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The use of multiplane transesophageal echocardiography to evaluate residual patent ductus arteriosus during video-assisted thoracoscopy in adults

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Abstract
Background: Video-assisted thoracoscopic surgery (VATS) has emerged as an innovative and popular procedure for interruption of patent ductus arteriosus (PDA), while intraoperative transesophageal echocardiography (TEE) has proven to be an effective monitor in the evaluation of residual patency. Previous reports on the adequacy of surgical interruption of PDA under VATS and TEE are available for pediatric patients, but only limited information is available for adults with PDA.
Materials and methods: Between August 1995 and October 1997, we monitored 35 adult patients undergoing PDA interruption via VATS with Hewlett-Packard color Doppler multiplane TEE throughout the procedure. The average PDA diameter was 10.2 ± 1.8 mm. All the PDA were completely ligated.
Results: Thirty-two patients showed no ductal flow after double ligation. In the other three patients, residual flow was detected intraoperatively after double ligation, but it was quickly abolished by the third ligation. One patient showed faint ductal flow by transthoracic echocardiography at postoperative follow-up, but no reintervention was needed.
Conclusions: Our study showed that, with the refinement of adult PDA interruption via VATS, intraoperative multiplane TEE provides higher resolution for direct evaluation of the entire course of PDA ligation without interrupting the surgical procedure and minimizes the incidence of complications.

Key words: Patent ductus arteriosus — Transesophageal echocardiography — Video-assisted thoracoscopic surgery

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Patent ductus arteriosus (PDA) is a common congenital cardiovascular anomaly encountered in infant and children. The incidence of persistent patency of the ductus arteriosus is approximately one in every 200 births and increases with great prematurity. Once the diagnosis is established, surgical intervention is always recommended. PDA is usually identified early in life. However, PDA may present in adulthood, or even in the elderly [6, 8, 27]. Patients with small shunts sometimes remain asymptomatic into adulthood. In adult patients, PDA may be accompanied by unexplained pulmonary hypertension or Eisenmenger's syndrome, and especially by irreversible hypertension that could lead to right ventricular failure when the PDA is closed.

In newborn and infants, direct visualization of PDA is usually successful with conventional transthoracic echocardiography (TTE) and color-coded Doppler [22, 24]. However, the ductus may be located far from the transducer on the chest wall. Because of interference from lung hyperinflation, ribs, and obesity in adults, it is usually difficult to show clearly this structure and the flow in it [20, 25]. Thus, conventional TTE usually fails to obtain diagnostic information in asymptomatic adult patients. When a satisfactory TTE recording cannot be obtained, transesophageal echocardiography (TEE) is the alternative procedure of choice. With the advent of TEE, there is a much better window to the posterior structures of the thoracic cardiovascular system [5, 17].

Traditionally, PDA was surgically ligated via a posterolateral thoracotomy. Although PDA ligation via thoracotomy is a highly successful procedure, there has been some concern over postthoracotomy syndrome and postoperative pain. With advances in video-assisted endoscopic techniques, video-assisted thoracoscopy (VATS) for PDA interruption has emerged as an innovative new approach to surgical procedures [2, 15]. The clinical implications of residual ductal flow include a continued need for endocarditis

prophylaxis and the hemodynamic consequences of left-to-right shunting. The true incidence of residual ductal shunting after PDA ligation has not been clearly defined, because follow-up generally has been based on auscultatory findings that have proved unreliable in identifying residual ductal shunting [18].

Because incomplete PDA ligation may necessitate reoperation or lifelong infection prophylaxis, it is important to identify patients with small residual ductal flow. Thoracoscopic interruption has become an attractive alternative to thoracotomy; however, it is impossible to assess the efficacy of surgical closure by palpating the duct through diminutive thoracoscopic windows. Therefore, intraoperative TEE monitoring has become invaluable in the evaluation of residual patency. In this study, we report our experience in using intraoperative multiplane TEE to demonstrate the complete interruption of ductal flow in real time during a video-assisted PDA procedure in adult patients.

Materials and methods

Between August 1995 and October 1997, we studied 35 adult patients with clinical diagnosis of PDA who has received elective PDA ligation under video-assisted thoracoscopy. They were 30.1 ± 9.6 years old (range, 20–57 years). Conventional TTE was practiced on all patients. The average diameter of PDA was 10.2 ± 1.8 mm (range, 8.4–11.5 mm). Preoperative mean pulmonary artery pressure was 26.7 ± 11.2 mmHg (range, 22–64 mmHg). Three of the 35 patients had moderate pulmonary hypertension confirmed by cardiac catheterization. Two patients had subacute bacterial endarteritis (group D *Streptococcus*) before the operation and had received 6 weeks of antibiotic treatment preoperatively; no aneurysmal change or calcification of PDA was found on TTE preoperatively.

All patients were taken to the operating room without premedication. Five-lead ECG, noninvasive arterial blood pressure, pulse oximeter, capnography, and body temperature were routinely monitored. 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. A double-lumen endotracheal tube (Broncho-cath; Mallinckrodt Medical, Athlone, Ireland) was applied for one-lung anesthesia. Anesthesia was maintained with low-dose fentanyl (5 μg/kg/h) and isoflurane (0.6–1.5%). Muscle relaxation was provided with vecuronium (0.01 mg/kg/h).

A 20-gauge catheter was placed in the right radial artery for continuous monitoring of arterial pressure, and end-tidal carbon dioxide tension and arterial blood gas analysis were routinely checked during the operation. A Hewlett-Packard 2500 system with an omni multiplane TEE probe were inserted after induction of anesthesia, and baseline evaluation was done while the patients were being prepared for surgical ligation. Real-time TEE monitoring was performed by the same physician throughout the entire course of procedure. A multiplane transducer was used at a distance of 30 cm from the incisor. Transgastric and transesophageal transverse and longitudinal plane images were obtained. Blood flow in the four chambers, great arteries, and systemic and pulmonary venous return were analyzed with Doppler.

PDA was established by using images in a multiplane with aortic recording at the level distal to the ductus. The probe was slowly withdrawn and slightly rotated 10–30° until PDA flow could be seen directly between the descending aorta (DAO) and the main pulmonary artery (MPA). The shunt between aorta and pulmonary artery was corroborated with color-coded Doppler.

Spectral analysis of the pulmonary flow showed increased velocity in systole and diastole. Quantification of pulmonary arterial systolic pressure was also obtained from TEE and studied by aligning the ultrasound beam in the direction of the ductus itself; the difference between aortic systolic pressure and the gradient across the ductus corresponded to the systolic pressure in the pulmonary artery.

After general anesthesia and intubation, the patient was placed in the right lateral decubitus position. Two thoracotomies were performed in the left hemithorax—a 5-mm incision through the sixth intercostal space on the middle axillary line for the endoscopic grasper and a 5-mm incision through the third intercostal space at the posterior axillary line for the video thoracoscope. A 3.5–4.0 cm incision was made through the anterior part of the third intercostal space for manipulation of the instruments. The PDA was first ligated with 2-0 Ethibon with Teflon pledgets anteriorly and posteriorly around the PDA. Two more ligations with Teflon pledgets were added for reinforcement. After PDA ligation, the lung was inflated and tube thoracostomy was done (only in the first two cases). At the end of surgery, residual muscle relaxation was antagonized with neostigmine (0.06 mg/kg) and atropine (0.02 mg/kg). Patients were extubated in the operation room or recovery room and transferred first to the intensive care unit, then to the ward. All patients were followed up after discharge from hospital and received a complete physical and echocardiography examination.

Table 1. Characteristics of video-assisted thoracoscopic operation (VATS) for interruption of patent ductus arteriosus (PDA) in adult patients. Data are presented as mean ± SD (range)

Variable	Value
Gender (male/female)	15/20
Age (yr)	30.1 ± 9.6 (20–57)
Body weight (kg)	51.7 ± 4.6 (42–70)
Size of PDA (mm)	10.2 ± 1.8 (8.4–11.5)
Procedure time (min)	55 (35–113)
Operative time (min)	92 (72–113)
Hospital stay (day)	2.7 (2–3)
Mortality	None

Results

Fifteen men and 20 women received PDA ligation during the study period. All adult patients were referred for echocardiography evaluation with typical continuous murmur heard at the left sternal border in conjunction with increased intensity of the aortic component of the second heart sound. Two patients had bacterial endarteritis before the operation and were treated with antibiotics. Patient and surgical characteristics are presented in Table 1.

The diagnosis of PDA (Fig. 1) was confirmed in all patients. A mosaic flow was found by multiplane TEE to originate from the descending aorta, entering the pulmonary artery through the duct. The mosaic flow representing a flow acceleration near the duct was easily detected by TEE in the descending aorta. Further manipulation of the probe revealed the flow into the pulmonary artery through the duct.

Pulse-wave Doppler studies were performed with sample volume at the ductal level. In all patients, a continuous high velocity flow with alias despite high-pulse repetition frequency was identified. Color-flow Doppler imaging revealed a discrete mosaic high-velocity jet that originated from the bifurcation of left and right pulmonary arteries and traveled in a retrograde manner to the medial portion of the main pulmonary artery. The PDA jet originated from the beginning of the descending aorta, and this high-velocity jet was directed toward the MPA, which was detected just distal to the aortic arch.

Thirty-two of the 35 patients showed no ductal flow on intraoperative TEE after double ligation. Immediately after placement of the second tie, three patients presented with residual ductal flow, which was detected by continuous monitoring of TEE (Fig. 2). These patients needed a third ligation to complete the interruption of the ductal flow (Fig. 3. Immediate detection of residual ductal flow in these patients did not prolong the surgical time significantly and precluded the need for another intervention. There was no

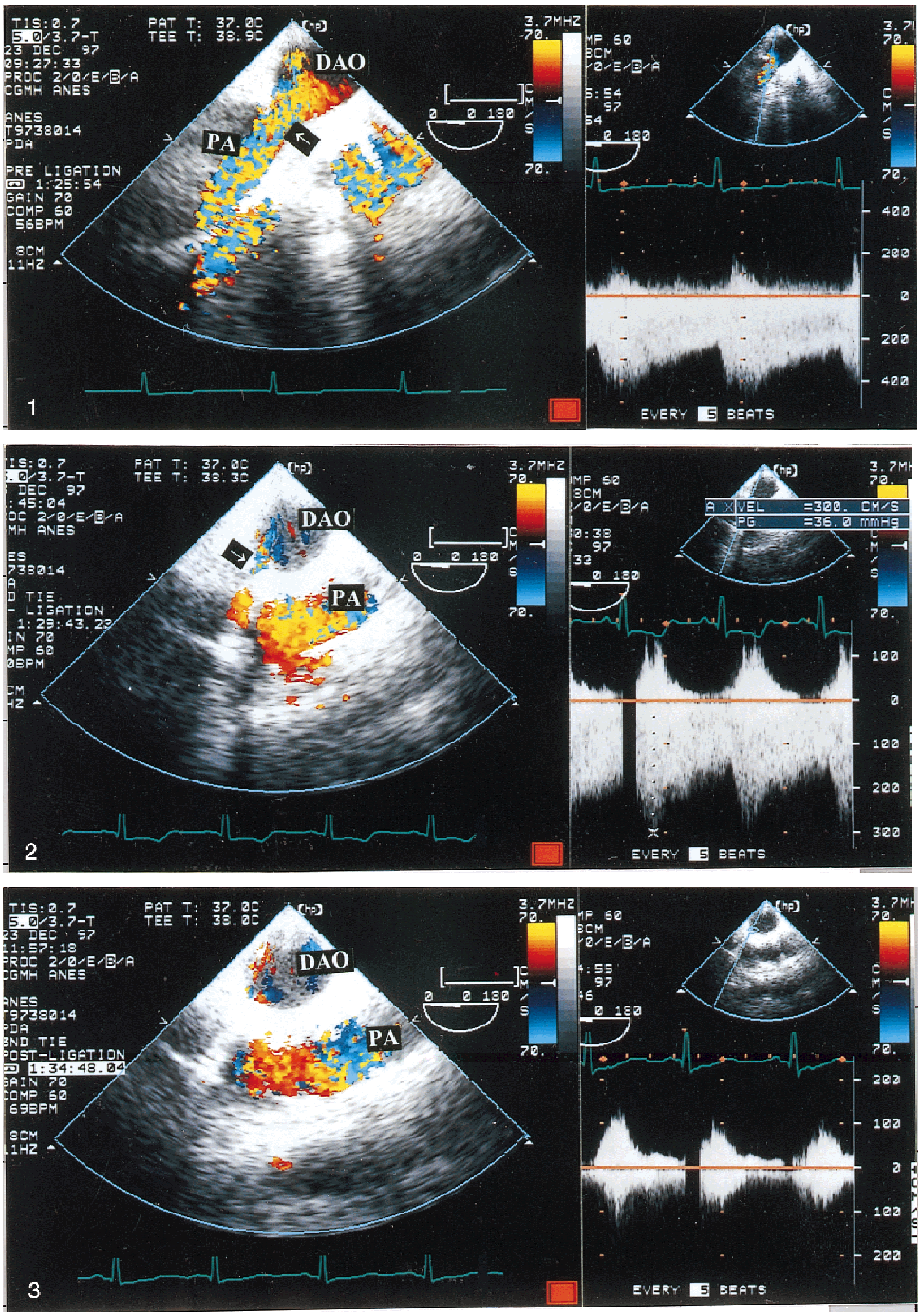

Fig. 1. Left multiplane TEE of the descending aorta (DAO) in short axis. Color-flow Doppler imaging demonstrates a mosaic turbulent flow between the aorta and the pulmonary artery (PA) (*arrow*), identifying the PDA. **Right** continuous-wave Doppler showed high-velocity flow pattern.

Fig. 2. Tee imaging with continuous-wave Doppler demonstrates residual flow across the ductus arteriosus following application of second tie.

Fig. 3. After application of the third ligation, there is no sign of a residual PDA shunt. The descending aorta (DAO) and pulmonary artery (PA) have regained a normal flow pattern.

residual flow in any of the 35 patients upon leaving the operating room. All patients had achieved successful ligation without any shunt under TEE monitoring at the end of the surgical procedure.

Thirty-one of the 35 patients were extubated in the operating room; the other four patients were extubated in the intensive care unit within 4 h after operation. None of the patients needed narcotic medication for postoperative chest wall pain. Most of them were discharged within 3 days after the procedure.

On postoperative follow-up, none of the patients showed residual ductal flow on auscultation. One patient showed a tiny residual ductal flow detected by TTE 1 month after the operation. The other 34 patients showed no residual shunt after discharge. The incidence of residual ductal flow was three of 34 (9%) on intraoperative TEE, none of 35 (0%) on discharge auscultation, and one of 35 (3%) on postoperative TTE. One patient developed transient recurrent laryngeal nerve paresis. The mean follow-up time was 2.3 months.

Discussion

PDA is an abnormal communication between the descending thoracic aorta and the proximal portion of the left branch

of the pulmonary artery. Unlike pediatric patients, older children and adults can present a wide spectrum of clinical manifestations, which vary from asymptomatic continuous precordial murmurs to severe pulmonary hypertension or a long-term febrile syndrome [26]. In these cases, when a satisfactory TTE recording cannot be obtained, TEE is the alternative diagnostic procedure of choice.

With TTE transverse plane recordings, it is difficult to visualize the ductus directly; it may be suspected because of systolic and retrograde diastolic flow in the pulmonary artery or its left branch. It can be identified with multiplane TEE. Multiplane TEE allowed both the identification of structures located at oblique angles to the heart and a careful inspection of the descending thoracic aorta. It offers an advantage in imaging the ductus arteriosus, which may run at an oblique angle, because it can obtain progressively higher sections that are complemented with color-coded Doppler to demonstrate the shunt as a mosaic color communicating the aorta with the pulmonary artery. Spectral analysis allows velocity in systole and diastole, and patients with or without pulmonary hypertension can be differentiated.

Video-assisted thoracoscopic operation for PDA ligation was first introduced in 1993 by Laborde et al. [15]. It was then applied to PDA by Burke et al. [2] in 1995. VATS PDA interruption has been reported to have some advantages over standard thoracotomy and thus is becoming an attractive alternative to thoracotomy. This procedure provides a safe, rapid, minimally traumatic method with better preservation of pulmonary mechanics, decreased hospital stay, decreased postoperative pain, and possibly prevention of the postthoracotomy syndrome [9, 15, 16].

Several authors have reported that intraoperative TEE is a reliable monitor of the adequacy of surgical repair during VATS PDA interruption in the pediatric population [11, 12]. Almost all the reported VATS experiences are in pediatric patients [10, 14]. However, there is an increasing awareness of PDA presenting in adulthood and even in the elderly [6, 8].

The natural history of a hemodynamically significant PDA has typically been associated with inexorable cardiovascular derangement, including progressively severe pulmonary hypertension and congestive heart failure. The life expectancy of patients studied has been approximately half that of the general population, with the average age at death being slightly <40 years [13]. Subsequently, Campbell [3] reported greater longevity in untreated PDA, with 60% of patients surviving to the age of 60 years. It is conceivable that the majority of long-lived patients with PDA have relatively small left-to-right shunts near the level of hemodynamic significance that thus do not overload the pulmonary vascular tree. Other patients may, over time, undergo a spontaneous reduction in the dimensions of the PDA [3]. Thus, small subsets of patients survive far longer than previously appreciated.

Estimated PA pressures determined via TEE before and after the ligation were very important. There was valid concern over the severity of the shunt because these adult patients are exposed to a left-to-right shunt for an extended period. Obtaining this information, before and after ligation, could help establish the adequacy of the right heart's ability to adapt if pulmonary vascular resistance was elevated, especially in cases of irreversible hypertension that could lead to right ventricular failure when PDA is closed. This problem helps to explain why having this procedure is different for adults than it is for the pediatric population. Occasionally, the ductus may become aneurysmal secondary to flow characteristics. The aortic aspect of the PDA is usually calcified in the older adult patient.

Our surgical department began using video-assisted thoracoscopic techniques for PDA interruption in August 1995 [4]. So far, 95 patients have been operated on, including both pediatric and adult patients. The surgical procedures for adults and children are almost the same, except for the manipulation wound length. The mean size of the PDA in our adult patients was 10.2 mm (range, 8.4–11.5 mm); it was not possible to apply a titanium clip or suitable transcatheter occlusion. Transcatheter closure with a double-umbrella device has proven to be an effective and safe treatment of PDA in the neonatal periods.

Although this procedure may be effective in closing adult PDA of the small to medium ductus, it may also cause major problems with obstruction of the left pulmonary artery and the descending aorta. Also of concern is the presence of residual leaks after transcatheter occlusion; it is likely to represent a persistent high risk for endovascular infection [19]. The twin goals of PDA closure are to achieve interruption of the shunt and to avoid the risk of bacteria endocarditis. Hence, the presence of residual leaks should be considered a failure of this procedure. Longer-term follow-up, more experience, and a prospective evaluation of transcatheter procedure are still needed before it becomes the standard technique for closure of PDA.

Thanks to its higher efficacy rate and low risk of endovascular infection, closure of a PDA using thoracoscopic techniques is another new alternative that is being explored; it allows safe and effective ligation of a PDA (especially a large PDA) with early hospital discharge. Our technique, using mostly conventional surgical instruments and ligature, with the aid of a video camera and a limited manipulation port, is universally applicable to all ages of patients and different sizes and situations of PDA.

The decision to intervene surgically in an adult PDA patient is influenced by many factors. A patent ductus is frequently complicated by aneurysmal dilatation of the ductus, ductal as well as aortic calcification, and pulmonary hypertension, which will hinder success in operation. In our series, four patients were found to have calcification in the aortic aspect of PDA. Thoracoscopic procedures should probably not be considered for these patients because of the high risk of rupture while tying the ductus. In these cases, the procedures were conducted via a median sternotomy on bypass. Ductuses with calcification were screened for this thoracoscopic procedure.

Our surgical department successfully extended the application of video-assisted duct interruption to patients with large ducts by developing an intercorporeal ligation technique. One of the more important facets of closure of the ductus under VATS is the fate of the residual shunt. However, assessing the efficacy of surgical closure by palpating the duct is impossible through diminutive thoracoscopic windows. Therefore, intraoperative TEE monitoring has become invaluable in the evaluation of residual patency. Many

authors, even in the most recent reports [7], have relied on postoperative auscultation findings to ensure ductal ligation, but some others have argued that auscultation will miss a significant number of residual shunts [10]. In an effort to ensure safe surgical interruption of a complicated or large ductus, intraoperative TEE is a useful monitoring device during VATS for PDA interruption.

Echocardiography findings of residual ductal flow have been reported to be as high as 23% after PDA ligation via thoracotomy [23]. In a recent study of patients who had undergone VATS for PDA interruption, follow-up TTE was done in the recovery room, and two of 38 patients were eventually brought back to the operating room for reintervention because of residual flow [15]. These patients did not receive intraoperative TEE monitoring.

Clinical consequences of residual patency includ hemodynamically significant left-to-right shunt that may result in congestive heart failure, pulmonary edema, and high-flow velocity, which is associated with an increased risk of endocarditis [21]. In the course of this study, residual flow was always detected intraoperatively. The first occurrence of residual flow was quickly abolished by the application of a third ligation. Real-time monitoring of the procedure allowed early detection of residual flow and precluded an additional surgical intervention in three patients. The standard triple-ligation technique commonly used for open PDA ligation was instituted with the goal of avoiding recanalization of the ductus [1]. The noticeable incidence of faint residual flow at 1 month follow-up TTE in our series of patients suggests that recanalization may be a possible mechanism of residual patency.

All patients received successful ligation without any shunt under TEE monitoring during the operation. There were no surgical mortalities. One patient developed a transient recurrent nerve injury, possibly due to inadequate exposure of the lower edge of the PDA during video-assisted thoracoscopy; the patient recovered 3 months later. The mean admission time in our hospital is significantly shorter (2–3 days) than for conventional thoracotomy (5–7 days).

This study demonstrates that TEE monitoring during PDA interruption detects residual flow reliably intraoperatively and may even improve the surgical result, preventing reintervention and the morbidity associated with residual flow. With refinement of the surgical techniques and instruments associated with intraoperative multiplane TEE monitoring, the procedure for PDA interruption under video-assisted thoracoscopic can be applied safely not only in pediatric patients but also in adults.

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