

## Original Article

# Transesophageal echocardiography guided patent ductus arteriosus occlusion in adults with severe pulmonary hypertension through a parasternal approach

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**Abstract:** Between April 2010 and April 2014, 39 consecutive adult patients (> 18 years) with PDA associated severe pulmonary hypertension underwent transesophageal echocardiography guided patent ductus arteriosus occlusion through a parasternal minimally invasive approach. Among 39 patients, the procedure was successful in 32 cases (82.1%) and failed in 7 cases (17.9%). In the failed cases, 3 cases had a large residual shunt and 4 cases had persistent pulmonary hypertension. The mean minimum diameter of the successfully closed PDAs was  $15.2 \pm 2.1$  mm (range 9 to 24), and the mean diameter of the mushroom-shaped occluder was  $17.5 \pm 2.5$  mm (range 11 to 26). The pulmonary artery pressure decreased significantly after occlusion ( $P < 0.05$ ), but there were no significant differences in the aortic pressure and blood oxygen saturation before and after occlusion ( $P > 0.05$ ). Echocardiography performed on the first postoperative day showed decreased volume within the left atrium, left ventricle, and pulmonary artery in 23 cases, decreased volume within the left atrium and left ventricle in 4 cases, and no change in the volume of the atrium and ventricle in 3 cases. A minor residual shunt was observed in 6 cases. The posteroanterior chest X-ray showed improved pulmonary congestion in all cases and significantly reduced cardiothoracic ratio in 25 cases. Patients were followed-up at least for 1 year. No symptoms including palpitation, dyspnoea, or chest tightness were observed. The heart function ranged from NYHA class I to II. A minor residual shunt was observed only in one case. There were varying degrees of decrease in volume within the atrium and ventricle. In conclusion, transesophageal echocardiography guided patent ductus arteriosus occlusion through a parasternal minimally invasive approach is a feasible and effective method for the treatment of PDA in adults with severe pulmonary hypertension.

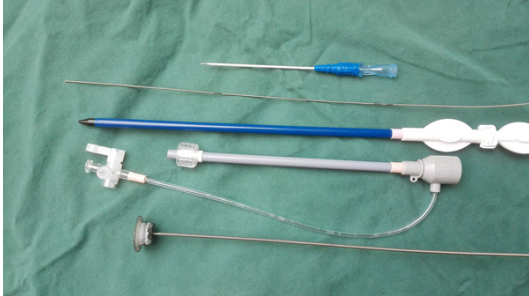
**Keywords:** Adult congenital heart disease, patent ductus arteriosus, pulmonary hypertension, minimally invasive

## Introduction

Patent ductus arteriosus (PDA) is one of the common congenital heart diseases, accounting for 5-10% of all congenital heart disease [1-3]. Most scholars consider that early surgical treatment should be carried out as soon as the diagnosis is definite and spontaneous closure is believed to be impossible [4, 5]. Due to various reasons, a considerable proportion of patients with PDA are diagnosed and treated late (> 18 years), especially in developing countries.

Adult patients with PDA are often associated with severe pulmonary hypertension (> 70 mmHg) [6, 7]. Some of the patients cannot undergo surgery because of the development of Eisenmenger syndrome, the other can be

accomplished by several methods, including surgical ligation, repair by cardiopulmonary bypass, video-assisted thoracoscopic, robotic surgery, and transcatheter occlusion [7]. Surgical ligation bypass has the disadvantages of significant trauma and the complications associated with the thoracotomy. Repair on pump has the injury of CPB. Video-assisted thoracoscopic surgery and robotic surgery are technically difficult and expensive. Transcatheter occlusion must be performed under fluoroscopy and angiography, in which radiation injury is inevitable [8]. Furthermore, closure of a large-sized PDA with significant pulmonary hypertension is technically challenging and has the risks of possible catastrophic bleeding in previous surgical techniques and device embolization in the transcatheter approach [9].



**Figure 1.** The occlusion delivery system: a puncture needle, a guide wire, a delivery sheath, a loading sheath, a push rod, a mushroom-shaped occluder.



**Figure 2.** A mushroom-shaped occluder: side view.



**Figure 3.** A mushroom-shaped occluder: front view.

The technique used at our institution is a hybrid technique, combining the advantages of open heart surgery and interventional cardiac catheterization. It is carried out using intraoperative transesophageal echocardiography-guided transthoracic occlusion through a small incision in the left chest close the ductus arteriosus. The purpose of this study to report the the feasibility and effectiveness of transesophageal echocardiography guided patent ductus arteriosus occlusion in adults with severe pulmonary hypertension through a parasternal approach.

## Subjects and methods

### Clinical data

Between April 2010 and April 2013, 42 adult patients (> 18 years) with PDA and associated pulmonary hypertension were admitted to our department. 3 patients (6.7%) with complete aorta-pulmonary artery shunt were diagnosed with Eisenmenger syndrome and excluded. Among the 39 enrolled patients, 18 were males. The mean age was  $30.2 \pm 17.5$  years (range 18 to 62) and weight was  $48.3 \pm 25.1$  Kg (range 35 to 85).

All patients had varying degrees of palpitation and shortness of breath after activity. 5 patients (12.8%) had lower-extremity cyanosis. 27 patients (69.2%) had continuous murmur in the precordial region, 8 patients had only systolic murmur (20.5%), and 4 patients (10.3%) had no significant murmur. All patients had increased pulmonary second heart sound. Preoperative arterial blood gas analysis showed that the blood oxygen saturation (SPO<sub>2</sub>) was more than 95% in 28 cases (71.8%), between 90% and 95% in 5 cases (12.8%), and less than 90% in 6 cases (15.4%). Preoperative chest x-ray showed pulmonary congestion, prominence of the pulmonary artery segment, and signs of pulmonary hypertension. Preoperative echocardiography showed enlargement of the left atrium and ventricle in all cases, enlargement of the right atrium and ventricle in 15 cases (38.5%), and the average pulmonary artery pressure was  $60.3 \pm 19.5$  mmHg. 3 patients (7.7%) had pericardial effusion, 8 patients (20.5%) had aortic regurgitation, 7 patients (17.9%) had mitral regurgitation, and 5 patients (12.8%) had tricuspid regurgitation.

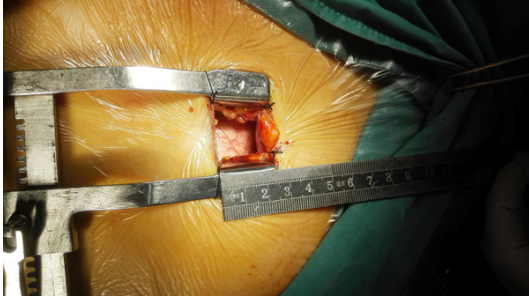
### Instruments and devices

The occlusion device set (Starway Medical Technology, Inc, Beijing China) (**Figure 1**) included a puncture needle, dilators, a guide wire, a delivery sheath, a loading sheath, a push rod, a mushroom-shaped occluder (**Figures 2, 3**) and a transesophageal echocardiography machine.

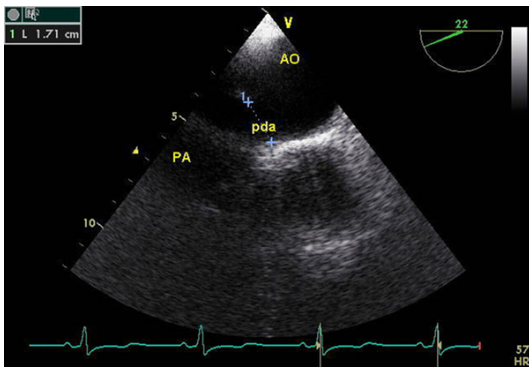
### Surgical procedure

This study was approved by our Institutional Review Board. Written informed consent was

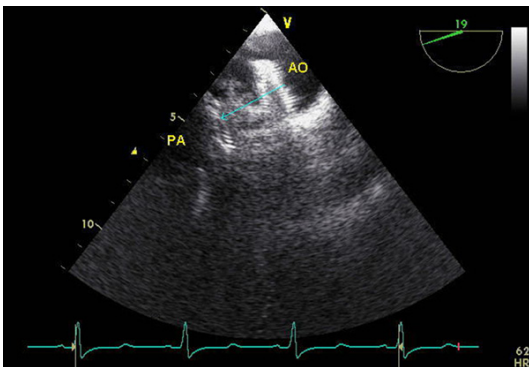
## Transesophageal echocardiography guided patent ductus arteriosus occlusion



**Figure 4.** A large patent ductus arteriosus with a diameter of 17.1 mm.



**Figure 5.** The mushroom-shaped occluder was placed in the patent ductus arteriosus.



**Figure 6.** The rest of the mushroom disc was then fully expanded and the opening within the ductus arteriosus on the pulmonary artery side was closed.

obtained after the entire research process was explained to the patient and all subjects took part in this study voluntarily.

General anesthesia with intubation was carried out prior to transesophageal echocardiography. The patient was placed in the supine position. A complete transesophageal echocardiographic evaluation was performed to determine the location and the configuration of the PDA. The

minimum PDA diameter, aortic ampulla dimension, and ductal length were also measured.

An incision measuring about 2.5 cm in length was made along the second intercostal space at the junction of the left front chest and the left midclavicular line (**Figure 4**). Superficial tissues were opened with blunt dissection without entering into the pleural space. The pericardium was incised and suspended to the skin, then exposure was optimized with a miniretractor. Systemic heparinization (125 U/Kg) was administered.

A purse-string suture of 4-0 Prolene (Ethicon Somerville, NJ) was made on the main pulmonary artery about 1 cm away from the opening of the ductus arteriosus on the side of the pulmonary artery. A puncture needle was inserted into the main pulmonary artery through the purse-string suture and the core was taken out. Under the guidance of transesophageal echocardiography, a guide wire was deployed, passed through the ductus arteriosus and reaching the descending aorta. Based on transesophageal echocardiography measurements, an appropriately-sized mushroom-shaped occluder was selected. The diameter of the selected occluder should be 2-3 mm more than the minimum diameter of the ductus arteriosus. A device stay suture of 3-0 prolene suture was stitched along the wire mesh of the mushroom under the recessed microscrew and pulled out of the sheath. The delivery rod was tightened with the corresponding mushroom disc after passing through the loading sheath, and the mushroom disc was pulled back into the loading sheath. Meanwhile, the prolene stay suture was delivered through the loading sheath and exposed at the side of delivery sheath. The pulmonary artery wall was dilated using dilators and the delivery sheath was inserted along the guide wire under the guidance of transesophageal echocardiography into the thoracic aorta to a distance of approximately 0.5 cm. The core was with drawn and the prepared loading sheath was connected. In this way, the delivery channel from the mushroom disc to the ductus arteriosus was established. The delivery rod was slowly pushed to release the mushroom disc along the prepared delivery channel. After the head of mushroom was expanded, the whole delivery sheath was pulled towards the pulmonary artery to closely

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**Table 1.** Comparison between preoperative and postoperative indicators (n = 29, x+s)

Items	Preoperative	Postoperative
Pulmonary artery systolic pressure (mmHg)	92.3+19.2	50.9+14.8
Pulmonary artery diastolic pressure (mmHg)	45.6+16.2	13.4+11.1
Mean pulmonary artery pressure (mmHg)	59.9+14.9	25.1+9.6
Mean aortic pressure (mmHg)	65.2+24.3	64.9+25.1
Lower-extremity blood oxygen saturation (%)	98.9+1.5	96.8+1.2

## Statistical analysis

SPSS 13.0 was applied to evaluate the data. Measurement data were represented as (Mean + SD), and the preoperative and postoperative data were compared using the paired *t*-test. A *P*-value < 0.05 was considered statistically significant.

attach the mushroom head to the opening of the ductus arteriosus on the aorta side. The rest of the mushroom disc was then fully expanded and the opening within the ductus arteriosus on the pulmonary artery side was closed (**Figures 5, 6**). The occluder should be not released and was observed for 30 minutes [10]. The pulmonary artery pressure, aortic pressure, and lower-extremity blood oxygen saturation were monitored continually. If the pulmonary artery pressure was increasing, while the aortic pressure was decreasing, and the blood oxygen saturation was decreasing, the mushroom device should be with drawn into the delivery sheath and the operation was terminated. If the pulmonary artery pressure was decreasing, there was no change in the aortic pressure, the blood oxygen saturation did not change or improved, there was no pressure gradient on the aortic side, and there was no shunt or only a small shunt in the ductus arteriosus, the delivery rod was rotated in the counterclockwise direction to release the occluder. At last, the prolene stay suture was tied down with the pursestring sutures of the pulmonary trunk to avoid dislocation of the device into the descending aorta.

## Postoperative follow-up

Echocardiography and posteroanterior chest X-ray were performed on the first postoperative day to confirm the location of the occluder and to exclude a possible residual shunt. In addition, the pulmonary artery pressure and heart function were monitored. During the postoperative follow-up, the clinical symptoms, signs, echocardiography, electrocardiogram, and chest X-ray were evaluated. The postoperative follow-up was carried out at 5 days, 1, 3, 6 and 12 months after surgery. Dipyridamole was routinely applied for anticoagulation after surgery for 3 months and captopril was used to reduce the pulmonary artery pressure for 6 months.

## Results

Successful occlusion was achieved in 30 of 39 patients (76.9%). The mean PDA diameter of all successfully occluded PDAs was  $15.2 \pm 2.1$  mm, and the average diameter of the applied mushroom-shaped PDA occluder was  $17.5 \pm 2.5$  mm. In the successfully occluded cases, the pulmonary artery pressure was reduced more than 30 mmHg or 20%. The pulmonary artery systolic pressure decreased from  $92.3 \pm 19.2$  mmHg before surgery to  $50.9 \pm 14.8$  mmHg after surgery, the pulmonary artery diastolic pressure decreased from  $45.6 \pm 16.2$  mmHg to  $13.4 \pm 11.1$  mmHg, the mean pulmonary artery pressure decreased from  $59.9 \pm 14.9$  mmHg to  $25.1 \pm 9.6$  mmHg, and all differences were statistically significant ( $P < 0.01$ ). The mean aortic pressure did not decrease significantly or slightly increased, and there was no significant difference between preoperative and postoperative values ( $65.2 \pm 24.3$  mmHg vs.  $64.9 \pm 25.1$  mmHg,  $P > 0.05$ ). The lower-extremity blood oxygen saturation increased mildly, but there was no significant difference ( $98.9\% \pm 1.5\%$  vs.  $96.8 \pm 1.2\%$ ,  $P > 0.05$ ) (**Table 1**).

Echocardiography on the first postoperative day showed that the volumes within the left atrium, ventricle, and pulmonary artery were reduced in 21 cases, the volumes within the left atrium and ventricle were reduced in 4 cases. There were no volume changes in 5 cases, and 6 cases had small shunts. Chest X-rays showed reduced pulmonary congestion in all cases and decreased cardiothoracic ratio in 25 cases. All patients were discharged with complete recovery.

Among 9 patients who failed occlusion, the mean diameter of PDA was  $17.8 \pm 3.2$  mm, and the average diameter of applied mushroom-shaped PDA occluder was  $19.1 \pm 4.1$  mm. In 7

of these 9 cases, the pulmonary artery pressure increased, the aortic pressure decreased, and the blood oxygen saturation decreased after complete opening of the disc of occluder ( $P < 0.01$ ). After withdrawal of the disc of the occluder, the pulmonary artery pressure decreased, the aortic pressure increased, and the blood oxygen saturation improved. Moreover, No. 24 and No. 26 occluders were used for two cases with a large PDA. Although the pulmonary artery pressure was reduced, a large residual shunt was observed, and we directly converted the procedure to open surgical repair under CPB.

31 patients who underwent successful occlusion were followed up 1, 3, 6 and 12 months after discharge. Symptoms, signs, echocardiography, electrocardiogram, and chest X-rays were evaluated. The rate of follow-up was 100%. No patient died during follow-up. No symptoms such as palpitation, shortness of breath, and chest tightness were observed. The heart functions were NYHA class I-II. A small shunt was observed only in one case. There were varying degrees of decrease in the volume of the atrium and ventricle.

### Discussion

Termination of blood flow within the ductus arteriosus is the best treatment for PDA in adults [2]. However, PDA in adults is often associated with severe pulmonary hypertension and the long-term left-to-right shunt sometimes induces an irreversible increase in pulmonary arteriolar resistance [4, 11]. Therefore, the possibility of intervention is the key point in the evaluation of these patients. Patients definitely diagnosed with Eisenmenger syndrome cannot undergo surgery. Many adult patients with PDA have associated pulmonary hypertension but do not have Eisenmenger syndrome [15]. These patients can be treated successfully by closing the ductus arteriosus.

Currently, the main surgical procedures available include open surgery and transcatheter occlusion. Surgical procedures include ligation with a left mini-thoracotomy and ligation via a median sternotomy under CPB. The ductus arteriosus in these patients is often calcified and easily broken at the time of ligation, and thoracoscopic surgery is not suitable. Traditional surgeries usually cause massive trauma,

numerous complications, and aesthetic problems. Moreover, recovery is slow [2]. For adult patients with PDA and serious pulmonary hypertension, pulmonary vascular resistance should be detected by a right heart catheterization or acute pulmonary vasodilator testing before surgery, and it restricts the application of traditional surgical techniques in the treatment of PDA in adults.

Interventional cardiac catheterization has developed greatly in recent years. It has the advantages of minimal invasiveness and quick recovery [16]. Moreover, it meets the aesthetic requirements of the patients. However, radiation exposure to surgeons and patients is inevitable, the procedure is complicated, the equipment is expensive and the learning curve is steep. In addition, as soon as complications such as occluder displacement and/or bleeding occur, the patient has to be transferred from the cardiac catheterization laboratory to the operating room, which may delay the rescue time.

Echocardiography-guided transthoracic occlusion used in the present study for adult patients with PDA and severe associated pulmonary hypertension is a hybrid technique combining the advantages of open surgery and interventional catheterization [12, 17]. This technique is carried out under the guidance of transesophageal echocardiography, which avoids excessive radiation exposure. In addition, the length of incision in the left anterior chest is only 2 cm, which avoids massive trauma and meets the aesthetic requirement of patients. The ductus arteriosus can be blocked temporarily (which is extremely important for patients with severe pulmonary hypertension, especially for those with possible Eisenmenger syndrome), the procedure is conducted on the surface of the main pulmonary artery, and the vertical operating makes the procedure simple. Thus, the learning curve is not steep. The mushroom-shaped disc can be fixed on the pulmonary artery wall by pulling the prolene suture to avoid serious complications like occluder displacement. Finally, this technique is performed by surgeons in the operating room, which ensures the maximal safety of patients [9].

Surgical indications for PDA in adults with severe pulmonary hypertension are primarily

based on whether the pulmonary hypertension is dynamic or resistant [12]. The surgical outcome of patients with dynamic pulmonary hypertension is satisfactory, but that of patients with resistant pulmonary hypertension is poor and may even lead to death. Many scholars used to believe that the PDA in adults is often associated with severe pulmonary hypertension and pulmonary arteriolar resistance is close to the diagnostic criteria of Eisenmenger syndrome, which requires a right heart catheterization or an acute pulmonary vasodilator testing to calculate pulmonary arteriolar resistance and determine the nature of pulmonary hypertension [13, 14]. However, our hybrid technique can block the ductus arteriosus temporarily during surgery to distinguish the nature of pulmonary hypertension. Therefore, right heart catheterization or acute pulmonary vasodilator testing is not required. We can occlude the ductus arteriosus and strictly monitor the aortic pressure, pulmonary artery pressure, and lower-extremity blood oxygen saturation during surgery. If the average pulmonary artery pressure decreases more than 20% (or 30 mmHg) and the aortic pressure and the blood oxygen saturation do not decrease significantly, pulmonary hypertension is considered to be dynamic and the occluder can be released. If the pulmonary artery pressure increases and the aortic pressure and lower-extremity blood oxygen saturation decrease, pulmonary hypertension is considered to be resistant, and the occluder should be withdrawn [15].

Among the 30 patients who underwent successful occlusion, continuous murmur was heard in 25 cases, systolic only murmur was heard in 4 cases, and no significant murmur was heard in 1 case. The remaining 5 cases were considered to possibly have Eisenmenger disease. After temporary occlusion, it was found that the pulmonary artery pressure decreased more than 20% (or 30 mmHg) and there were no significant changes in the aortic pressure and lower-extremity blood oxygen saturation. Therefore, these cases were considered to have dynamic pulmonary hypertension and the occluder was released. Among the nine patients who could not undergo successful occlusion, continuous murmur was heard before surgery in two cases, but the ductus arteriosus was too large and the occluder could not completely block the blood flow. Therefore, we gave up on occlusion. In seven other cases, only systolic murmur was heard in four cases

and no significant murmur was heard in three cases before surgery. After temporary occlusion, the pulmonary artery pressure increased and the aortic pressure and lower-extremity blood oxygen saturation decreased. Therefore, it was considered to be resistant pulmonary hypertension and we gave up on occlusion for these cases.

The patients who underwent successful occlusion were followed up for at least 24 months and no patient died during the follow-up. There were no symptoms such as palpitation, shortness of breath, or chest tightness. The heart functions were NYHA class I-II. Chest X-ray showed reduced pulmonary congestion and contraction of the prominence in the pulmonary artery segment. Echocardiography showed a small amount of shunt in only one case. No dislocation of the occluder was observed and there were varying degrees of decrease in the volume of the atrium and ventricle. The results at follow-up showed that our hybrid technique can be used for PDA in adults with severe pulmonary hypertension as long as there is no definite cyanosis or Eisenmenger syndrome. The success rate was relatively high and the short-term outcome was satisfactory.

Transesophageal echocardiography guided patent ductus arteriosus occlusion through a parasternal approach is a hybrid technique for the treatment of PDA in adults with severe pulmonary hypertension. It is minimally invasive, simple, and relatively safe, and can determine the nature of pulmonary hypertension (dynamic or resistant) by temporary occlusion to decide on the permanent release of the occluder [9, 17].

In conclusion, the hybrid technique is safe and effective to treat PDA in adults with severe pulmonary hypertension. The short-term and mid-term outcomes were satisfactory. However, the number of cases in the present study was relatively small and long-term outcomes should be evaluated by a larger-scale, multicenter study.

### Disclosure of conflict of interest

None.

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