

Original Article

Applications of transesophageal echocardiography in treating ventricular septal defect with aortic valve prolapse by transthoracic minimally invasive closure

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Abstract: Objective: The aim of this study was to investigate the application methods and values of transesophageal echocardiography (TEE) in treating ventricular septal defect with aortic valve prolapse (VSD-AVP) by transthoracic minimally invasive closure (TMIC). Methods: A total of 34 pediatric patients with congenital heart disease plus VSD-AVP were applied TMIC. TEE was applied intraoperatively to obtain the cross sections of esophageal four-chamber view, five-chamber view, aortic short axis, and left ventricular long axis so as to assess whether TMIC is suitable for VSD, and if suitable, TEE was used to guide surgeons for the surgery. Postoperative TEE was applied to evaluate the closure position, possible residual shunt, and the impacts on the valve. Results: Of the 34 patients, 31 (91.1%) were successfully performed TMIC. The follow-up lasted from 5 months to 2 years, and no complications were found yet. Three cases failed in the early closure phase, so they were transferred to the VSD repair under external circulations. Conclusions: TEE has great effect in preoperative evaluation and intraoperative guidance in TMIC for VSD-AVP.

Keywords: Echocardiography, transesophageal, ventricular septal defect, surgical procedures, minimally invasive, closure device

Introduction

Congenital heart disease (CHD) is one of the most common congenital malformations in children. The incidence of ventricular septal defect (VSD) ranks the first among all types of CHD. If the self-cure is not possible, the surgery is the only method for VSD cure. Open heart surgery under cardiopulmonary bypass is the firstly used method to treat VSD. This method has great trauma and long operation time, and needs blood transfusion, so the postoperative recovery is slow. Percutaneous transcatheter closure of VSD is applied in some countries, but it must be guided by radial line, leading to obvious radiation injury. In addition, due to the limitation of vascular condition and defect location, it has not been extensively used in many patients [1-4]. Transesophageal echocardiography (TEE) guided transthoracic minimally invasive closure (TMIC) is a new technique for VSD. In this method, one small incision with 1-2 cm length is made on the chest wall. The heart can

be directly seen. The puncturing is performed from the heart surface. After establishing a track, the special delivery device is placed to close the VSD. This technique has advantages of little trauma, short operation time and wide indication.

Currently, TEE-guided TMIC toward CHD has been carried out more and more widely in the world, and closure technologies toward conventional perimembranous VSD have become more and more mature [5-11]. Minimally invasive closure toward high VSD in such locations as interior crista, superior crista, and inferior brain stem also has accumulated more experience. However, TMIC toward VSD with aortic valve prolapse (VSD-AVP) has always existed some controversies. The focus of dispute is mainly the stability of closure device and the possible aortic complications. Our center had performed TEE-guided TMIC toward 34 cases of VSD-AVP from February 2013 to May 2015, and this study summarizes the application experience.

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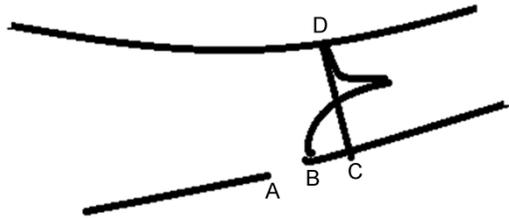


Figure 1. Measuring the basal size of VSD-AVP in the TEE-left ventricular long-axis view. A: Ventricular septal crista side of VSD; B: Aortic valve side of VSD; D: Left coronary aortic valve root; DC: Vertical perpendicular to aortic wall; AB: Shunt diameter of VSD; BC: Depth of aortic valve prolapse.

Materials and methods

General information

A total of 34 pediatric patients admitted into our center for CHD combined with VSD-AVP were applied TMIC from February 2013 to May 2015, aging 3 months -8 years old, weighing 7-25 kg, average weight 10.6 ± 3.33 kg, including 23 males and 11 females. The defect locations included: 7 inferior-crista cases, with the basal size of left VSD, measured by TEE, as 5-10 mm, and the shunt opening size of right ventricular surface as 1.7-3.5 mm; 7 interior-crista cases, with the basal size of left VSD as 4-12 mm and the shunt opening size of right ventricular surface as 2-8 mm; 14 superior-crista cases, with the basal size of left VSD as 4-11 mm and the shunt opening size of right ventricular surface as 2-8 mm; and 6 inferior-brain stem cases, with the basal size of left VSD as 6-10 mm and the shunt opening size of right ventricular surface as 2-7 mm. TMIC was performed via one 2-3 cm incision in the superior sternal segment so as to facilitate extending the incision for intraoperatively transferring to direct open heart surgery for the patients failed TMIC. This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Ethics Committee of Dalian Medical University. Written informed consent was obtained from all participants.

Instrument

Instrument: Philips iE Elite-type ultrasonic diagnostic apparatus (Philips, Amsterdam, Netherlands), with the probe as S7-3T esophagus probe and the frequency as 3~7 MHz.

Anesthesia and pre-scanning instrument adjustment

After performed general anesthesia via intravenous injection plus inhalation, as well as endotracheal intubation, each patient was placed the conventional esophageal probe to a suitable depth according to the individual conditions. Clear echo images should be obtained satisfactorily through adjusting the gain and amplification degrees before the scanning. The focus was placed on the defect area, and dual-screen was conventionally used so as to simultaneously display the 2D and color Doppler sonographs of different cross sections to facilitate the operations.

VSD scanning

The four-chamber view, five-chamber view, aortic short axis view, and left ventricular long axis view were sequentially scanned conventionally, among which the left ventricular long axis view is the most common section used for guiding TMIC for VSD-AVP.

Measurement of defect size and selection of closure device

Multi-section scanning was performed so as to comprehensively understand the overall single value decomposition (SVD) shape, AVP extent, and inferior-VSD ventricular-septal thickness, as well as whether poor para position existed or not. As for the patients with right coronary valve prolapse, one line perpendicular to the anterior aortic wall should be drawn from the non-prolapsed coronary valve leaflet root, and its intersection with the right aortic wall was the real VSD edge (**Figure 1**). Normally, the clear image of the left shunt opening can be obtained firstly, after that, the probe can be slowly advanced or pulled around the defect, slightly left or right-turned, as well as adjusting the wafer angles, to display the cross sections of long and short axes, so the size, walking, adjacent relationships, and ventricle-septum-crista thickness of SVD can be obtained. Meanwhile, the difficulties of establishing the track from the right ventricle to the left ventricle side should be determined according to the shunt directions. If the shunt opening on the right defected ventricular surface was small, the surgeons should prepare hard bougie to facilitate the import of guide wire. After all the VSD data were accu-

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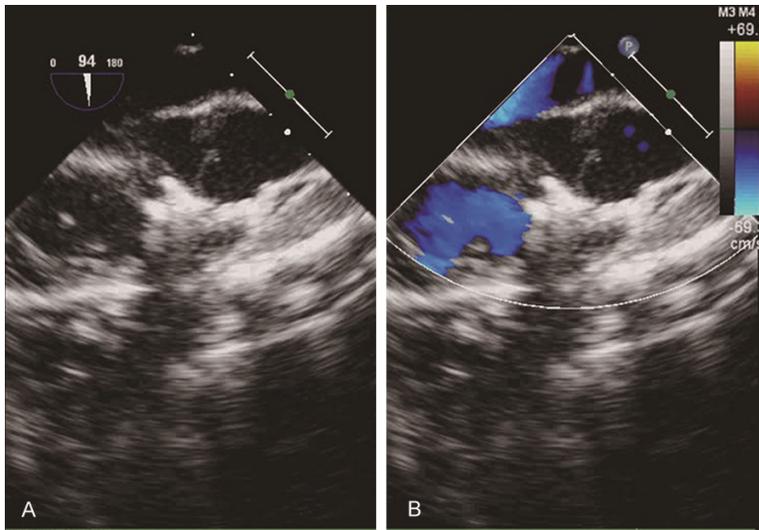


Figure 2. Symmetric occluder used for TMIC for VSD-AVP.

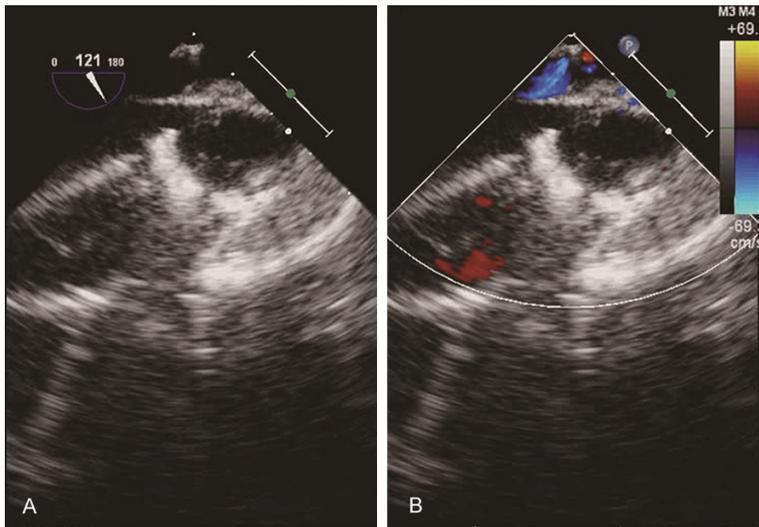


Figure 3. Eccentric occluder used for TMIC for VSD-AVP.

rately obtained from the clear sections, certain closure device can be selected following the principle of individualization, which was not limited to the eccentric type, and the symmetric occluder can also be used for this type of VSD (Figures 2, 3).

Intraoperative installation guidance and real-time monitoring of occluder

Firstly, the surgeon was guided to select the appropriate right ventricular puncture site, which still needed to be co-determined by the short-axis, long-axis, and four-chamber view sections. The puncture point should be facing

the shunt bundles as much positively as possible so as to facilitate guiding the guide wire into the shunt opening. Generally, the left ventricular long-axis view was selected as the guiding section for VSD-AVP because this view can clearly display the aortic valve, thus avoiding injuries as much as possible. One 16 G trocar was inserted into the puncture site so as to guide one 0.035-inch soft guide wire; the probe was then adjusted to clearly display the guide wire and guide the surgeon to pass the wire through VSD and enter the left ventricular cavity. At the same time, the position of the guide wire tip should be paid attention to in order to avoid perforating the tricuspid and aortic valve. After fixing the guide wire inside the left ventricle, the needle sheath was pulled out, and along the in vitro end of the guide wire, the expansion sheath and the delivery sheath were sent into until reaching the left ventricular cavity via VSD to establish a transportation track, and the hollow delivery sheath should be inside the left ventricle in TEE. At this time, the relationships between the position of the sheath tip with the mitral and aortic valves

should be paid attention to, which must be ensured to reach the left ventricle instead of the left atrium or the ascending aorta before delivering the closure device. Meanwhile, any occluder disk planes should be avoided being released in the left atrium or the ascending aorta. The occluder was then pushed into under the real-time monitoring of TEE; after releasing the left disk, the delivery sheath was withdrawn so as to make the left disk gently adhere the left ventricular septal surface tightly. If the eccentric occluder was required, the “mark” position should be adjusted, and the delivery sheath should be rotated so as to allow the “mark” leaving away from the aortic

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Table 1. Measurement and assessment of VSD performed by TEE toward the 34 patients

VSD type	n	Basal diameter of left VSD (mm)	Shunt opening diameter of right ventricular surface (mm)
Inferior-crista	7	5.5-9.5	1.9-3.5
Interior-crista	7	3.8-11.6	2.0-8.0
Superior-crista	14	4.2-11.3	2.2-7.5
Inferior brain stem	6	6.0-10.3	2.5-7.3

valve toward the apex. The atrioventricular valve activities, as well as whether the surrounding tissues were entrapped, were then carefully examined. At this time, because the prolapsed aortic valve was pushed up by the occluder, the shunt opening might be increased than before, the release of the left disk may cause significant residual shunt, and if the occluder was selected appropriately, the residual shunt will disappear gradually after the right disk was released. Therefore, it can be determined after the right disk was released. If no abnormalities appeared after the release of the left disk, the sheath can be gently withdrawn, and then released the occluder waist and right disk, making the right disk adhere the right ventricular septal surface tightly. At this time point, multi-TEE sections can be used to observe the position and shape of the occluder. The occluder can then be tested pulling and pushing repeatedly, and if the occluder location was fixed, with good plasticity and normal heart rhythm while without residual shunt and valvular regurgitation, the closure device can be released, followed by withdrawing the transportation device.

Postoperative follow-up

TEE was also used in the postoperative follow-up, focusing on the opening and closing events, as well as the reflux, of each valve, occluder position, shaping, etc.

Results

Intraoperative assessment of VSD

Intraoperative measurement and assessment of VSD were performed by TEE toward the 34 patients. As shown in **Table 1**, 7 cases had infracristal ventricular septal defect (VSD), with diameter of left ventricular defect basal part 5.5-5.9 mm and diameter of right ventricular surface shunt 1.9-3.5 mm; 7 cases had intrac-

ristal VSD, with diameter of left ventricular defect basal part 3.8-11.6 mm and diameter of right ventricular surface shunt 2.0-8.0 mm; 14 cases had supracristal VSD, with diameter of left ventricular defect basal part 4.2-11.3 mm and diameter of right ventricular surface shunt 2.2-7.5 mm; 6 cases had subpulmonic VSD, with diameter of left ventricular defect basal part 6.0-10.3 mm and diameter of right ventricular surface shunt 2.5-7.3 mm.

TEE-guided VSD closure

31 patients were performed successful closure (91.1%, 31/34), and immediately evaluated intraoperatively by TEE: the push-pull test confirmed that the occluder was reliably fixed, with good shaping while no residual shunt; the aortic valve's opening and closing events were good without regurgitation; the left and right ventricular outflow tract showed no accelerated bloodstream and no thrombosis. In the earlier stage of this study, 3 cases (8.9%, 3/34) failed the closure, and then transferred to heart surgeries under cardiopulmonary bypass and direct vision. These three cases all used the eccentric occluder, among who two cases (one case with the superior-crista type and one case with the inferior-brain stem type) exhibited residual shunt after the occluder was released, and repeatedly adjusting the occluder also showed no satisfactory results; the open heart surgery confirmed that the actual defect range was bigger than the measured by 2-3 mm. One case with superior-crista type VSD exhibited larger residual shunt and significant aortic regurgitation after the closure, and the open heart surgery confirmed the patient suffered from right coronary valve prolapse combined with coronary valve-free prolapse. Among the 31 patients succeeded the closure, 29 cases used the eccentric occluder (93.5%, 29/31), with the diameter ranging within 4 mm-10 mm; 2 cases used the equilateral occluder (6.5%, 2/31), with the diameter ranging within 6-10 mm.

Postoperative follow-up results

The pediatric patients were orally administrated aspirin 3~5 mg/kg·d for six months after the

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surgery. The postoperative follow-up was performed once every month in the first three months, and then once every three months, to review echocardiography and electrocardiogram. The five-month to 2-year follow-up reviews that no cases with successful closure occur thrombosis, complete atrioventricular block, valvular involvement (tricuspid or aortic regurgitation was significantly increased, poor valve activity), etc., so far, and their heart and lung functions are recovered normal.

Discussion

Due to the close distance of high VSD to the pulmonary artery, as well as the large shunt, the symptoms often appear early. Even if the aortic valve prolapse reduces the shunt opening, and reduces the shunt, once the aortic valve damages occur, the consequences will be worse. Therefore, such VSD should be performed surgical treatment as early as possible. Since TEE-guided TMIC has been widely used, plenty experience has been accumulated, its indications have been expanded, and its long-term efficacies have been affirmed [11-16]. However, on one hand, because VSD-AVP is close to the aortic valve, the closure process may easily lead to valve damages; on the other hand, such defects commonly exhibit bad contraposition, so the occluder's stability may have risks, so it has been considered as the relative contraindication to minimally invasive closure. However, during our clinical work toward these types of patients, we considered it possible to solve these types of defect using minimally invasive closure, so it needs to be discussed and promoted, and the important points lie on the profound understanding of deformity, selection of occluder, and operation skills. The success of this surgery must rely on TEE, which not only requires TEE to assess the VSD situation so as to select the appropriate occluder and guide the whole operation process but also provide such basic information about valvular regurgitation, residual shunt, etc., so it proposes higher demands toward the sonographer.

The profound understanding of VSD by ultrasound doctors is the decisive factor in realizing the closure success in these pediatric children. Preoperative multi-angle and multi-plane repeated measurements and judgments of the VSD size, shape, and its relationships with sur-

rounding valves and tissues should be performed [17-21]. The VSD scanning normally begins from the four-chamber view, which can clearly display the relationships between VSD and tricuspid valve, thus confirming the conditions of adhesion and regurgitation in mitral and tricuspid valves. The probe can also be adjusted upward and downward so as to display the coronary sinus opening and the blood flow. If the coronary sinus opening is widened, and the blood flow is speeded, the left superior vena cava may remain residual possibly. The five-chamber view can well show the relationships of VSD with the aortic valve, AVP, regurgitation, and whether there remains subaortic ventricular septal tissue, so it's the section that must be carefully scanned in high VSD, as well as an important intraoperative guiding section. The aortic short axis view can clearly display the relationships of the defect with anterior ventricular crista and pulmonary arterial valve so as to facilitate observing the aortic valve morphology, as well as the hyperplasia and stenosis in the right ventricular outflow tract. So, it's one of the main sections to judge the conditions of high VSD. The left ventricular long axis view can be used to the most directly observe the relationships of VSD with the right coronary aortic valve, AVP status and extent, and aortic regurgitation, and it's the easiest section to find the residual subaortic ventricular septal organization. Therefore, this section must be carefully scanned before closing VSD-AVP, and it's also the most common guiding section in the closure. Special notice should be paid not to only concern the four-chamber and five-chamber views which are normally used in perimembranous VSD closure. At this time, the importance of 2D ultrasound should be emphasized due to the strong flow spillover effects in color Doppler, which may mislead the selection of a larger occluder. The results of this study showed that the actual bigger VSD diameter than the measured by ultrasound caused post-occluder release residual shunt was one of the important reasons toward the final abandonment of MIC. In this study, the failure of the three TMIC cases was caused by lacking the knowledge of VSD forms in the early TIMC application stage, so TEE did not exhibit the complete picture of the defects, thus leading to the inappropriate selection of the closures. Therefore, exactly selecting the true edge of VSD has critical importance toward the suc-

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cess of the surgery. In many cases, although the aortic valve prolapses, it's not the real leaflet prolapse, but the sinus valve prolapse still may exist slight septal tissue at the inferior edge of the valve leaf, so the occluder can have one attachment point, and this is the prerequisite for the successful closure in these patients. Because these children often exist poor para position, so the angle formed between the occluder and the septum after it's released is large, it'll easily fall off after released. Therefore, if there is not subaortic septal tissue at all, it's generally not recommended for the closure. The inferior-brain stem type VSD has the highest position, although there is no subaortic septal tissues, there may exist certain attachment point at the subpulmonary aortic valve, so it also has the possibility of success, and it should not be listed as contraindications.

Many high VSDs are not a perfect circle or similar to a perfect circle, and their long and short axes sometimes differ a lot. Furthermore, partial high VSD exist obvious poor para position, together with AVP, so the defected left and right ventricular surface cannot even be shown in the same section. Different patients also have different ventricular septal crista thickness at the lower edge of VSD. Therefore, selecting the appropriate occluder is the key to the success of closure. The selection principle toward selecting the occluder for conventional perimembranous VSD is to increase 1-2 mm, based on the maximum diameter of VSD, as the waist diameter of the occluder, but it's suitable in high VSD-AVP. Once heart surgeons have profound understanding of cardiac anatomies, they also should have full understanding of TEE-displayed VSD forms, and form 3D images in their mind. The selection of occluder must follow the principle of individualization and be based on the age, weight, VSD position and shape, and relationships with surrounding tissues. The selection of occluders should be emphasized the individualization, and changes with different patients. The inferior-crista type VSD is close to the membranous part, and the defected right ventricular surface also has adhesions with the septum, so the occluder can have more attachment points, and the selection of occluders is often small. The interior and superior-crista types of SVD usually select the eccentric occluder [22-24], at which time it needs the only attachment point of the

occluder to be fully force-loaded so as to ensure the stability; therefore, at the patient's own permitted conditions, a larger occluder is often selected. Additionally, such defects do not necessarily need to use the eccentric occluder. In this study, one patient, 12-month boy, exhibited the base of left VSD as 11 mm and the shunt opening as 3 mm, and after repeated observation, one 6mm symmetric occluder was selected, and the closure succeeded. The aortic valve was not injured, and the occluder shaping was good.

The release skills of the occluder are also one important part for the success. In such defects, releasing the left ventricular umbrella plate must embed the umbrella edge into the angle between the aortic valve and the residual ventricular septum, so it will produce better and more table occluder shaping while not affect the left ventricular blood outflow tract. Conventional operations often inserted the transporter deep into the left ventricle, withdrew after released the left ventricular umbrella plate, and then release the right ventricular right umbrella plate when the left firmly bonded with the ventricular septum. However, because the subaortic ventricular septal stump is normally covered by the aortic valve, this operation mode is difficult to insert the umbrella plate under the valve and will easily damage the valve. Our experience is to stop the delivery sheath tip when it just passes the ventricular septum under the TEE monitoring, and try to open the left ventricular umbrella plate in the rear part of the aortic valve, which can directly insert the umbrella plate into the angle of the aortic valve and residual ventricular septum. The success rate of closure can thus be greatly enhanced.

This study summarized the experience of TEE-guided preoperative patient selection and basic operation steps and skills in 34 high VSD-AVP cases. It can be seen from the results that high CSF-AVP is not the contraindication of TIMC. The results also confirmed the important role of TEE in this type of surgeries. As long as the patient screening is accurately performed under the TEE guidance, as well as the occluder is selected appropriately, and the intraoperative guidance is proper, the success rate of closure can be guaranteed. Compared with open heart surgeries with cardiopulmo-

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nary bypass, the risks of this surgery can be reduced greatly, so it's very worthy of promotion. Meanwhile, long-term follow-up should also be actively carried out, particularly the long-term aortic valve situations in such children should be continuously monitored.

Disclosure of conflict of interest

None.

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