Usefulness of Intraoperative Transesophageal Echocardiography in the Assessment of Surgical Repair of Pediatric Ventricular Septal Defects with Video-Assisted Endoscopic Techniques in Children

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Background: Mini cardiac operative procedures with video-assisted endoscopic techniques for closure of ventricular septal defects (VSDs) in pediatric patients have become quite popular for cardiac surgery. A precise diagnosis is very important for determining the surgical approach, and evaluation by intraoperative transesophageal echocardiography (TEE) plays a major role in confirmation of the preoperative diagnosis, residual defects, and the need to return to the bypass after repair.

Methods: Sixty-five patients (30 boys and 35 girls; aged 8.7 ± 5.3 years) who were undergoing minimally invasive closure of VSDs were monitored with a Hewlett-Packard color Doppler pediatric TEE throughout the procedure.

Results: Closure of the defect was successfully performed in all patients. Sixty-two patients showed neither residual shunt nor aortic regurgitation after the repair. Residual leaks were detected intraoperatively in 3 patients after the repair. One patient required a return to the bypass with an immediate reoperation due to a residual color jet diameter of >3 mm. One patient was changed from video-assisted endoscopic techniques to a surgical approach for closure of the VSD from a conventional median sternotomy after identification by TEE of an outlet-type perimembranous VSD with 2 additional muscular VSDs.

Conclusions: Our study showed that, with refinement of surgical closure of VSD via video-assisted endoscopic techniques, intraoperative TEE provides valuable and accurate information for decision-making in surgical management, provides immediate assessment of surgical repairs, and prevents reintervention and the morbidity associated with residual flow.

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Key words: **ventricular septal defect, transesophageal echocardipgraphy, video-assisted endoscopic technique.**

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Advancements in transducer technology and the continued miniaturization of transesophageal echocardiographic (TEE) probes have led to rapid increases in the use of intraoperative TEE for monitoring and diagnosis of repairs of congenital heart defects.[1] Intraoperative TEE has made contributions to surgical interventions and results by providing surgeons with instant information concerning cardiac structure and function. It is now routinely employed to confirm the preoperative diagnosis, to permit direct evaluation of surgical repair, and to assess operative success.

A median sternotomy is the standard surgical approach for the repair of ventricular septal defects (VSDs).[2] For better cosmetic healing, bilateral submammary skin incisions with a vertical incision of the sternum may be used as an alternative to a midline surgical incision. However, long midline or thoracotomy skin incisions, postoperative pain, poor cosmetic effects, mediastinitis, and osteomyelitis occasionally cause trouble in the repair of VSDs. With advances in video-assisted endoscopic techniques, the use of minimally invasive cardiac surgical techniques might be an alternative approach in the surgical treatment of VSDs.[3,4] Decision-making in the surgical intervention of VSD closure under video-assisted endoscopic technique depends on the location and position of the VSDs. Precise preoperative diagnostic information should be obtained before corrective surgery. After surgical repair, it is important to determine if the defect has been completely closed. The clinical implications of a significant residual defect include increased hemodynamic burden of this lesion and increased patient risk of pulmonary hypertension. Because hemodynamic study of a significant residual shunt may necessitate a reoperation or result in irreversible pulmonary vascular change that will influence symptoms and long-term advice,[5] it is important to obtain precise hemodynamic and morphological information of significant residual shunt in the early postoperative period after surgical repair of VSDs. Minimally invasive cardiac surgical techniques have become an attractive alternative approach for closure of VSDs. In order to achieve high efficacies of surgical repair with video-assisted endoscopic techniques, it is important to determine confirmation of the preoperative diagnosis, the existence of significant residual shunt, and the need for future medical and/or surgical interventions. Therefore, intraoperative TEE monitoring has become a sensitive tool for reevaluation of the preoperative diagnosis and detection of significant residual VSDs. In this study, we report on our experience with using intraoperative pediatric biplane TEE to demonstrate the efficacy of the surgical repair of VSDs in real time while using minimally invasive cardiac surgical techniques for closing VSDs in pediatric patients.

METHODS

Sixty-five selected pediatric patients were operated on for VSDs and associated cardiac lesions with minimally invasive cardiac surgical techniques since March 1996. There were 30 boys and 35 girls with a mean age of 8.7 ± 5.3 (range, 1.5 to 18.9) years. Their mean body weight was 29.6 ± 12.5 (range, 11.2 to 59.0) kg. The indication for operation was a pulmonary-to-systemic blood flow value of 2:1 as documented by aortography. Preoperative clinical variables were documented, including pulse pressure, cardiothoracic ratio on chest radiography, and electrocardiographic evidence of left ventricular hypertrophy. Preoperative conventional transthoracic echocardiography (TTE) was performed on all patients to locate the position of the septal defect. The pulmonary-to-systemic flow ratio was 1.9 ± 0.3 (range, 1.5 to 2.7). The mean pulmonary artery pressure was 22 ± 4 (range, 15 to 26) mmHg.

All patients were taken to the operating room without premedication. Routine monitors included a 5-lead electrocardiogram (ECG), invasive arterial blood pressure, and central venous pressure monitors, pulse oximetry, capnography, and a temperature monitor. Following preoxygenation, induction of anesthesia with intravenous administration of fentanyl (5 μg/kg), midazolam (0.1 mg/kg), and vecuronium bromide (0.1 mg/kg) was performed to facilitate endotracheal intubation. Anesthesia was then maintained with fentanyl (5 μg/kg/h) and isoflurane (0.5-1.5%). Muscle relaxation was provided with vecuronium (0.01 mg/kg/h).

A 20-gauge catheter was placed in the right or left radial artery for continuous monitoring of arterial pressure, and end-tidal carbon dioxide tension was checked and arterial blood gas analysis was carried out during the operation. A Hewlett-Packard 2500 system with a 7.5/5.5-MHz pediatric biplane TEE transducer was inserted into a patient's esophagus after induction of anesthesia and was left in place throughout the operation. Baseline reevaluation confirmation of the preoperative diagnosis was done while patients were being prepared for surgical repair. The following features were evaluated before the bypass: (a) anatomic classification (location and landmarks); (b) aortic regurgitation associated with VSD; (c) aneurysmal transformation and aortic valve prolapse; and (d) the diameter of the VSD. The diameter of the VSDs was measured from the 2D image and was compared to color flow mapping. Features evaluated after the bypass were residual shunts and additional VSDs. A VSD with color flow through it of >3 mm was defined as hemodynamically significant.[6] Transgastric and transesophageal transverse and longitudinal plane images were obtained. Blood flows in the 4 cardiac chambers, the great arteries, and the systemic and pulmonary venous return were analyzed with Doppler. The location, size, and position of the VSD, the presence of aortic valve prolapse and regurgitation, and their relation to the VSD were assessed by the 5-chamber and short-axis views of the aortic root (horizontal plane), and the ventricular outflow tract cuts (longitudinal plane).[7] Optimal imaging was obtained by advancement and rotation but without angulation of the transducer. Throughout the study, color flow gain was set and maintained at immediately below the level where artifacts appeared. All images were recorded on videotapes for both on- and off-line analyses. The effectiveness of the surgical procedure was assessed in terms of (1) any residual shunt through the repaired defect, and (2) the severity of the residual aortic valvular regurgitation.

After reevaluation and confirmation of the diagnosis of the VSD by TEE, the patient was placed in a supine position with the left groin exposed. A cardiopulmonary bypass was established through cannulation of the left femoral artery and left femoral vein. A membranous oxygenator (Maxima Plus oxygenation system; Medtronic, Cardiopulmonary Division, Anaheim, CA) was used, and systemic hypothermia was begun immediately after initiation of the cardiopulmonary bypass. A left anterior parasternal minithoracotomy (4 to 6 cm) was performed, and the pleural space was entered through the third or fourth intercostal space in patients with a subarterial or perimembranous VSD. A 10-mm endoscope (Stryker Endoscopy, San Jose, CA) and other conventional surgical instruments were introduced through a thoracotomy. Because the illumination during repair of the VSD was not good due to the short length of the thoracotomy and ventriculotomy, a video-assisted endoscope was used to provide illumination and guide the repair procedure. The pericardium was carefully incised longitudinally anterior to the phrenic nerve to expose the right ventricle. The aorta was not cross-clamped, and the heart was protected with continuous coronary perfusion with hypothermic fibrillatory arrest (rectal temperature, $27.3 \pm 3^{\circ}C$). After the heart fibrillated, a 1- to 2-cm incision was made in the right ventricular outflow tract, and the VSD was identified with the assistance of the endoscope by means of images projected on the video screen monitor. Conventional hand suturing for closure of the VSD and ventriculotomy was smoothly performed through the thoracotomy, guided by the endoscope. The VSD was directly closed with 4-0 polypropylene interrupted sutures in 12 patients and with a knitted Dacron patch in 33 patients. The cardiopulmonary bypass was terminated after rewarming of the patient. After surgery, patients were transferred to the intensive care unit, and all the patients regained consciousness promptly after the operation.

RESULTS

Intraoperative pediatric biplane TEE was performed without complications in all 65 patients. Patient and surgical characteristics are presented in Table 1. The location of the VSD was subarterial in 31 patients and perimembranous in 34 patients. Prolapse of the aortic cusp was noted in 21 patients, with mild aortic regurgitation in 18 patients. Infundibular stenosis was observed in 1 patient, with a pressure gradient across the right ventricular outflow tract of 57 mmHg. A right sinus Valsalva aneurysm which had ruptured into the right ventricle was also seen in 1 patient. TEE was able to clearly delineate the different types of VSD. Both the perimembranous and subarterial VSDs were well visualized on the transverse or longitudinal view. In 1 patient with a perimembranous VSD found on TTE, the conclusion based on TEE was that the patient had a small outlet-type perimembranous VSD associated with 2 additional anterior and mid-muscular VSDs.

Table 1. Characteristics of Video-assisted Endoscopic Techniques for Surgical Repair of Ventricular Septal Defects (VSDs) in Pediatric Patients. Data are Presented as the Mean±SD (Range).

Variable	Value
Gender (male/female)	30/35
Age (yr)	8.7±5.3 (1.5~18.9)
Body weight (kg)	29.6±12.5 (11.2~59.0)
Pulmonary-to-systemic flow ratio	1.9±0.3 (1.5~2.7)
Mean pulmonary arterial pressure (mmHg)	22±4 (15~26)
Cardiopulmonary bypass time (min)	41±10 (28~100)
Operative time (h)	2.2±0.8 (1.3~3.5)
Hospital stay (day)	4.1 (3~5)
Mortality	None

This patient was initially arranged to undergo a minimally invasive cardiac surgical technique by the surgeon based on the TTE findings. After identifying the error, the surgeon changed his surgical approach to close the VSDs through a conventional median sternotomy because the coarse trabeculations within the right ventricle made delineating the edges of the muscular VSD nearly impossible in the confined space.

The diagnosis of a persistent VSD was confirmed in all patients from the appearances on 2-D and color Doppler echocardicardiograhy (Fig. 1). A view of the ventricular septum, including a better appreciation of the ventricular septal defect size and better visualization of the angle for Doppler interrogation, was obtained from the vertical plane, especially for VSDs in the outlet septum. Closure of the defect (directly in 22 patients and by patch in 43 patients) was successfully performed in all patients. The infundibular stenosis and ruptured right sinus of a Valsalva aneurysm in 1 patient each were also successfully repaired. Sixty-two patients showed no residual shunt or aortic regurgitation after the repair. In the other 3 patients, residual leaks were detected intraoperatively after the surgical repair. Only 1 patient, with residual VSD color jet diameter of > 3 mm and a significant shunt as determined via oximetry (Q_P/Q_S= 2.2), needed to return to the bypass with an immediate reoperation. This patient was placed back on cardiopulmonary bypass, and the repair was satisfactorily revised. Immediate detection of the significant residual shunt in this patient precluded the need for another intervention. The other 2 patients with residual color jet of < 3 mm and hemodynamic

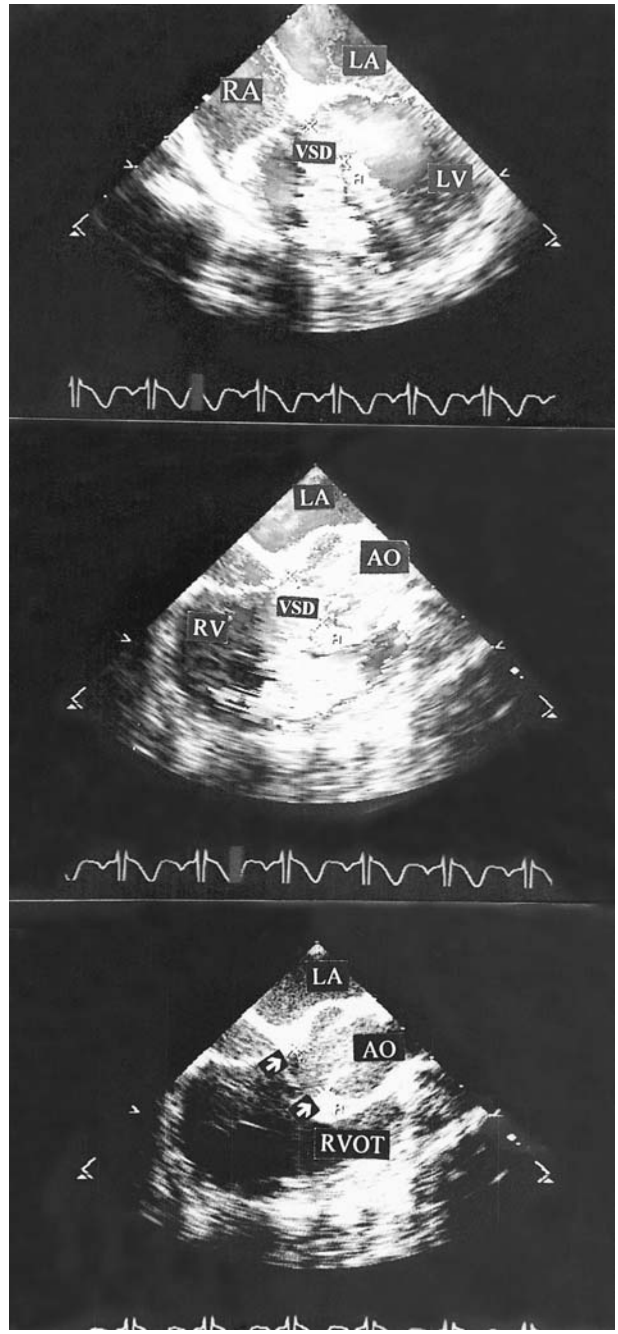

Fig. 1 Measurement of VSD size (arrow) using the 2D longitudinal plane (bottom), color flow mapping transverse plane (top), and longitudinal plane (middle). RA: right atrium; LA: left atrium; LV: left ventricle; AO: aorta; VSD: ventricular septal defect; RVOT: right ventricular outflow tract.

studies revealed no significant shunt, and no intervention was needed. There were no significant residual shunts in any of the 65 patients upon leaving the operation room.

All patients regained consciousness promptly after the operation. The endotracheal tube was removed on the first postoperative night. All patients were transferred out of the intensive care unit on the first postoperative day. None of the patients needed narcotic medication for postoperative chest wall pain. There were no arrhythmias or organ failure during the postoperative course, which was uneventful overall. The mean hospital stay was 4.1 (range, 3 to 5) days.

On postoperative follow-up, 2 of the small insignificant residual leaks were not detected at all by subsequent TTE 5 days after the operation. None of the patients showed a residual shunt or ventricular dysfunction after discharge. The incidence of residual shunt was 1 (hemodynamically significant) of 65 patients (1.5%) on intraoperative TEE, none of 65 (0%) on discharge TTE, and none of 65 (0%) on postoperative follow-up TTE. The diagnosis determined by TEE studies performed before surgery was modified in only 1 (1.5%) patient. Follow-up was completed on all patients for a mean of 6.2 (range, 3 to 9) months.

DISCUSSION

VSD is one of the most common lesions in congenital heart disease, with an incidence of at least 12 per 10,000 live births.[8] Although many of the defects close spontaneously, surgical repair is indicated for large defects and for significant associated lesions. These include aortic valve incompetence, which develops in fewer than 1%, and right ventricular outflow tract obstruction, which develops in approximately 3% of patients.[9] The nomenclature describing the anatomy of VSD has changed over recent decades, mainly because of the improved ability to visualize and define the anatomy more precisely with angiographic and echocardiographic studies. Precisely defining the VSD location and size is essential for accurate and complete surgical repair.

Intraoperative TEE has been recognized as a useful investigatory tool to provide important surgical information, directing corrective operation, and assessing immediate surgical results.[10] The miniaturization of TEE probes, together with the development of the capability for biplane imaging from the esophagus, has increased the use of TEE in pediatric cardiology. Its utility in surgical correction of congenital heart disease has also been reported.[1] Interference with surgery, such as that which occurs during epicardial echocardiography, and the need for sterilized probes and/or covers are not inherent in an intraoperative TEE study.[11]

Recently, a mini cardiac operative procedure with video-assisted endoscopic techniques has been growing in popularity in cardiac surgery. Since the early 1990s, the development of video technology and its incorporation into endoscopic methods as well as the creation of adapted instrumentation have given rise to video-assisted cardiac surgery. Recent advances in endoscopic imaging technology have extended the applications of video-assisted surgical procedures. It has been a rapidly expanding and useful modality for the surgical treatment of intrathoracic disease.[12] It offers the promise of expediency, safety, minimal discomfort, reduced postoperative pain, quick functional recuperation, excellent cosmetic healing, shortened hospital stay, and cost savings.[13] Technically successful video-assisted procedures have been reported in congenital heart operations including patent ductus arteriosus interruption,[14] vascular ring division,[15] and ASD closure.[16] Our surgical department began using a minimally invasive cardiac surgical technique through a left anterior minithoracotomy for VSD repair in March 1996.[17] This surgical technique is technically feasible and can safely and effectively be carried out with a decreased amount of postoperative bleeding and excellent cosmetic healing. A decreased length of stay, decreased incisional pain, better preservation of pulmonary mechanics, and prevention of the postthoracotomy syndrome are the hallmark benefits of VSD closure under video-assisted endoscopic techniques. In order to achieve good surgical outcomes and successful rates of operation in minimally invasive cardiac surgical techniques during VSD repair, a precise diagnosis is very important for determining the surgical approach, and reevaluation by intraoperative TEE may play a major role in confirmation of the preoperative diagnosis.

Previous reports on the utility of TEE have documented improvements in the precise anatomical delineation of congenital heart disease. TEE can clearly delineate the different types of VSDs. Both perimembranous and malaligned VSDs are well visualized in the transverse or longitudinal view. The superior images of TEE allow the precise location and sizing of VSDs. Cineloop with frame-to-frame analysis facilitates clear definition of any prolapsed leaflet. Color flow mapping further detects and clearly defines VSDs and any related aortic regurgitation to the incomplete valvar coaptation, which is secondary to the prolapsed cusps herniating through the septal defect.

The decision to intervene surgically in a VSD closure under video-assisted endoscopic techniques is influenced by the location and position of the VSD. In our study, there was close concordance between the positions of the VSDs on preoperative TTE and TEE. Only 1 patient was described as having a perimembranous VSD after TTE, whereas TEE showed a small outlet perimembranous VSD associated with 2 additional anterior and mid-muscular VSDs. After identifying the error in this patient, the surgeon changed his initial surgical approach for closure of the VSD from a video-assisted endoscopic technique to a conventional median sternotomy. Repair of a subarterial VSD can be accomplished through a pulmonary arteriotomy, and the right atrial approach is the route of choice for the closure of other types of VSDs. However, exposure of a perimembranous VSD through a right anterior minithoracotomy is rather difficult. Exposure of a subarterial VSD through a pulmonary arteriotomy is also limited by the small incision of a left anterior minithoracotomy. Our previous surgical experience showed that the transventricular approach can provide excellent exposure for subarterial and perimembranous VSDs.[18] Exposure of the VSD through the right ventricular outflow tract, with the aid of a video-assisted endoscope, was excellent, and closure of VSDs was easily accomplished. But muscular VSDs present a special problem and may need to be approached from the left ventricle. When viewed from the right-side ventricle, these defects often appear to be multiple because the coarse trabeculations within the right ventricle make delineating the edges of a VSD nearly impossible in the confined space. Due to the above difficulty of approach of video-assisted endoscopic techniques in this kind of patient, a left ventriculotomy through a median sternotomy is usually performed. In this study, we have shown that new TEE diagnostic information obtained before corrective surgery has direct benefits to patients. Changes in anatomical detail or physiological assessment by preoperative TEE examination resulting in a different surgical approach were found in only 1 of 65 (1.5%) patients.

Our surgical department successfully extended the application of video-assisted endoscopic technique to the closure of VSDs (directly in 22 patients and by patch in 43 patients). After surgical closure of a VSD, it is important to determine if the defect has been completely closed, since this will influence symptoms and long-term advice.[5] Even a small residual shunt, especially when associated with other defects such as pulmonary insufficiency or tricuspid insufficiency, may cause clinical deterioration that can only be improved by a reoperation.[19] Obtaining precise hemodynamic and morphological information in the early postoperative period after surgical correction of congenital heart disease is important in determining the need for future medical and/or surgical intervention. Information concerning the hemodynamic importance of residual shunting may be obtained noninvasively by a variety of methods. However, physical examination with cardiac auscultation may be difficult in ventilated postoperative patients due to adventitious sounds, and it is impossible to assess the efficacy of the surgical repair by palpation through the confined space. Therefore, intraoperative TEE monitoring has become invaluable in detecting significant residual VSDs.

Advancements in cardiac surgery have resulted in the ability to successfully repair congenital heart disease with a relatively low incidence of residual defects. Immediate post-bypass TEE, especially color flow Doppler, has proven to be a reliable tool for assessing residual VSDs, an observation which may warrant a reoperation before chest closure. By displaying real-time blood flow velocity and direction in relation to the cardiac structure, Doppler color flow mapping allows the analysis of spatial dimensions of abnormal flow patterns in the heart.[20] In our study, only 3 patients were intraoperatively detected to have residual leaks after surgical repair. A return to the bypass with an immediate reoperation was undertaken in 1 patient who had a significant shunt with a residual VSD color jet diameter of > 3 mm. All patients achieved successful repair under TEE monitoring during the operation. There were no surgical mortalities under minimally invasive cardiac surgical techniques. On postoperative follow-up, 2 of the small residual leaks were not detected at all by TTE 5 days after the operation. None of the patients showed a residual shunt or ventricular dysfunction after discharge. The mean admission time in our hospital was significantly shorter (mean, 4.1 days) than that for uncomplicated VSD closure performed by a conventional median sternotomy (mean, 8.2 days).

In conclusion, new developmental therapeutic modalities using video-assisted endoscopic techniques for VSD closure provide a new surgical modality for congenital operations. This study demonstrated that TEE monitoring can be a crucial tool in reevaluating preoperative diagnoses of VSDs, which is important in determining the surgical approach and outcome of the operation. With refinements in surgical techniques, intraoperative TEE can now provide valuable and accurate information for decision-making for surgical management, and most importantly, provide immediate assessment with surgical repairs, preventing reintervention and the morbidity associated with residual flow.

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小兒使用經食道心臟超音波來評估視訊輔助內視鏡技術於心室中隔缺損修復之成效

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背 景： 經由視訊輔助內視鏡技術來縫補小兒心室中隔缺損的這種顯微心臟手術，在兒童心臟外科領域已經獲得廣泛的注意與重視。術前要如何做正確的診斷，以及術後評估是否有殘餘的缺損，經食道心臟超音波在手術中扮演著極爲重要的角色。

方 法： 共有65位病人（男生30人，女生35人，年齡平均8.7±5.3歲）皆接受心臟顯微手術來修補心室中隔缺損，術中使用Hewlett-Packard彩色都卜勒小兒經食道超音波來做全程的監測。

結 果： 所有病人都成功地完成缺損修補。62人術後沒有殘餘的分流，或者主動脈瓣逆流的現象。另外3人在修補後發現有殘留的破損，其中1人因爲破損大於3mm，所以立即再度使用心肺循環重新進行手術；另1人因經食道超音波發現，除了有出口型膜性心室中隔缺損之外，還多了二處肌肉型心室中隔缺損，所以放棄「視訊輔助內視鏡技術」，改採傳統正中胸骨切開術來手術。

結 論： 我們的研究顯示，經食道心臟超音波提供了很有價值且正確的訊息，對於視訊輔助內視鏡心室中隔缺損線縫補術有很大的幫助，不論是術前的評估，修補成效的立即判斷，以及預防避免反覆的手術，和減少因殘留血流所導致的後遺症，都有很顯著的貢獻。

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關鍵字： 心室中隔缺損，經食道心臟超音波，視訊輔助內視鏡技術。

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