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Original Article

A study of clinical implementation of ventricular septal defect closure using three transthoracic approaches

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Abstract: Objective: To investigate the clinical implementation of ventricular septal defect closure using the three transthoracic approaches. Methods: A total of 70 children with septal defects admitted to our hospital from January 2017 to December 2020 were selected as the study subjects. Among them, 10 children with the left thorax-right ventricle-left ventricle approach were assigned to Group A, 8 children with the right thorax-atrium dextrum-right ventricle-left ventricle approach were assigned to Group B, and 52 children with the subxyphoid-right ventricle-left ventricle approach were assigned to Group C. The surgical indices were recorded, the success rates of closure and cardiopulmonary function indices were compared, electrocardiogram (ECG), echocardiogram and X-ray film were investigated at 1, 3 and 12 months after surgery, and the incidence of complications was recorded. Results: There was no statistically significant difference in the success rate of closure among the three groups ($P > 0.05$). The duration of intracardiac operations in Groups A and C was remarkably shorter than that in Group B, and the duration of skin incision and suture and hospital stay in Groups A and B were noticeably shorter than those in Group C ($P < 0.05$). After surgery, there was statistically significant difference in the contents of creatine kinase MB (CK-MB) isoenzyme, lactate dehydrogenase (LDH), serum malondialdehyde (MDA) and superoxide dismutase (SOD) among the three groups ($P > 0.05$). Airway resistance (Raw), oxygenation index (OI), and alveolar-arterial oxygen gradient ($AaDO_2$) indicated that the postoperative pulmonary function in Group C was more effectively protected. There was no statistically significant difference in the incidence of complications among the three groups ($P > 0.05$). Conclusion: Ventricular septal defect closure using the three transthoracic approaches exhibited a high success rate and a high safety profile.

Keywords: Children, ventricular septal defect, closure, transthoracic approaches, minimal invasiveness, echocardiogram

Introduction

Congenital heart disease (CHD) is one of the most common types of birth defect. A previous study suggests that the incidence rate of CHD is about 0.1%, and negative treatment may lead to abortion [1]. Ventricular septal defect (VSD) is a very common CHD. VSD is usually accompanied by abnormalities, which are induced by incomplete ventricular septal development during embryonic period. It is life-threatening, and there is a high surgical risk [2]. Surgery is the only option for treating VSD. The methods for surgical closure include vascular intervention therapy and thoracotomy repair. Among them, thoracotomy repair using the peripheral vascular approach has been widely used in clinical practice [3]. It has been shown that this surgical option exhibits a remarkable therapeutic effect, but it leads to massive trauma and multiple postoperative complications, and a longer hospital stay, hindering the rehabilitation of children [4]. Interventional closure therapy may lead to a small trauma, but cause elevated radiation risks. Therefore, the exploration of a minimally invasive, effective and safe surgical option is of great significance to the life and health of children. With advances in medical minimally invasive and ultrasound techniques, minimally invasive surgery has been extensively implemented in the treatment of VSD [5]. Minimally invasive transthoracic closure is a new therapeutic technique. The transthoracic approaches can close VSD, and eliminate left-to-right shunts at interventricular septum. As a result, the murmur in the precordial

region is eliminated, and growth and development are no longer affected. Recent clinical studies show that minimally invasive transthoracic closure is superior to traditional thoracotomy repair, and can reduce myocardial damage and complications in children [6, 7]. Since short-term follow-ups are performed in most studies instead of long-term follow-ups, some scholars have concerns about the long-term therapeutic effect of this option [8, 9]. Currently, there are few studies on the clinical efficacy using different transthoracic approaches for the treatment of VSD. In this study, a total of 70 children with VSD admitted to our hospital were selected as the study subjects, and the implementation effects and incidence of complications using three transthoracic approaches were analyzed, thereby providing a reference for the formulation of clinical surgical protocol.

Materials and methods

General data

A total of 70 children with VSD admitted to our hospital from January 2017 to December 2020 were selected as the study subjects. Among them, there were 38 males and 32 females aged from 3 months to 10 years, with an average age of (3.12±1.08) years, and 10 children with the left thorax-right ventricle-left ventricle approach were assigned to Group A, while 8 children with the right thorax-atrium dextrum-right ventricle-left ventricle approach were assigned to Group B, and 52 children with the subxyphoid-right ventricle-left ventricle approach were assigned to Group C.

Inclusion and exclusion criteria

Inclusion criteria: (1) aged < 18 years; (2) the diameter of ventricular septum was 3-15 cm; (3) left-to-right shunts; (4) pulmonary artery pressure of < 70 mmHg. This study has been approved by the Ethics Committee of Ganzhou People's Hospital. All patients and their families agreed to participate in the experiment and signed the informed consent form.

Exclusion criteria: (1) cardiac abnormalities; (2) arterial oxygen saturation of < 95%; (3) children with septicaemia; (4) right-to-left shunt was the mainstream; (5) allergic to antiplatelet drugs; (6) severe heart failure; (7) coagulation disorders; (8) severe hepatic and renal dysfunction; (9) lost to follow up.

Methods

Group A: an incision of about 1-2 cm was made beside the left sternum, the pericardium was exposed and suspended, and the two purse-string sutures were made on the surface of the right ventricle with a 5-0 Prolene thread. Under the guidance of the guidewire, the left ventricle was entered through the right ventricle, a disposable conveyer device for conveying ventricular septal occluder was placed, and the occluder was conveyed. After the color Doppler ultrasound of the esophagus showed that the occluder was in good position, the occluder was released. The heart rhythm, atrioventricular conduction, aortic valve function and structure, and residual shunts were inspected. The occluder was installed firmly, released, and observed for 10 min. Abnormalities were not observed, the purse was ligated, the pericardial cavity was flushed, the drainage tube was removed, and sternal closure was performed.

Group B: an incision of about 1-2 cm was set beside the right sternum, the right thoracic cavity was entered, the right half of the pericardium was exposed, the pericardium was cut and suspended, the right atrium was exposed, and the two purse-string sutures were put on the surface of the right atrium with a 5-0 Prolene thread. Under the guidance of the guidewire, the right ventricle was entered through the tricuspid valve, the left ventricular surface was reached through VSD, the occluder was conveyed after establishment of the track, and the occluder was released after the color Doppler ultrasound of the esophagus showed that the occluder was in good position. The heart rhythm, atrioventricular conduction, aortic valve function and structure, and residual shunts were inspected. The occluder was installed firmly, released, and observed for 10 min. Abnormalities were not observed, the purse was ligated, the pericardial cavity was flushed, and sternal closure was performed.

Group C: a subxyphoid incision of about 1-2 cm was made, and the part of sternum was cut off. After the pericardium was suspended, the right ventricle was exposed, and the purse-string sutures were made on the surface of the right ventricle with a 5-0 Prolene thread. Under the guidance of the guidewire, the left ventricle was entered through the right ventricle, a disposable conveyer device for conveying ventricular

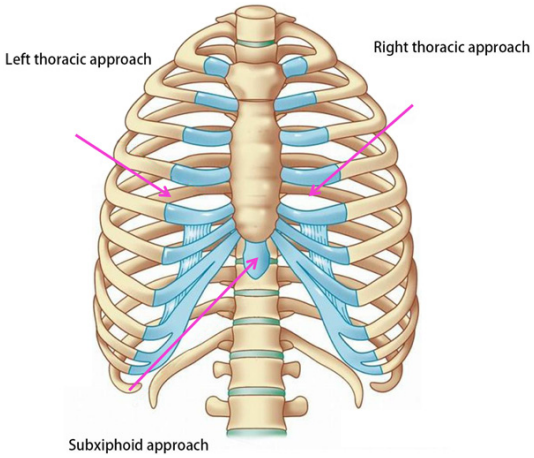

Figure 1. Schematic diagram of the three surgical approaches.

septal occluder was placed, and the occluder was conveyed. After the color Doppler ultrasound of the esophagus showed that the occluder was in good position, the occluder was released. After the drainage tube for pericardium was retained, sternal closure was performed (**Figure 1**).

At 6 h after surgery, aspirin enteric-coated tablets with a dose of 3-5 mg/kg were administrated orally after 24 h. The treatment lasted for 6 months, and all children were followed up for 12 months after surgery.

Observational indices

The surgical indices (*e.g.*, hospital stay and surgical duration) in the three groups were recorded and collected. Electrocardiogram (ECG), echocardiogram and X-ray films were investigated at 1, 6 and 24 months after surgery. The incidence of complications (*e.g.*, postoperative residual shunts, valvular insufficiency, and severe arrhythmia) was recorded, and the success rates of closure were compared among the three groups. The airway resistance (Raw), oxygenation index (OI), and alveolar-arterial oxygen gradient ($AaDO_2$) were measured and recorded before the bypass and 6 h after surgery in the three groups. The arterial blood was collected, and the contents of creatine kinase MB (CK-MB) isoenzyme, lactate dehydrogenase (LDH), serum malondialdehyde (MDA), and superoxide dismutase (SOD) were measured.

Statistical method

SPSS 25.0 was adopted for statistical analysis. The measurement data were expressed by mean ± standard deviation ($\bar{x}$±s), and data conformed to normal distribution were detected using t test. The comparisons among the three groups were detected using the variance test. The enumeration data were expressed by [n (%)], and detected using χ^2 test. $P < 0.05$ indicated a statistically significant difference.

Results

Comparisons of general data among the three groups

In Group A, there were 6 males and 4 females, with an average age of (3.89±1.75) years, an average arterial pressure of (41.95±18.59) mmHg, and a mean interventricular septum diameter of (6.89±1.93) mm. In Group B, there were 4 males and 4 females, with an average age of (3.25±1.46) years, an average arterial pressure of (40.36±16.74) mmHg and a mean interventricular septum diameter of (6.92±1.78) mm. In Group C, there were 28 males and 24 females, with an average age of (3.02±1.26) years, an average arterial pressure of (42.13±20.04) mmHg and a mean interventricular septum diameter of (6.95±2.02) mm. There was no statistically significant difference in the data among the three groups ($P > 0.05$), which were comparable (**Table 1**).

Comparisons of success rates of closure among the three groups

There were 9 cases with successful closure in Group A, with a success rate of 90.00%, 7 cases with successful closure in Group B, with a success rate of 87.50%, and 50 cases with successful closure in Group C, with a success rate of 96.15%. There was no statistically significant difference in the success rate of closure ($P > 0.05$) (**Figure 2**). In Group A, 1 case had tricuspid insufficiency, and the occluder was immediately withdrawn and traditional thoracotomy repair was implemented. In Group B, 2 cases had atrioventricular block, and the condition disappeared immediately after the occluder was withdrawn, and traditional thoracotomy repair was implemented. In Group C, 1 case had the occluder fall off, and the child

Table 1. Comparisons of general data among the three groups

Groups		Group A (n=10)	Group B (n=8)	Group C (n=52)	F/X^2	P
Average age (years)		3.89±1.75	3.25±1.46	3.02±1.26	0.981	0.223
Gender	Male	6	4	28	1.112	0.221
	Female	4	4	24		
Average pulse pressure (mmHg)		41.95±18.59	40.36±16.74	42.13±20.04	0.634	0.565
Ventricular septum diameter (mm)		6.89±1.93	6.92±1.78	6.95±2.02	0.554	0.653

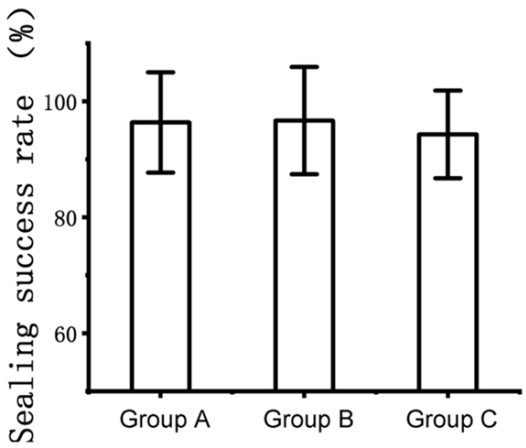

Figure 2. The success rates of sealing in the three groups.

underwent closure. All the children were cured after surgery.

Comparisons of surgical indices among the three groups

The duration of intracardiac operations and skin incision and suture and hospital stay in Groups A, B and C were (10.45±6.38) min, (40.68±16.72) min and (6.01±2.19) d, (16.57±10.84) min, (42.35±16.42) min and (5.34±2.62) d, and (18.76±4.59) min, (52.18 ±20.42) min and (7.32±2.89) d, respectively. The duration of intracardiac operations in Groups A and C was markedly shorter than that in Group B ($P < 0.05$). The duration of skin incision and suture and hospital stay in Groups A and B were significantly shorter than those in Group C ($P < 0.05$) (**Figure 3**).

Comparisons of myocardial damage indices among the three groups

The contents of CK-MB isoenzyme, LDH, serum MDA and SOD in the three groups before surgery were noticeably lower than those after surgery ($P < 0.05$). There was no statistically significant difference in the contents of CK-MB, LDH, MDA and SOD ($P > 0.05$) (**Figures 4** and **5**).

Changes of indices of pulmonary function damage

There was no statistically significant difference in Raw, OI and $AaDO_2$ among the three groups before surgery ($P > 0.05$). At 6 h after surgery, Raw in Group A was remarkably higher than that in Group B. Raw and OI in Group A were significantly higher than those in Group C, while $AaDO_2$ in Group A was markedly lower than that in Group C. Group B had a lower Raw than Group C ($P < 0.05$) (**Table 2**).

Comparisons of incidence of complications among the three groups

There was no statistically significant difference in the incidence rate of arrhythmia, tricuspid regurgitation, residual shunt and aortic regurgitation among the three groups ($P > 0.05$) (**Table 3**).

Postoperative follow-ups

After relevant treatment, the condition of the children disappeared completely at 6 months after follow-ups, and no complications (*e.g.*, valvular regurgitation, arrhythmia, hemolysis and fall-off of occluder) occurred at 24 months after follow-ups. All children survive. **Table 4** shows the postoperative satisfaction of the family relatives of the patients.

Discussion

Surgical repair is a standard surgical option for treatment of VSD, which shows a high success rate of closure and a remarkable efficacy. However, it can lead to massive trauma, a long postoperative recovery, and an obvious cicatrix, hindering the growth and development of children [10]. Additionally, the large VSD diam-

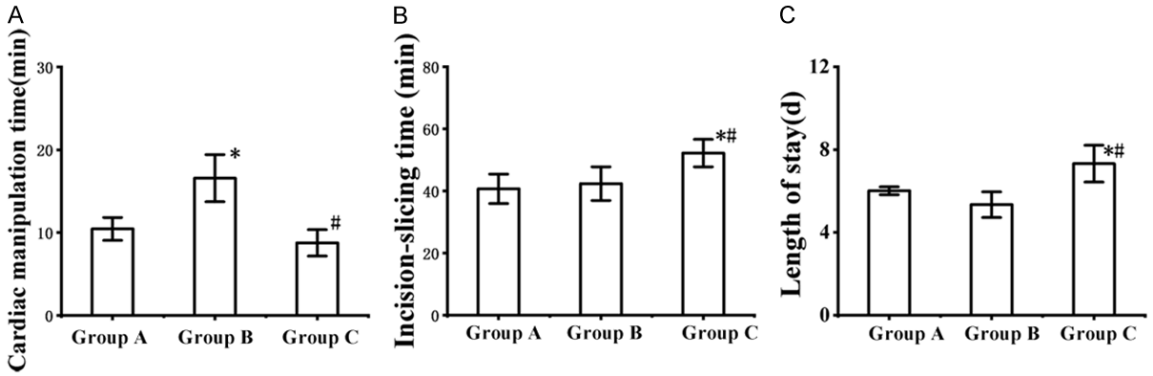

Figure 3. Surgical indices in the three groups. (A) shows the duration of intracardiac operations (min), (B) shows the duration of intracardiac operations (min), and (C) shows the hospital stay in the three groups. Note: * indicates the comparison with Group A ($P < 0.05$). # indicates the comparison with Group B ($P < 0.05$).

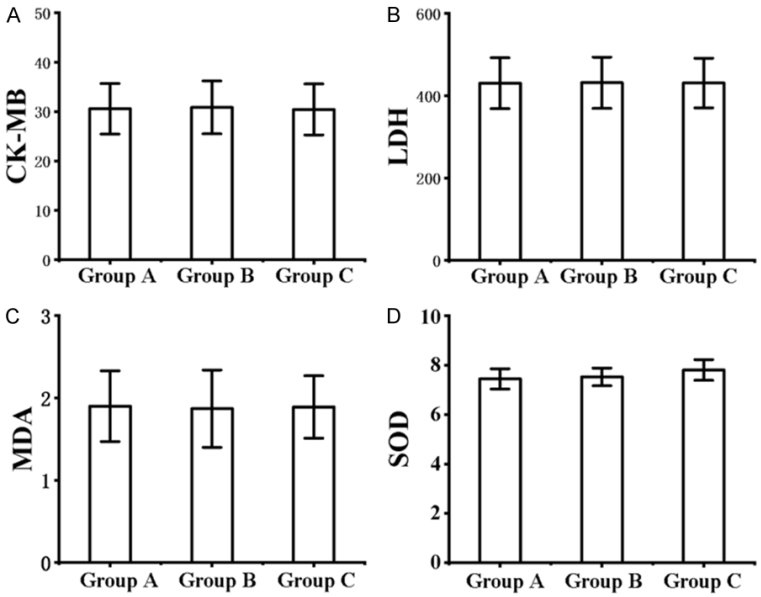

Figure 4. Comparisons of preoperative myocardial damage indices among the three groups. (A) shows the content of CK-MB isoenzyme, (B) shows the content of LDH, and (C) shows the content of serum MDA and (D) shows the content of SOD.

eter of the infants may lead to feeding difficulties, shortness of breath, and relatively slow growth and development, and upper respiratory tract infections often occur, which may result in postoperative complications [11]. A study reported that early completion of VSD repair can facilitate the growth and development of children. Longer surgical duration may increase the incidence rates of cardiovascular diseases and metabolic syndrome, thereby affecting the quality of life of children [12]. Chen et al. [13] compared the repair of septal defect using three surgical options, and the results showed that there were noticeable differences in the clinical treatment between transthoracic closure and thoracotomy, and the specific surgical options should be selected based on the conditions of children.

Transthoracic VSD closure is a surgical option for "small incision" puncture and closure under the guidance of echocardiogram. The transthoracic approaches have been extensively adopted because they are not limited by the inner diameter of blood vessels, resulting in a shorter operational approach and a higher success rate. Liu et al. [14] has reported that echocardiogram-guided transthoracic small incision closure was a safe and effective surgical option. This option can clearly reveal the position of the occluder and VSD in children. The surgical conditions are observed, and appropriate adjustments are made based on the ultrasound results to improve the success rate of closure [15]. Transthoracic VSD closure can avoid sternal exposure, significantly reduce surgical trauma and the risk of complications, and is conducive to postoperative rehabilitation. A small incision has an insignificant effect on aesthetics [16]. A study reveals that transthoracic VSD

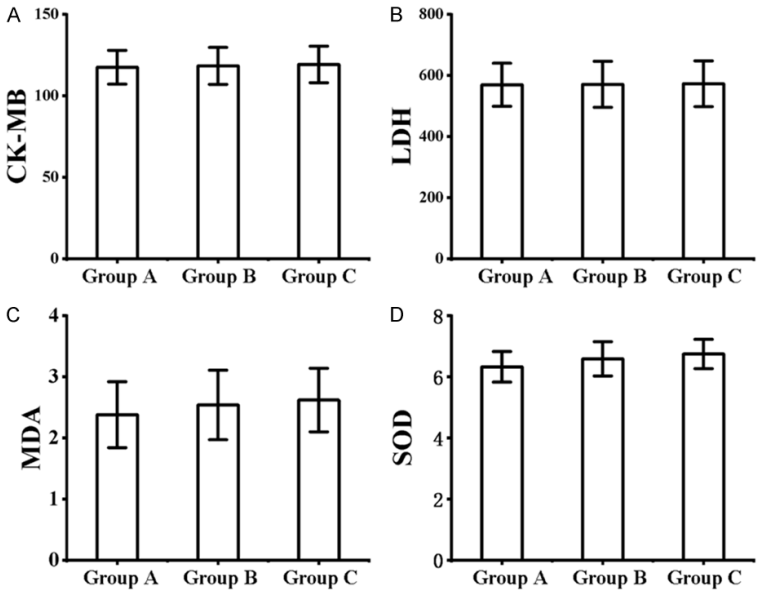

Figure 5. Comparisons of postoperative myocardial damage indices among the three groups. (A) shows the content of CK-MB isoenzyme, (B) shows the content of LDH, and (C) shows the content of serum MDA and (D) shows the content of SOD.

Table 2. Changes of indices of pulmonary function damage before and after surgery

	Group	Raw	OI	$AaDO_2$
Preoperative	Group A	0.35±0.1	53.6±12.5	258.6±50.4
	Group B	0.34±0.11	54.5±13.6	266.8±55.2
	Group C	0.35±0.09	54.9±14.2	265.4±49.8
Postoperatively(6 h)	Group A	0.59±0.16[a]	396.7±66.5[a]	425.3±78.9[a]
	Group B	0.56±0.15[a,b,c]	394.5±67.9[a]	427.6±82.6[a]
	Group C	0.48±0.17[a,b]	390.2±70.8[a,b]	430.5±85.4[a,b]

Note: Airway resistance (Raw), oxygenation index (OI), and alveolar-arterial oxygen gradient ($AaDO_2$). [a]indicates the comparison before and after surgery ($P < 0.05$), [b]indicates the comparison with Group A ($P < 0.05$), and [c]indicates the comparison with Group B ($P < 0.05$).

closure can be used as an alternative to open surgical repair [17]. Transthoracic VSD closure can reduce the trauma and complications associated with traditional thoracotomy, avoid the radiation effects of UI patients treated by vascular intervention therapy, and is not affected by age and weight of children [18]. Transthoracic VSD closure can be performed using three approaches: the left thorax-right ventricle-left ventricle approach, the right thorax-atrium dextrum-right ventricle-left ventricle approach, and the subxyphoid-right ventricle-left ventricle approach. Each of the aforementioned approaches has its own operational adaptability and restrictions in clinical implementation. The left thorax-right ventricular approach has been widely used abroad over these years. Using this approach, the surgery can be performed with only a small incision, which shortens the duration of suture and reduces the damage to the body [19]. When the right ventricle is selected as the puncture point, it is necessary to pull the puncture point to the incision with a pair of small curved forceps, so as to facilitate the surgical operations. When the angle of sheathing canal is significantly lower than 90°, the VSD is small, and the direction of shunts deviates from the puncture direction, it is necessary to fold the head of sheathing canal at 90° to make it easily pass through the VSD. The puncture point using the right thorax-atrium dextrum-right ventricle-left ventricle approach is located in the right atrium. At this time, it is necessary to establish the track using an "S" shaped bougie. This method is relatively complex and requires a long duration of operations. Using this method, the cut-off of the sternum is not required, puncture in the right ventricle can be avoided, and there is a less trauma [20]. This approach is applicable to VSD with a diameter of 4-8 mm and a shunt direction deviating from parietal septum of trictricuspid valve. The subxyphoid-right ventricle-left ventricle approach requires a small incision in the mid-thoracic region, and it has been widely used in previous clinical studies. The approach can be used for various types of VSDs. Using this approach, the coronary arteries can be accurately avoided, and thus facilitate the release of the occluder. Additionally, the occluder with a diameter of 8-15 mm has been widely used for this approach [21]. However, it requires the cut-off of the sternum, leading to a large incision and a long surgical duration, and causing great trau-

Table 3. Comparison of the incidence of complications in the three groups [n (%)]

Group	Arrhythmia	Tricuspid regurgitation	Residual shunt	Aortic regurgitation	Total incidence
Group A (n=10)	1	1	0	1	3 (30.00)
Group B (n=8)	1	1	1	0	3 (37.5)
Group C (n=52)	5	0	3	5	13 (25.00)
F					1.098
P					0.876

Table 4. Comparisons of satisfaction of parents of children with treatment

Group	Cases	Satisfaction	Basically satisfaction	Dissatisfaction	Satisfaction rate
Group A	10	6	3	1	9 (90.00)
Group B	8	5	2	1	7 (87.50)
Group C	52	30	17	5	47 (90.38)
F	-				0.871
P	-				0.334

ma to the body. In addition, this approach may result in intraoperative myocardial damage and epicardium damage. The methods for conveying the occluder include step-by-step method and one-step method. The step-by-step method is used in complex puncture approaches, and one-step method is often used in simple and direct puncture approaches. The intraoperative tools are conducive to closing VSDs [22]. In this study, there was a high success rate of VSD closure using three approaches, and there was no significant difference. The duration of intracardiac operations in Groups A and C was shorter than that in Group B, and the duration of skin incision and suture and hospital stay in Groups A and B were shorter than those in Group C. This signaled that the success rate of VSD closure using three transthoracic approaches was high, and each approach had its own characteristics and advantages.

Thoracotomy inevitably causes friction and contusion to the lungs. The inattention to protect the lung during surgery can lead to pulmonary function damage and complications (*e.g.*, pneumothorax, subcutaneous emphysema, and mediastinal emphesema). In addition to postoperative pulmonary function decline, tissue edema and release of inflammatory factors can cause varying degrees of cardiac and pulmonary function impairment. There was no remarkable difference in the contents of CK-MB, LDH, MDA and SOD ampong the three groups, exhibiting that there was no noticeable difference in the surgery-induced myocardial damage among the three groups. Raw, OI, and $AaDO_2$ indicated that the postoperative pulmonary function in Group C was more effectively protected.

Currently, opinions on the implementation closure using transthoracic approaches vary greatly, which is due to the lack of data pertaining to long-term follow-ups [23, 24]. In this study, there was no significant difference in the incidence rates of arrhythmia, tricuspid regurgitation, residual shunt and aortic regurgitation among the three groups. A total of 70 children were followed up for 24 months, and all of them survive. There were few postoperative complications, no serious complication was observed, and the families of children had a high satisfaction. Using the three transthoracic approaches, Group A had a low incidence rate of complications, and very few complications occurred in Group B. There was no remarkable difference in the incidence rate of postoperative complications among the three groups. The complications were effectively improved after follow-ups. Huang et al. [25] indicated that the results using transthoracic VSD closure were satisfactory, and no additional complications occurred during the follow-ups, exhibiting that this method was safe and effective, which are consistent with the results of this study.

In summary, the left thorax-right ventricle-left ventricle approach, right thorax-atrium dextrum-right ventricle-left ventricle approach, and subxyphoid-right ventricle-left ventricle approach exhibited a high success rate of VSD closure in children. An optimal approach should be selected based on the conditions of children, so as to achieve the optimal efficacy and improve the quality of life of the patients. There are also some limitations in this study. The

included sample size is small, relatively concentrated and the source is relatively single, which may affect the accuracy of the research results and lead to biased results. Therefore, a multi-center study with a larger sample size is planned to conduct in the next step, so as to provide more accurate data to support for clinical practice.

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Disclosure of conflict of interest

None.

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