 ± 2.6	0.398
Boys	61	50	0.085
Weight, kg	20.5 ± 12.4	22.1 ± 13.8	0.390
Patients with low weight for age	25 (25.3)	28 (27.7)	0.692
Clinical manifestations			
Clinical symptoms	35	28	
Hemodynamic changes	56	66	
Heart murmur with clinical findings	7	6	
Previous IE	1	1	
Echocardiographic data			
Defect size, mm	5.9 ± 5.3	5.2 ± 6.1	0.388
LA dimension, mm	21.5 ± 4.3	20.7 ± 3.8	0.220
LVEDD, mm	54.6 ± 15.3	51.4 ± 16.8	0.161
LVEDD Z-score	+1.8 ± 1.5	+1.7 ± 1.4	0.493
Invasive data			
RA mean pressure, mm Hg	4.8 ± 4.2	5.2 ± 4.7	0.527
RV end-diastolic pressure, mm Hg	7.8 ± 9.3	6.4 ± 12.5	0.371
PA systolic pressure, mm Hg	35.6 ± 11.4	33.6 ± 9.8	0.185
PA diastolic pressure, mm Hg	13.6 ± 4.8	12.8 ± 4.3	0.216
PA mean pressure, mm Hg	19.2 ± 7.4	18.1 ± 6.8	0.275
Qp/Qs	2.3 ± 2.2	2.5 ± 2.7	0.567
Procedural details			
Blood transfusion, ml	213.2 (298.7)	0	<0.001
Patient received transfusion	19	0	<0.001
Procedural duration, min	180.5 ± 66.1	38.2 ± 24.6	<0.001
Hospital stay after intervention, days	7.2 ± 5.7	3.3 ± 1.6	<0.001
ICU stay, h	20.1 (22.6)	0	<0.001
Hospitalization cost, US\$ equivalent	4,846.3 ± 1,628.1	3,550.4 ± 745.9	<0.001
Blood loss, ml	211.6 (197.3)	47.6 (25.8)	<0.001
Time to return to normal activities, days	17.6 (19.3)	3.5 (7.1)	<0.001

Values are n, mean ± SD, or n (%).

ICU = intensive care unit; IE = infective endocarditis; LA = left atrium; LVEDD = left ventricular end-diastolic dimension; PA = pulmonary artery; Qp/Qs = pulmonary-to-systemic flow ratio; RA = right atrium; RV = right ventricular.

and peaked at 24 h. ALT levels in the transcatheter group remained unchanged after the procedure. A comparison of ALT levels between the 2 groups displayed a significant difference at 1 and 24 h following pmVSD closure ($p < 0.01$). The trends of changes in AST levels were the same as those for ALT. There were also significant differences in the AST levels at 1 and 24 h following pmVSD repair ($p < 0.01$). BUN levels in the surgery group rose 1 h after removal of the aortic cross-clamp. The BUN level in the transcatheter group remained constant. There was no significant difference in BUN level alteration between the 2 groups at any time after pmVSD closure. Creatinine levels showed a more significant increase in the surgery group than in the transcatheter group during the 24 h after the procedure ($p < 0.01$) (Fig. 4).

The concentrations of CK-MB and cTnI before intervention were normal in both groups. In the surgery group, CK-MB levels peaked after 24 h, whereas cTnI levels began to rise after aortic clamping and peaked 12 h later. The levels of cTnI did not return to normal even 72 h

after declamping. In the transcatheter group, both the CK-MB and cTnI levels remained unchanged after the deployment of the device. The 0- to 72-h area under the curve of CK-MB and cTnI release was significantly higher in the surgery group than in the transcatheter group (3,415.8 vs. 425.1 and 597.6 vs. 4.7, respectively; $p < 0.001$) (Fig. 5). No hemoglobinuria was detected in either group.

Echocardiography. TTE examination revealed that 97 of the 99 pmVSDs in the surgery group were completely closed 3 days following the operation and before discharge (Fig. 6). Two patients had residual shunts at the rim of the patch, measuring 1 and 1.5 mm by color-flow Doppler mapping. Two patients in the surgery group had mild tricuspid insufficiencies.

In the transcatheter group, a shunt that measured <2 ml by ventriculography through the occluder was noted in 28 of the 101 patients (27.7%). One patient got a residual shunt before discharge, and all shunts diminished at the 3-month follow-up. One patient developed new tricuspid insufficiency

Table 2 Major and Minor Adverse Events Observed in Device Compared With Surgical Closure Groups

	Transcatheter Group (n = 101)	Surgery Group (n = 99)	p Value
Major adverse events	0	1	1
Death	0	0	
Complete atrioventricular block	0	0	
New-onset valvular regurgitation that required surgical repair	0	0	
Thoracic re-exploration	0	1	
Minor adverse events	7	31	<0.001
Hematoma of the groin	1	0	
Blood transfusion because of blood loss	0	23	
Residual shunt before discharge	1	2	
Left bundle-branch block	1	1	
Right bundle-branch block	1	3	
Junctional rhythm	2	0	
New or increased valvular regurgitation <2 grades	1	2	
Total	7	32	<0.001

(3-mm vena contracta by color-flow Doppler mapping). The patient was asymptomatic and was followed closely.

Two-year follow-up and clinical outcomes. All of the 101 patients in the transcatheter group and 99 patients in the

surgery group were followed for a median duration of 2 years. No mortality, neurological deficits, thromboembolism, or endocarditis were reported in either group. All patients displayed New York Heart Association functional class I to II with a normal sinus rhythm. Echocardiographically, the Z-scores of the left ventricular end-diastolic dimension decreased from 1.8 ± 1.5 to 0.8 ± 0.6 in the surgery group ($p < 0.001$) and from 1.7 ± 1.4 to 0.7 ± 0.8 ($p < 0.001$) in the transcatheter group at the 2-year follow-up. Comparison of Z-scores showed no statistical significance between the catheter and surgical groups either before ($p = 0.626$) or after the procedure ($p = 0.319$) (Fig. 7).

In the surgery group, 1 patient with a residual shunt experienced spontaneous pmVSD closure at the 2-year follow-up. Another patient had a small residual VSD shunt (1.5 mm) but was asymptomatic. No further intervention was indicated. The 2 patients with tricuspid valve insufficiency still had mild regurgitation but did not require intervention. Six patients had arrhythmias at the 2-year follow-up, including 4 with right bundle-branch block and 2 with partial left bundle-branch block. In the transcatheter group, all pmVSDs were closed at the 2-year follow-up, which was confirmed echocardiographically by the stable position of the device and the lack of a residual VSD shunt. At the 1-year follow-up, the patient who had a residual shunt

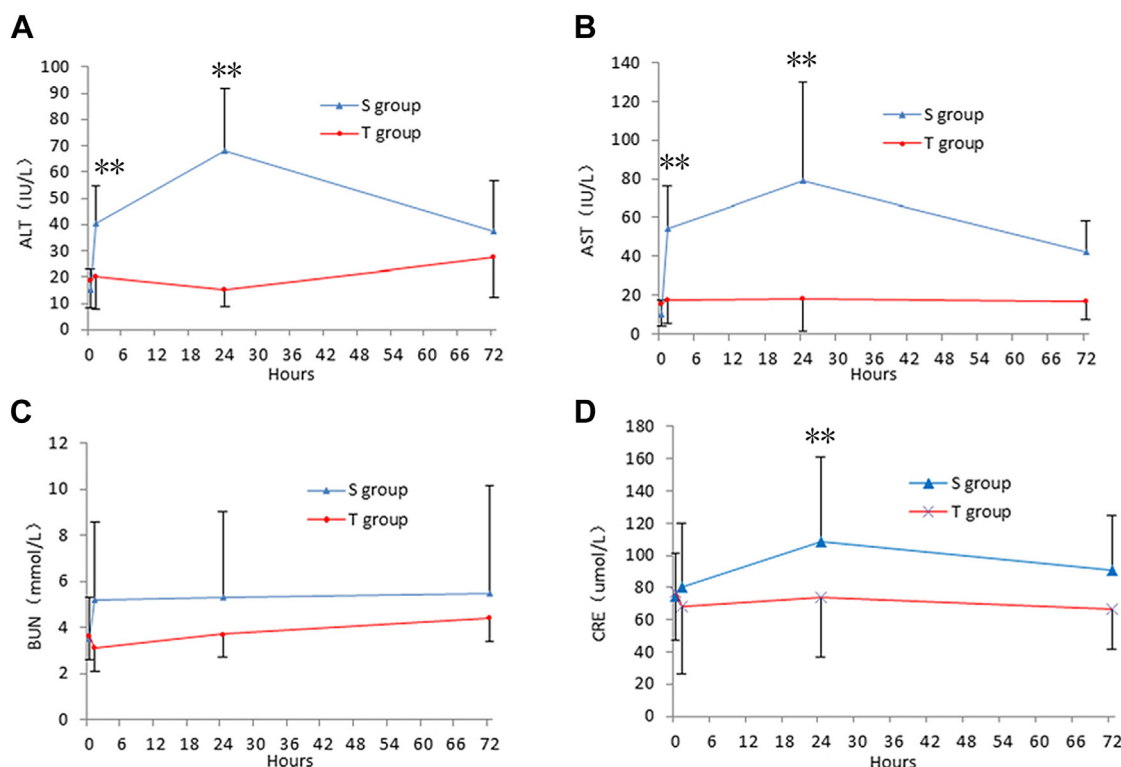


Figure 4 Laboratory Data for the 2 Groups Within 72 h of pmVSD Closure

(A) Alanine aminotransferase (ALT) levels. (B) Aspartate aminotransferase (AST) levels. (C) Blood urea nitrogen (BUN) levels. (D) Creatinine (CRE) levels. Data are presented as mean $\pm$ SD (range bars). ** $p < 0.01$ between the 2 groups. pmVSD = perimembranous ventricular septal defect; S = surgical group; T = transcatheter group.

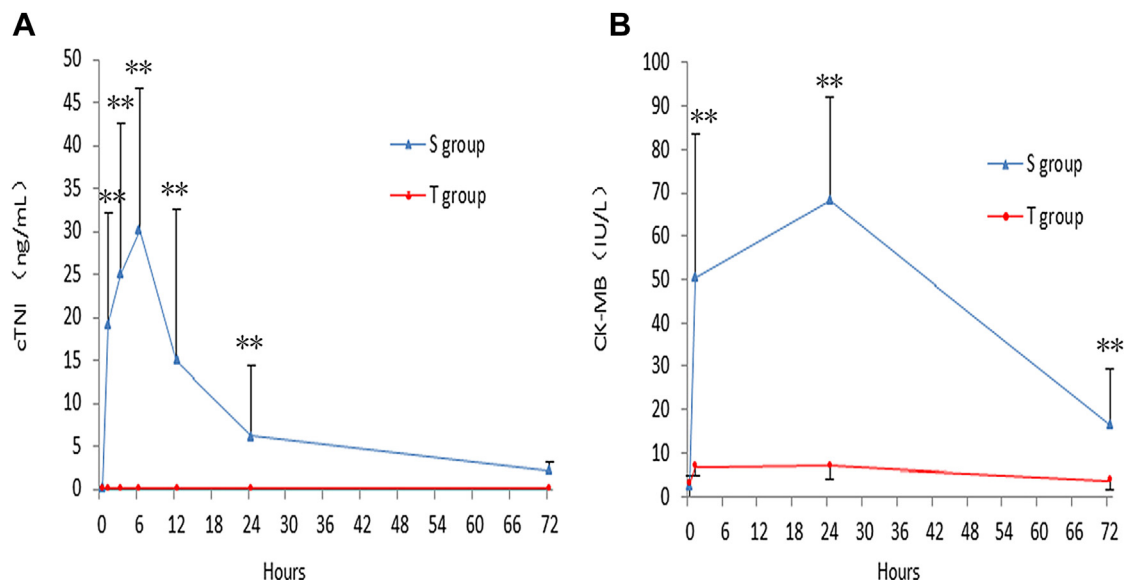


Figure 5 Changes in Myocardial Injury Indexes Between the 2 Groups

(A) Serum cardiac troponin I (cTnI) release during the 72 h following pmVSD repair. (B) Creatine kinase-MB (CK-MB) release during the 72 h following pmVSD repair. Area under the curve (arbitrary units) of serum cTnI release was measured in both groups. Data are presented as mean $\pm$ SD (range bars). ** $p < 0.01$ between the 2 groups. Abbreviations as in Figures 1 and 4.

prior to discharge exhibited no left-to-right shunt across the interventricular septum. Overall, 5 patients had arrhythmias, including 1 with right bundle-branch block, 3 with junctional rhythms (1 additional patient developed junctional rhythm at the 3-month follow-up), and 1 complete left bundle-branch block. The patient with mild post-interventional tricuspid regurgitation was asymptomatic and required no further treatment. During a median follow-up of 2 years, no

differences were observed in the closure rate, adverse events, or complications between the 2 groups.

Discussion

In developing countries, many children with congenital heart disease are waiting to be treated. Among congenital heart diseases, pmVSD is perhaps the most common,

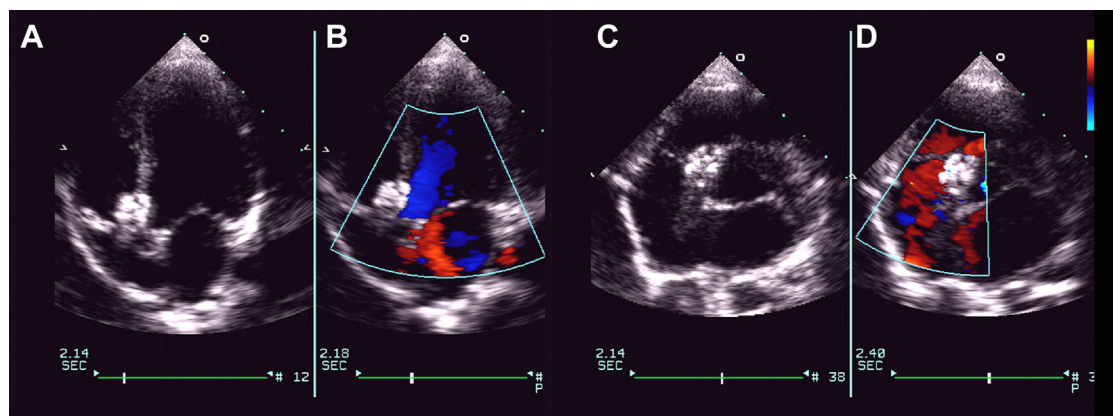
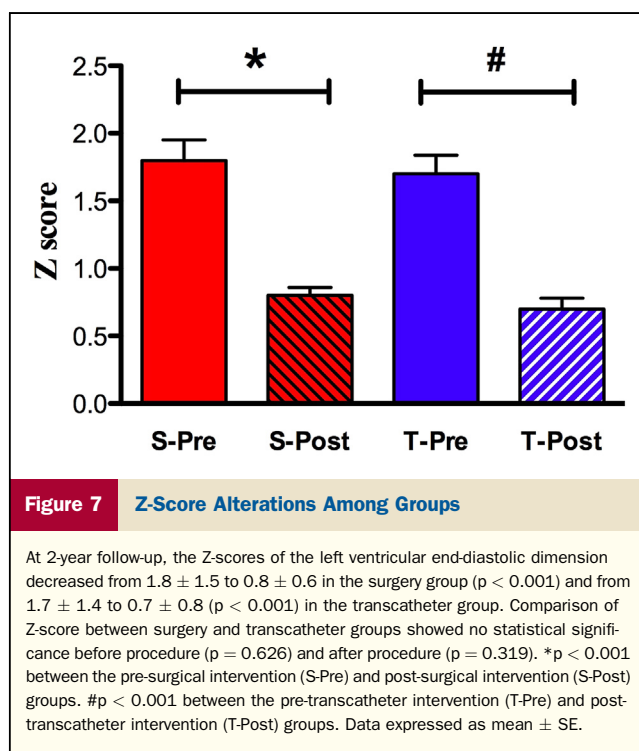


Figure 6 2-Year Echocardiographic Follow-Up Displaying Intact Ventricular Septum Without Residual VSD Shunt in the Transcatheter Group

(A) Two-dimensional, 4-chamber view. (B) Two-dimensional and color-flow Doppler mapping image. (C) Two-dimensional, short-axis view. (D) Two-dimensional and color-flow Doppler mapping. VSD = ventricular septal defect.



accounting for almost one-fifth of all defects. There is an immediate need for an economical, effective, less-invasive technique. In 2002, Hijazi et al. (17) first closed pmVSDs using an Amplatzer membranous VSD occluder. Whether this less-invasive approach may replace open-heart surgery as the treatment of choice is debatable. Over the past decade, the Amplatzer occluder has been proven to be superior to previous devices, such as the Gianturco coils (Cook Inc., Bloomington, Indiana), the Rashkind device (USCI Angiographics, Billerica, Massachusetts), and Sideris immediate release patch (Custom Medical Devices, Athens, Greece) (18–20), in closing congenital heart defects. However, the Amplatzer pmVSD occluder has been associated with a relatively high risk of complete atrioventricular block; consequently, the sponsor voluntarily stopped the U.S. clinical study (5,10,21,22). In recent years, similar devices from China have been adopted in developing countries with good results (23,24). Interest is growing as to whether this new technique can replace traditional open-heart surgery as the “gold standard” for treatment of pmVSD. Therefore, we designed this randomized, controlled trial as a prospective comparison of the 2 treatments for children with pmVSD.

Both transcatheter device closure and surgical repair have achieved excellent midterm results for children with pmVSD. Safety and efficacy are considered in terms of success of the procedure, complications, cost, hospital stay, and time to return to normal activities. There was no mortality or complete atrioventricular block in either group. Minor complications, such as residual shunt, arrhythmia, and valve insufficiency, were minimal in both groups. Our results showed that the Z-score of the left ventricular

end-diastolic dimension of both groups returned to normal at the 2-year follow-up, and compared with open-heart surgical repair, transcatheter device closure possesses several advantages, including no requirement for intensive care unit stay, shorter procedural time, less blood loss, lower medical expenses, and a much faster recovery time (Table 1).

We found that tubular, window, and infundibular types of pmVSD were technically easier to repair using transcatheter intervention and had few complications. Several technical issues were crucial to the overall success of transcatheter pmVSD closure, especially for the aneurysmal type. First, crossing the pmVSD was the most crucial step toward successful transcatheter closure and was especially challenging for the aneurysmal type of pmVSD. In such circumstances, selection of different types of catheters (e.g., right Judkins, 3DRC, or partly-cut pigtail catheter) and different wires may be helpful. Second, for the aneurysmal type of pmVSD, placing the occluder inside the aneurysmal sac at all times was an important step for minimizing heart rhythm disturbances and complications (Online Video 10). In our series, occluders were placed away from the ventricular septum and inside the aneurysmal tissue in 23 of 26 patients with aneurysmal pmVSD. Meanwhile, given that aneurysmal tissues were often adjacent to or even part of the tricuspid valve, caution should be taken when the operator passes the wire and catheter through the tricuspid valve to establish the arteriovenous circuit. Furthermore, detection of new tricuspid regurgitation using TTE was routinely carried out before the occluder was released. Third, selection of the size of the device is important for a successful transcatheter pmVSD intervention. We recommended previously that the relationship between occluder size (y) and pmVSD size (x) as measured by ventriculography was $y = 0.966x + 2.073$, $R^2 = 0.967$ (17). An oversized device (150% over the calculated size) should be avoided to prevent possible complete atrioventricular block and valve impingement. Finally, strict adherence to the inclusion and exclusion criteria for transcatheter pmVSD closure is crucial to the overall success of the intervention. We excluded patients with low body weight (<10 kg) and those younger than age 3 years to ensure higher success rates and fewer complications.

We chose cTnI to evaluate myocardial injury. Although cTnI has been used routinely to assess myocardial injury in open-heart surgery, little information is available regarding the changes in cTnI levels in transcatheter pmVSD closure. The results of our study have contributed to the current literature and indicate the remarkable advantage of transcatheter intervention over surgical repair in preventing myocardial injury. By obviating the need for the ischemia-reperfusion process and diminishing the side effects of cardiopulmonary bypass, the transcatheter closure technique remarkably decreased myocardial injury associated with open surgical repair of pmVSD.

Although our 2-year follow-up study showed excellent midterm outcomes in treating pmVSD in children,

indications for intervention in children are based on clinical, echocardiographic, and catheterization data. We excluded patients who presented with small defects without hemodynamic changes or symptoms due to the possibility of spontaneous closure and good life-long survival. We also excluded patients whose anatomy was not suitable for transcatheter closure. These patients were referred directly for surgical repair. In addition, a Qp/Qs ratio of 1.5:1 to 2.5:1, or evidence of increased left ventricular overload, is an indication for closure. The benefits of avoiding cardiopulmonary bypass, reducing the psychological impact, and offering the less painful and less uncomfortable percutaneous intervention are extremely attractive for both patients and physicians (3,7,25). Recently, clinical trials with the new Amplatzer membranous VSD occluder 2 and Amplatzer duct occluder II device (AGA Medical Corporation, Plymouth, Minnesota) have demonstrated promising results in initial studies (26–28). With more refinement to the devices and new clinical trials for patients with pmVSD, the treatment of choice is likely to be updated frequently.

Study limitations. First, as in our previous study and in accordance with the consensus of Chinese experts (29), we followed strict inclusion/exclusion criteria. Only children >3 years of age were enrolled. Also, because of the design of this study, we only evaluated the results of children <12 years of age; adult patients were excluded. Second, according to the design of the study, patients with small defects without hemodynamic changes or symptoms and patients whose anatomy was not suitable for transcatheter closure were excluded from the current study (i.e., the results of the current study cannot be applied to all kinds of patients with pmVSD). Third, the patients were enrolled from 3 large-volume centers in northwest China and may not be representative with respect to ethnicity and other factors. Last, the number of patients was relatively small, and the 2-year follow-up period was short. Additional data are required to evaluate the 2 procedures longitudinally.

Conclusions

We demonstrated that both transcatheter device closure and surgical repair are effective treatments, with excellent mid-term outcomes, for pmVSD in children who met our inclusion criteria. In our study, compared with surgical repair, transcatheter device closure had fewer myocardial injuries, fewer transfusions, shorter hospital stays, reduced medical costs, and faster recovery times. Therefore, transcatheter device closure is the treatment of choice for pmVSD in children in this cohort.

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- Key Words:** mortality ■ randomized controlled trial ■ surgery ■ transcatheter ■ ventricular septal defect.

APPENDIX

For a supplemental methods section as well as videos and their legends, please see the online version of this article.