Hindawi
Journal of Interventional Cardiology
Volume 2024, Article ID 1859229, 5 pages
https://doi.org/10.1155/2024/1859229

Research Article

Value of Intracardiac Echocardiography in the Interventional Closure of Patent Foramen Ovale with Adjacent Atrial Septal Defect

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Received 21 December 2023; Revised 23 April 2024; Accepted 6 May 2024; Published 13 May 2024

Academic Editor: David G. Iosseliani

Objective. This study aimed to investigate the application value of intracardiac echocardiography (ICE) in transcatheter closure of a patent foramen ovale (PFO) combined with an adjacent atrial septal defect (ASD). *Methods*. This retrospective study included five patients with PFO combined with adjacent ASD who underwent transcatheter closure and were admitted to the Zhongshan Hospital of Fudan University from June to September 2023. General conditions, ultrasound and ICE findings, and operative data were recorded and followed up for 2–6 months. *Results*. Of the five patients, two and three had embolic stroke of undetermined source and migraine, respectively, aged 45.6 ± 12.0 years. All patients underwent successful transcatheter closure via the PFO tunnel under the guidance of ICE, without complications or new stroke, and showed significantly reduced migraine at the follow-up. *Conclusion*. In patients with PFO combined with adjacent ASD, closure of a PFO tunnel could be successfully achieved under ICE guidance; its clinical efficacy was accurate and worthy of promotion.

1. Introduction

Patent foramen ovale (PFO) affects approximately one in four adults, with potential complications including paradoxical embolism, undetermined-source embolic stroke, and migraines [1–4]. Interventional closure, a proven beneficial approach, is commonly performed using X-ray fluoroscopy. Transesophageal echocardiography (TEE) and intracardiac echocardiography (ICE) enhance the success rate, particularly in complex or "latent" PFO cases [5, 6].

Atrial septal defects (ASD) account for approximately 20%–30% of adult congenital heart diseases. Significant left-to-right shunt can result in increased volume load of the right heart and pulmonary blood flow, which ultimately leads to clinical manifestations such as pulmonary hypertension and right heart failure. Currently, interventional closure has become the preferred choice for treatment of anatomically appropriate ASD [7].

Patients with PFO combined with ASD are commonly encountered in clinical practice. In these patients, interventional treatment has proven to be safe and effective, particularly when the two are in close proximity to each other and can often be treated with single occlusion device placement. However, in clinical practice, determining the gap at which the catheter enters the left atrium is difficult. The catheter entering the left atrium through the ASD defect may lead to various problems, such as inappropriate selection of the occluder, dislocation and dislodgement of the occluder, and residual right-to-left shunt, thereby failing to achieve a preventive effect on strokes or migraines.

Accurate catheterization of the left atrium through the PFO channel is pivotal in these cases. Distinguishing

between catheter entry points (the left atrium through the PFO or ASD) optimally is often challenging using traditional methods, including X-ray fluoroscopy and transthoracic echocardiography (TTE). This study aimed to investigate the value of ICE for guiding interventional closure of PFO combined with proximal ASD.

2. Materials and Methods

2.1. Research Objectives. This retrospective study included patients with PFO combined with adjacent ASD who underwent interventional closure between June 2023 and September 2023 at the Department of Cardiology, Zhongshan Hospital, Fudan University. The inclusion criteria were preoperative TTE, contrast TTE, and TEE. This study was approved by the Medical Ethics Committee of Zhongshan Hospital, Fudan University (approval no.: B2022-452).

2.2. Interventional Closure Procedure. Under local anesthesia, the femoral vein was punctured twice, and 6Fr and 11Fr sheaths were implanted. A 10Fr ICE catheter (Biosense Webster, 31 Technology Drive, Suite 200, Irvine, CA 92618, USA) was introduced through an 11Fr sheath into the right atrium. The direction of the probe was adjusted to the optimal position for observing the fossa ovalis. Two-dimensional color flow imaging and spectral Doppler were performed to observe the anatomical morphology of the PFO and ASD, the distance between them, peripheral structures, and hemodynamics. The catheter, guided by ICE, was positioned against the fossa ovalis. The guidewire, assisted by the Swartz sheath and Valsalva maneuver if needed, traversed the foramen ovale into the left atrium, reaching the left upper pulmonary vein to establish the pathway. After the release of an Amplatzer PFO occluder (Abbott Medical, 5050 Nathan Lane North, Plymouth, MN55442, USA), ICE was used to observe its morphology, position, stability, and presence of residual shunts.

2.3. Follow-Up. Postoperatively, patients received oral aspirin at a dosage of 0.2 g once daily for the first month, followed by 0.1 g once daily for the subsequent 5 months. All patients visited the hospital or were followed up by telephone for 2–6 months. TTE and contrast TTE were performed during the follow-up.

3. Results

3.1. Baseline Date. A total of five female patients with PFO combined with adjacent ASD were included, aged 45.6 ± 12.0 years. Among these patients, two and three had embolic stroke of undetermined source migraine, respectively. Atrial and ventricular parameters, ejection fraction, and pulmonary artery systolic pressure were within normal ranges in all patients (Table 1). The lengths of the PFO in these five patients were 4 mm, 8 mm, 23.8 mm, 7 mm, and 6 mm, respectively. The diameter of the PFO, measured by esophageal ultrasound in the resting state, was ≤1.9 mm; the diameter of the ASD was 2.9 ± 0.7 mm. Among all patients, one and three had long-tunnel PFO and combined atrial septal aneurysm, respectively. One patient had two ASDs: one adjacent to the PFO and the other near the entrance of the inferior vena cava. The ASD at the inferior vena cava, farther from the PFO, had a small septal flow and normal pulmonary artery pressure. Therefore, the preoperative strategy was not to close the ASD individually and review the situation at regular intervals.

3.2. Surgical Outcomes. All patients underwent successful ICE-guided PFO occlusion with an Amplatzer PFO occluder, including an 18/25 mm occluder in one case and a 25/35 mm occluder in four cases. Intraoperative ICE showed that the shape and position of the occluders were good: all of them assisted in achieving cosealing of the PFO and ASD without a residual shunt (Figure 1). No perioperative complications occurred, such as death, infection, bleeding, coronary embolization, occluder displacement or dislocation, or pericardial tamponade.

3.3. Follow-Up. At the 2–6 month postoperative follow-up, all patients maintained a good occluder position without displacement or thrombus formation. Adjacent cardiac tissues showed normal structure. No strokes occurred, and preoperative migraines disappeared or were significantly reduced postoperatively.

4. Discussion

In recent years, the diagnosis and management of PFO have gained increasing attention. In patients with embolic stroke of undetermined source, transient ischemic attacks, and PFO-associated migraines, interventional closure proves more to be effective compared with anticoagulant therapy [8]. With results from international randomized controlled studies on transcatheter closure of PFO versus pharmacological treatment, transcatheter closure of PFO has been recommended by many domestic and international guidelines [4, 9–12]. In patients with PFO and ASD, ensuring catheter entry into the left atrium through the PFO is challenging. There are only a few reports on closure in this specific patient population. Our findings showed that ICE, in transcatheter closure of PFO combined with adjacent ASD, could offer clear visualization of PFO, ASD, and atrial septum morphology, accurately guiding catheter placement through the PFO. Simultaneous closure of the PFO and adjacent ASD was successfully achieved in five patients, without residual shunt. Compared with TEE, ICE does not require general anesthesia; patients can be instructed to perform the Valsalva maneuver during the operation, which is crucial, particularly in those with difficult-to-pass PFOs. At the same time, the effect of closure can be viewed in real time, which improves the success rate of the operation and reduces the number of complications.

At our center, PFO closure mainly uses X-ray fluoroscopy. In "latent" or difficult-to-pass PFO cases, techniques, such as right atrium-ovoid fossa contrast imaging, Swartz sheath reinforcement support, coronary guidewire

Table 1: Transthoracic echocardiography data in five patients.

Patient	LAD (mm)	LVIDs (mm)	LVIDd (mm)	RVDd (mm)	PASP (mmHg)	EF (%)
1	39	24	41	30	30	62
2	32	28	46	32	24	70
3	39	30	48	33	28	67
4	37	32	46	33	35	58
5	38	28	46	35	28	69

LAD: left atrium diameter; LVIDs: left ventricle internal diameter in systole; LVIDd: left ventricle internal diameter in diastole; RVDd: right ventricular end diastolic diameter; PASP: pulmonary artery systolic pressure; EF: ejection fraction.

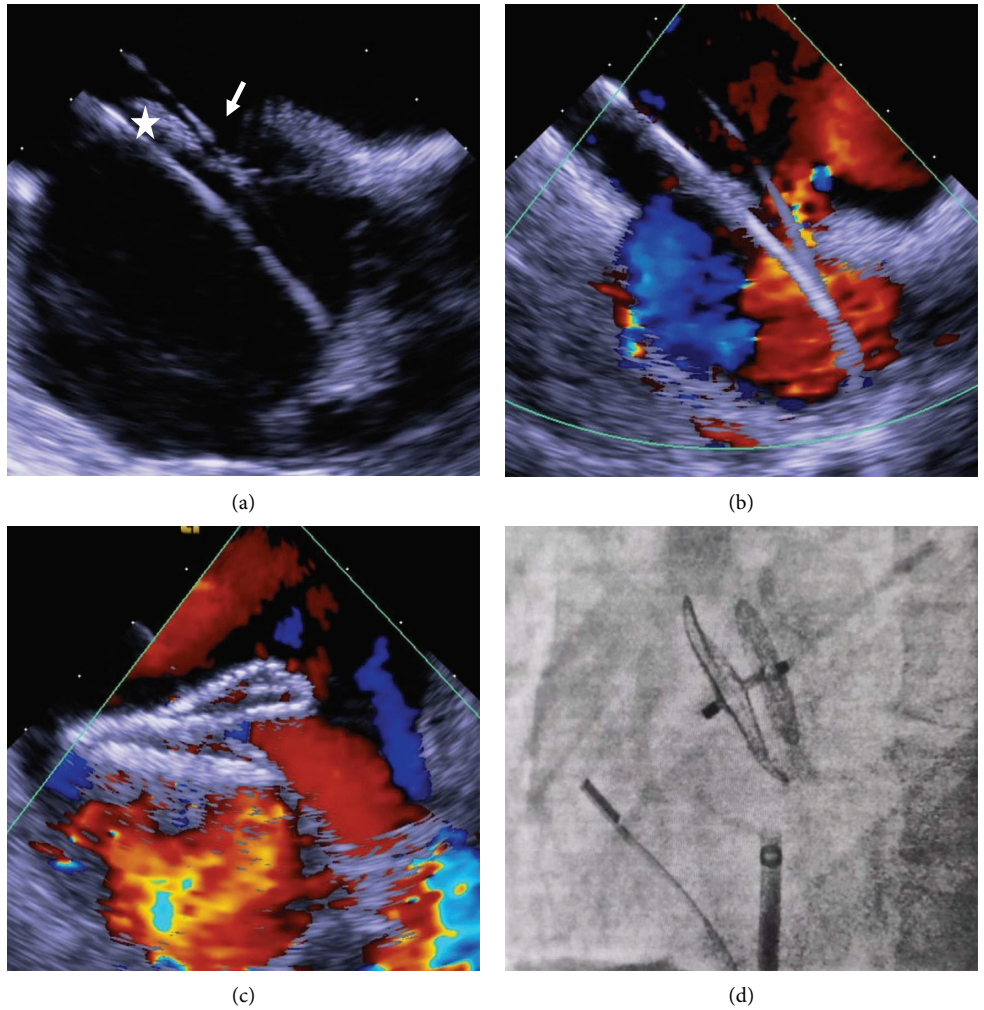

Figure 1: Transcatheter closure of the PFO and adjacent ASD under ICE and X-ray fluoroscopy guidance. (a) Atrial septal defect (arrow) and foramen ovale (asterisk) on ICE two-dimensional imaging. (b) Left-to-right shunting at atrial septal defect on ICE Color Doppler Flow Imaging. (c) No residual shunting after occluder closure. (d) Percutaneous PFO closure with the double disk device guided by X-ray fluoroscopy. ASD, atrial septal defect; ICE, intracardiac echocardiography; PFO, patent foramen ovale.

assistance, and coordination with the Valsalva maneuver, enhance the success rate of PFO closure under X-ray fluoroscopy alone, with less reliance on TEE and ICE. However, during treating PFO combined with adjacent ASD, challenges not only lie in passage difficulty but also in determining whether the passage is PFO. Complete PFO closure is crucial for preventing stroke and migraine, differentiating it from adjacent ASD clinical consequences.

The structure of the PFO occluder resembles the ASD occluder, with the slender center waist as the major difference. If the occluder is placed through ASD, the PFO occluder lacks radial support in the case of a large ASD defect diameter; thereby, it becomes less stable and prone to residual shunting. It may also fail to cover the foramen ovale or only partially cover it, leading to a persistent right-to-left shunt that does not achieve the preventive effect on strokes or migraines.

X-rays cannot accurately determine whether the guidewire enters the left atrium via the ASD or PFO. In addition, TTE is often affected by various factors such as obesity and excessive lung air, which often do not clearly show the anatomical structure of the PFO [13]. TEE often requires general anesthesia, endotracheal intubation, and a prolonged operative time, which may result in increased complications.

Compared with TEE, ICE acquires clearer images and more accurate data and does not require general anesthesia, thus reducing the risks and complications associated with general anesthesia [14, 15]. More importantly, in patients wherein the guidewire cannot be easily passed through the PFO, the Valsalva maneuver can be performed during ICE. However, ICE catheters are relatively expensive, limiting their clinical use to a certain extent. In the vast majority of PFOs, closure can be successfully accomplished using X-ray fluoroscopy and TTE.

However, in patients with PFO combined with an adjacent ASD, ICE remains of great clinical value for ensuring the efficacy of closure. ICE can not only clearly show the diameter and length of the PFO channel but also reveal various morphological variations of the septum coexisting with it, which provides important information on the selection of the appropriate type of occlusion. For example, when PFO is combined with atrial septal aneurysm, proximal ASDs, and secondary septal thickening, the incidence of residual shunt is high after sealing with a small occluder and a larger PFO or ASD occluder is usually preferred. ASD occluders may also be necessary for large-diameter PFOs [16]. In "latent" or difficult-to-pass PFO cases, ICE can better guide the sheath to align with the opening of the foramen oval, thereby reducing complications such as intraseptal dissection and pericardial tamponade caused by the guidewire searching for and passing through the PFO.

This study has some limitations. This study was a real-world observational study with a small sample size, no control group, and a short follow-up period. In the future, we will conduct a study with a larger sample size and long-term follow-up.

In conclusion, ICE could offer clear visualization and accurately guide catheter placement through the PFO tunnel, which improved the success rate of the operation, and thus achieved the effect of preventing PFO-related strokes or migraines. In patients with PFO combined with adjacent ASD, the clinical efficacy of ICE was accurate and worthy of promotion.

Of note, ICE has many limitations. Most notably, ICE catheters are for single-use and costly, making them more expensive when ICE was used for interventional procedures compared with TEE. In terms of procedural complications, ICE catheter needs to be inserted into the central vein, which may increase complications associated with vascular punctures. ICE catheter manipulation in the cardiac chambers may irritate the endocardium, causing arrhythmias. In addition, lacking experience in ICE use by domestic cardiovascular interventionalists has also limited the popularization of this technology.

Data Availability

The authors confirm that the data supporting the findings of this study are available within the article.

Disclosure

The funder had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Boqian Zhu, Tao Zhu, and Jianing Fan have contributed equally to this work.

Acknowledgments

This study was supported by the National Natural Science Foundation of China (Research Grant #81900237), the Natural Science Foundation of Jiangsu Province (Research Grant #BK20191093), and the Summit Talent Program of Jiangsu Province Hospital of Chinese Medicine (Research Grant #y2021rc40).

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