Transthoracic echocardiographic guidance of minimally invasive perventricular device closure of perimembranous ventricular septal defect without cardiopulmonary bypass: initial experience

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Background
Our purpose was to investigate the feasibility of transthoracic echocardiographic (TTE) guidance for minimally invasive perventricular device closure of perimembranous ventricular septal defects (VSDs).

Methods
From June 2011 to September 2011, we enrolled 18 young children with perimembranous VSDs to receive minimally invasive device closure in our hospital. All of the patients were examined by TTE to determine the VSD morphology, diameter, and rims. During intra-operative device closure, real-time bedside TTE alone was used to guide device implantation.

Results
Device implantation using TTE guidance was successful in 16 patients. Symmetric devices were used in 14 patients, and asymmetric devices were used in 2 patients. Only one patient experienced mild aortic regurgitation, and there were no instances of residual shunt, significant arrhythmias, thromboembolism, or device displacement. Two patients were transferred to surgical closure, one due to residual shunting and the other as a result of unsuccessful wire penetration of the VSD gap.

Conclusions
Our data indicate that TTE-guided VSD closure is feasible in young children, although a longer follow-up may be needed to document the long-term success.

Keywords
CHD • Septal defects • Cardiac intervention • Echocardiography

Introduction
Echocardiography plays a very important role in the diagnosis and interventional management of ventricular septal defect (VSD). Until recently, transoesophageal echocardiography was considered absolutely necessary for guiding transcatheter or per-ventricular device placement, and, in the absence of reports to the contrary, most physicians have viewed transthoracic echocardiography (TTE) as unsuitable for this purpose. Because TTE also provides an accurate and non-invasive definition of the VSD anatomy using subcostal views in most children, we hypothesized that the subcostal window could provide a suitable alternative for guiding interventional device placement. This initial study assessed the feasibility and efficacy of TTE-guided VSD perventricular device closure.

Methods
Selection of patients
From June 2011 to September 2011, 18 young children with perimembranous VSDs received intra-operative minimally invasive device
closure in our hospital. Written informed consent was obtained from the parents of each child. The patients ranged in age from 2 to 36 months (mean ± standard deviation, 12.0 ± 7.4 months) and weighed from 5.0 to 18 kg (mean = 10.2 ± 3.6 kg). The following special criteria were required for inclusion in the study: (i) perimembranous VSD; (ii) a distance of >2 mm from the rim of the VSD to nearby major cardiac structures, such as aortic and tricuspid and pulmonary valves; and (iii) no aortic regurgitation. Six patients presented with moderate pulmonary hypertension (pulmonary arterial systolic pressure >40 mmHg). All patients had a normal sinus rhythm and normal left ventricular (LV) systolic function, with no additional congenital lesions.

**Echocardiography**

VSD anatomy was evaluated by TTE using a Philips iE33 (Philips Medical System, Andover, MA, USA) or a GE Vivid 7 (GE Medical Systems, Milwaukee, WI, USA) imaging system. The VSD position and size were assessed using standard subcostal, apical, and parasternal views. TTE subcostal views were used mainly for accurate determination of VSD location, morphology, and size (the largest diameter), and rim visualization. Because of variations in the shape of the right ventricular rim of perimembranous VSDs, measurement of the LV rim of the VSD during diastole has been recommended. Our recommendation is to use device closure in patients who weigh >5 kg or have VSDs of <10 mm in diameter, with subaortic rims measuring >2 mm. Patients meeting the above inclusion criteria underwent intra-operative device closure of the VSD under general anaesthesia. Subcostal TTE views of patients in a supine position did not interfere with the surgical field or procedure and were used primarily to guide device placement. The subcostal LV outflow tract view and the right ventricular outflow tract view were used mostly in this situation (Figure 1).

**Device and implantation procedure**

The devices used were self-expanding, double-disc VSD occluders (Lifetech Scientific Co, Ltd of Shenzhen, China). There are two types of occluders, symmetric and asymmetric, that differ in their LV dish style. On the LV side of the asymmetric device, the aortic end of the disc is 1 mm wider than the waist, so as to avoid impinging upon the aortic valve. The other side is 5–6 mm wider than the waist and has a platinum marker to guide device orientation. The symmetric device has a LV disc that is 2 mm larger than the waist. The right ventricular disc is 2 mm larger than the waist in both types of occluders (Figure 2). The size of the occluders is based on the waist diameter, which ranged from 6 to 14 mm in 1-mm increments (Table 1).

Under general anaesthesia, patients received a probe placed below the xiphoid process to guide the whole procedure. The size of the occluder was determined on the basis of the maximal measured diameter by TTE plus 1–2 mm. An incision of 2–3 cm in length was made in the lower sternum to expose the right ventricle, and heparin (1 mg/kg) was then administered. The location of the puncture was determined by protruding the right ventricle towards the VSD guided by TTE. The right ventricular-free wall was punctured using a trocar, and then a floppy guide wire was inserted and advanced to cross the VSD into the left ventricle (Figure 3). An appropriately sized delivery sheath was advanced along the wire into the left ventricle (Figure 4), and TTE subcostal views were used to make sure the wire and sheath were directed through the VSD into the left ventricle. The VSD occluder was screwed into the delivery cable, and the device was loaded and introduced into the delivery sheath and then advanced to the tip of the sheath. Before release, TTE subcostal views were used to evaluate the device position

![Figure 1](https://academic.oup.com/ehjcimaging/article-abstract/13/9/739/2397255)

(A) Subcostal left ventricular outflow tract view. (B) Subcostal right ventricular outflow tract view.

![Figure 2](https://academic.oup.com/ehjcimaging/article-abstract/13/9/739/2397255)

The asymmetric device, the symmetric device, and the entire delivery system.
The position of occluder discs and potential impingement of the device on adjacent cardiac structures were evaluated. Colour Doppler assessment of residual shunting, aortic regurgitation, and atrioventricular valve function were also assessed (Figure 6). The asymmetric device was implanted by using a gentle rotation to position the platinum marker of the distal disc downwards and ensure that the flat part of the disc was not directly under the aortic valve. The waist and the right disc of the occluding device were deployed while maintaining moderate traction on the delivery cable (Figure 7). The occluder device was released only if the echocardiogram demonstrated a correct position with no evidence of significant residual shunting, cardiac valve malfunction, or outflow tract obstruction. The sheath and delivery cable were then withdrawn with the suture tied firmly. All patients underwent echocardiographic examination before discharge from the hospital and at follow-up visits.12,13

Table 1  Clinical data of patients undergoing intra-operative device closure of perimembranous VSD

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Figure 3  (A) Subcostal left ventricular outflow tract view shows the perimembranous VSD. (B) A floppy guide wire was advanced through the VSD into the left ventricle.

(Statistical analysis) Values were expressed as mean ± standard deviation. Student’s t-test was used for the comparison of quantitative variables; statistical significance was set at P < 0.05.

Results
Successful device closure was achieved in 16 patients. One patient developed a residual shunt, and Doppler analysis indicated that the velocity across this shunt was over 300 cm/s. This patient was transferred to surgical closure. One other patient with an aneurysmatic formation was transferred to surgical closure due to an unsuccessful floppy wire insertion across the defect. The only
Additional issue arising during device implantation was the identification of moderate aortic regurgitation in one patient. The aortic regurgitation disappeared after removing the symmetric occluder and replacing it with an asymmetric device. Symmetric devices were used in 14 patients, and asymmetric devices were used in two patients.

**Figure 4** (A) The sheath was advanced along the wire through the VSD into the left ventricle. (B) The delivery cable was advanced through the VSD into the left ventricle, with the floppy guide wire withdrawn.

**Figure 5** (A) The final image shows a symmetric deployed device near the aortic valve. (B) Colour Doppler imaging shows trivial aortic regurgitation after VSD closure.

**Figure 6** (A) The floppy wire was advanced through the VSD towards left ventricular outflow tract into the aorta. (B) A symmetric VSD occluder was successfully released and deployed in the right position.
Minor complications were encountered in two patients. These included transient arrhythmia in the course of device implantation in one patient and mild aortic regurgitation in another patient. There were no episodes of cardiac block, thromboembolism, or device displacement in the post-hospitalization follow-up period. The closure rate remained 100% over the follow-up period, no residual shunting occurred, and none of the patients in our group developed complete heart block. All patients were extubated within 12 h and were discharged within ~1 week of the operation.

Discussion

Our study demonstrated that TTE may be employed for the definitive assessment of perimembranous VSDs, the selection of patients eligible for device closure, and the guidance of intra-operative placement of periventricular devices in young children. Because of the relatively clear definition of the perimembranous VSD anatomy in young children, especially in infants, subcostal views are practicable for guiding the placement of periventricular devices.

A comparison of patients in our study with those who underwent TEE-guided device closure in our centre shows statistically similar results in the mean defect size (6.5 vs. 7.0 mm, respectively, \(P = 0.13\)), the mean device size (8.1 vs. 8.2 mm, respectively, \(P = 0.12\)), and the procedure success rate (89 vs. 86.7%, \(P = 0.28\)). However, patients in the TTE-guided group had lower average body weights (10.2 vs. 22.8 kg, respectively, \(P < 0.05\)), were younger (12 vs. 78 months of age, respectively, \(P < 0.05\)), and had slightly shorter operation times (45 vs. 48.3 min, respectively, \(P < 0.05\)).

TEE is superior to any other method for the measurement of rims and localization of the perimembranous VSD. In young children, TTE is also able to clearly reveal the anatomy of perimembranous VSDs. Because morphological variations of VSDs are common, we chose patients with single perimembranous VSDs or with aneurysmatic formations for intra-operative device closure. In our experience, an aortic rim deficiency is considered a risk factor for unsuccessful closure and a significant predictor for residual leakage,\(^1\) and patients with aortic regurgitation were not included in this study. We included only patients with aortic rims of at least 2 mm, due to the major concern that only trivial or mild aortic regurgitation is acceptable after the device closure procedure. Fortunately, the majority of perimembranous VSD patients in our study had sufficient aortic rim measurements, and symmetric devices were mainly applied in these circumstances. This minimal aortic rim length is crucial for the safe and stable positioning of the device and to prevent the device from impinging upon the aortic valve. When aortic regurgitation does occur, we recommend either the use of an asymmetric device or transfer of the patient to a surgical procedure.

TEE is considered the best choice for all types of patients undergoing periventricular device placement, because it offers a clear view of cardiac structures.\(^{14,15}\) The resolution and quality of TTE images are not as good as those of TEE, but echo examination under general anaesthesia in young children or infants usually produces very good quality images, which determine the accuracy of examination results and the suitability for guiding VSD closure procedures. As with TEE, the use of TTE guidance is aimed at resolving problems related to VSD closure. Currently, there are no literature reports on the use of TTE alone to guide intra-operative periventricular VSD device closure, and doubts about the suitability of the procedure may arise among the various members of an operating team. A sense of trust and cooperation between members of the operating team—including surgeon, anaesthetist, and echocardiographer—is required to perform the procedure smoothly. TTE-guided perimembranous VSD closure should only be performed by experienced surgeons and echocardiographers. In recent years, we have performed ~200 cases of TEE-guided VSD closure in our centre, and it is with this extensive experience that we decided to use TTE subcostal views to guide the procedure, as an alternative option in young children. The young children in this study were selected because they had very good acoustic windows, and the majority of our patients are young children with perimembranous VSDs. Transthoracic device closure of VSDs without cardiopulmonary bypass is reported to be safe and feasible for younger children.\(^{16–18}\) Our intention was not to raise concerns about the
reliability and importance of TEE, and we may continue to use TEE as before to guide VSD device closure. At the time of this study, we were having problems with our TEE probe, but we are not intending to use TEE to completely substitute for TEE. We chose the ‘suitable’ type of perimembranous VSD for device closure guided by TTE alone, as we knew this type of VSD was more amenable to device implantation. Our initial study shows that TTE by subcostal views may also offer a feasible method for guiding the placement of VSD devices. This initial result was inspiring, even though it was applied only to perimembranous VSDs. We hope this may be a first step in routinely performing VSD closure under TTE guidance alone in selective patients.

Compared with TEE, TTE has several disadvantages as a method for guiding device closure of VSDs. First, the location of the surgical field just at the lower sternum is a little inconvenient, making it difficult for the echocardiographer to hold the probe in a fixed location. Fortunately, we could clearly show most primary structures from the right/left inflow to outflow tract from the subcostal views. Usually subcostal views are desirable in young children, although sometimes an apical four-chamber view can also be used to find a reflection echo of the wire and sheath, and by tilting the probe we could trace the echo of the wire even if the wire was heading towards the right atrium or pulmonary artery during the procedure. Secondly, the problem of contamination must be emphasized. Because the subcostal windows are closely adjacent to the surgical sterilized area, we used a germ-free sheath to cover the probe. Thirdly, because most echocardiographers are not well acquainted with subcostal views, some doubts or problems may arise regarding the evaluation of residual shunting or aortic regurgitation. It is actually a somewhat meticulous and challenging task for the echocardiographer to hold the probe steadily in this setting.

TEE remains the first-choice method for guiding VSD device closure. The use of TEE in infants may still present some complications that should raise concerns, such as gastro-esophageal injury and respiratory compression. The use of TTE guidance can eliminate such complications, and may expand the application of echocardiography in the operating room or catheter laboratory. As we know, many centers now prefer to use TTE to guide atrial-septal defect closure, and even complex atrial-septal defects can be closed with TTE in patients with good acoustic windows. Because high-quality two-dimensional echocardiographic subcostal views were reliable in the detection and localization of the VSD, we can hope that with increasing experience TTE-guided VSD closure can reduce procedure times and provide increased patient comfort, reducing the need for TEE.

Conclusion

Our initial study shows that TTE subcostal views can be used as an alternative to guide VSD device placement. TTE-guided VSD closure in young children and infants is safe and feasible.

Conflict of interest: none declared.

References