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EDITORIAL

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Intracardiac echocardiography in the diagnosis and closure of patent foramen ovale

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Patent foramen ovale (PFO) which is caused by failed fusion of septum primum and septum secundum, is the first leading congenital heart abnormality, affecting about 25% of the general population.[1–3] PFO is associated with many diseases, including decompression sickness, platypnea-orthodeoxia, and migraines.[4–6] Importantly, it has been hypothesized that PFO allows the thrombus to move directly from the right side of the heart into arterial circulation and may cause cryptogenic stroke, particularly in patients with deep venous thrombosis and other structural abnormalities like atrial septal aneurysms, Chiari network, and Eustachian tube dysfunction.[7–14] This hypothesis may be confirmed by the images of thrombus in the tunnel of PFO, which moves through the foramen ovale.[15,16] One study showed that approximately 40% of cryptogenic strokes are accompanied with PFO and patients with cryptogenic stroke are more likely also experience PFO than patients with strokes from known causes.[17,18] Clinical trials have shown that the closure of PFO can help to prevent stroke recurrence in patients who have already had a cryptogenic stroke. Other studies have also shown an association between PFO and migraines because the vasoactive substances can also pass directly to the left side of the heart without being metabolized in the lung and thus stimulates the brain.[19,20] Therefore, the diagnosis and treatment of PFO are important especially for those with symptoms.

Treatment of PFO includes medical therapy,[21] surgery,[22,23] and percutaneous transcatheter closure.[24–27] Percutaneous transcatheter closure has high efficacy and safety, and it is currently the first choice. Conventional echocardiography was used to guide PFO closure. Intracardiac echocardiography (ICE) outperforms conventional echocardiography (e.g., transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE)), which have some limitations in guiding PFO closure. It has become widely used in clinical practice, producing high quality images and offering the flexibility of multi-angle images. This study was intended to summarize some aspects of PFO. We placed particular focus on the application of ICE in PFO diagnosis and closure, including operation, strength, complications, and prospects.

INITIAL DIAGNOSIS OF PFO

Clinically, if patients have PFO-related symptoms (e.g., cryptogenic stoke or migraine) and are suspected of having PFO, imaging techniques including TTE, transcranial doppler (TCD), and TEE are initially used.[28] TTE can not only provide structural information but also allow the user to assess the size of the PFO, which is important for the initial diagnosis. TCD has greater sensitivity than TTE and can indirectly diagnose PFO by detecting the right-to-left shunting. However, because TCD cannot directly indicate the presence of PFO, it is difficult to distinguish PFO from atrial septal defects and intra-pulmonary shunting.[29] Furthermore, TCD cannot directly determine PFO size or provide structural information. TEE can also be used in outpatient settings without any need for anesthesia and allows direct observation and measurement of the PFO. Combined with agitated saline and Valsalva maneuver under the assistance of anesthesiologists, it can increase the sensitivity and specificity of the detection process.[30]

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IMAGING TECHNIQUES DURING PFO CLOSURE

After initial diagnosis, the patient and doctor decide whether to perform percutaneous PFO closure. During percutaneous PFO closure, structural information is of the utmost importance to size and locate PFO and to guide the procedure. In this case, TCD was not possible. TTE is a reasonably convenient procedure, and obtaining the necessary structural information can still be practical. However, TTE has a relatively low resolution because of the long distance from the heart and artifacts that may be present in the bone and lungs. In fact, it has been shown that TTE might underestimate the size of PFO and it is relatively difficult to effect good visualization on posterior and inferior parts of the septum. TEE can also be used during PFO closure with high sensitivity and specificity. However, this procedure requires anesthesia during the PFO closure. Over the past several years, ICE has been widely used in guiding radiofrequency ablation, facilitating transseptal puncture, measuring ejection fraction, left atrial appendage closure, and aortic valve replacement.[31–37] Recently, it has been shown that ICE can also be used in PFO closure, providing detailed information with high image quality and increasing surgical efficacy.

STRENGTH OF ICE IN PFO CLOSURE

ICE has higher image resolution and continuously provides detailed images from different angles in the procedure.[38] It can directly diagnose the PFO and continuously guide the procedure. ICE avoids the X-ray artifacts made by the esophageal probe of TEE. X-ray is only used before the catheter arrives at the right atrium, reducing the duration of radiation exposure, which can be crucial for children and pregnant women. In the heart, ICE can accurately assess the size, position, and edges of PFO at different angles and evaluate the surrounding cardiac structures like pulmonary veins, which is essential for device deployment and wire positioning.[39] It has been shown that ICE can reveal the anatomical information missed by TEE including the atrial myxoma, Chiari network with thrombus, and additional septal defects.[38,40–42] Septum rim of the posterior and inferior parts can be better and more easily visualized by ICE than by TEE. Furthermore, ICE does not require general anesthesia, esophageal probe, or assistance from a sonographer during PFO closure. Complications related to general anesthesia and intubation can be avoided, and the interventional cardiologist can perform both imaging and catheterization procedures. Without assistance from a sonographer, the cardiologist can directly and efficiently produce excellent images, which can decrease the time needed for surgery. Studies showed that ICE could significantly decrease the necessary radiation dose, and time needed for surgery and fluoroscopy[38,43,44]. ICE can also be used to detect residual shunting immediately after percutaneous PFO closure.[45] It can be used to directly monitor acute complications, such as thrombus formation and pericardial effusion.

PROCEDURE OF ICE IN PFO CLOSURE

ICE can be used to directly observe the PFO and continuously guide the procedure. The 10F catheter is inserted from the left or right femoral vein via an 11F sheath and is then guided through the inferior vena cave to the middle of the right atrium. Here, it is considered in the "home" position with the transducer facing the tricuspid valve. In this position, the right atrium, right ventricle and tricuspid valve can be observed. Then by superior advancing, clockwise rotation, and posterior tilting, the "septal" position is achieved. In this view, PFO can be observed directly. Later, by advancing the transducer toward the superior vena cave, the "long axis" position is achieved. In this position, it is feasible to directly observe the PFO and the interatrial septum from the superior part to the inferior part. If PFO is not apparent, ICE can be combined with the Valsalva maneuver and the injection of contrast or saline, which produces small bubbles in the left atrium.[46] After a deep inhalation, the patient is asked to hold his or her breath, which can decrease the venous return to the right atrium; thus, the volume of the right atrium decreases. Later, inject the contrast medium into the right atrium, and then the patient is asked to breathe normally. Breathing can increase the pressure on the right atrium relative to that of the left atrium and the contrast moves to left atrium through the PFO. This procedure can be repeated many times until high-quality images of the right to left shunting are produced. If the Valsalva maneuver is negative, other provocation like a sharp sniff or cough can be used.

In treatment, percutaneous transcatheter closure is the most commonly used method. It is highly safe and efficacious. The procedure starts with a complete anatomic evaluation of the PFO and surrounding structures by ICE. Then, the proper size Amplatzer PFO occluder is selected. The closure starts by advancing the device delivery sheath over the guidewire toward the left upper pulmonary vein. First, the left side disk of the occluding device is deployed in the left atrium. Second, the device and sheath are then pulled back against the atrial septum. Third, after the left disk comes into close contact with the septum, the right atrial disk is deployed by further withdrawal of the sheath.[47] After implantation and before release, ICE can determine whether the disk is tilted or in any abnormal position. After release, ICE can determine whether the septum primum and septum secundum have come into contact. Color Doppler can be used to detect the residual shunting. ICE can help re-position the closure device and detect embolization. This is meaningful because, in the closure of atrial septal defects, malposition and embolization are the most common complications at the early stage where patients may need surgical retrieval even though the embolization has not been shown in PFO closure.[48]

COMPLICATIONS AND LIMITATIONS OF ICE IN PFO

The use of ICE is operator-dependent because the operator needs to learn how to perform the procedure and analyze the images without a sonographer. ICE needs second venous access and has a higher risk of vascular injury, which is not suitable for primary diagnosis. Theoretically, ICE may cause vascular injury during placement of the 11F sheath to allow ICE catheter access, which may be more important for children. Fortunately, it has been shown that the risk of vascular injury in children was low and could be avoided by using an 8F ICE catheter, which should be more appropriate for children.[49] In one study of 94 patients from the Mayo Clinic, ICE complications only occurred in 4% of adults, including one patient with supraventricular tachycardia and three with atrial fibrillation.[42] Of these, two of four patients with atrial fibrillation saw their condition corrected by electrical cardioversion, while the other two patients were spontaneously resolved. Later, a study of 115 patients from the same institution showed one patient developed vascular-access-related bilateral groin hematoma after ICE-guided atrial septal defect closure.[50] Another study showed patients developed atrial tachycardia (4.1%) and paresthesia in the lateral aspect of the right thigh (4.1%).[51] Nearly all of the studies showed the superior safety and efficacy of using ICE during closure and even for long periods after the closure.[41,44,52,53]

However, although the safety of ICE is well accepted, it is still an invasive intervention and not practical for initial diagnosis. Instead, TTE, TCD, and TEE are relatively easy to access and are used for initial clinical diagnosis. ICE is used when performing the closure operation after the initial diagnosis, providing detailed structural information and continuous guidance.

PROSPECTS OF ICE

Real-time three-dimensional ICE (RTICE) has not been widely used in clinical practice.[54,55] However, some studies showed that, relative to two-dimensional ICE, it could improve the image quality and provide more information, including allowing clear tracking devices and detection of the relationship with surrounding structures.[56,57] One study on detecting the efficacy of RTICE on mitral balloon valvuloplasty showed it further decreased the time needed for fluoroscopy and necessary dose of radiation.[58]

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