Cardiac Magnetic Resonance Imaging of Atrial Septal Defect for Transcatheter Closure

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Abstract

Background : The location, size of the defect and age of the patient are the major determining factors for transcatheter closure of an atrial septal defect (ASD). The precise shape and anatomy surrounding the defect cannot always be understood by the traditional transesophageal (TEE) echocardiographic technique.

Objectives : The authors compared the measurement of ASD size and atrial septal rim using cardiac Magnetic Resonance Imaging (MRI) and TEE to the balloon sizing technique and device size.

Patients and Method : Patients having an ASD which met established criteria were selected for evaluation with cardiac MRI and TEE for a closure procedure. Comparison of the ASD imaging and sizing between the different methods was made.

Results : There were 22 patients who had complete transcatheter closure. The mean age and standard deviation of the patients was 33.2±15.1 (8-67) years old. The mean weight of the patients was 51.6±13.1 (20-99) kg. The average cardiac MRI measurement of the ASD was 24.9± 6.4 mm compared to the TEE measurement of 20.8±5.5 mm. The transcatheter balloon measurement of the ASD was 25.2±6.9 (11-36) mm and the device closure size was 24.8±6.6 (11-36) mm. The correlation coefficient of cardiac MRI to device closure size was $r = 0.784$ ($p < 0.001$) when compared to TEE measurement to device closure size; $r = 0.761$ ($p = 0.001$).

Conclusion : The authors demonstrated the capability of the cardiac MRI in assessment of the ASD morphology and anatomy for transcatheter closure of the ASD with an Amplatzer™

Septal Occluder. Cardiac MRI can provide information about the type, location, size of the defect and direct visualization of the atrial septum anatomy. This detailed information enabled us to provide a safer, more effective application of the ASD occluder.

Key word : Cardiac Magnetic Resonance Imaging and Atrial Septal Defect

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Atrial septal defect (ASD) accounts for 10 per cent of congenital heart disease at birth and as much as 30-40 per cent of cases seen in adults who present with a congenital heart problem[1]. It is generally agreed that an ASD associated with a large left-to-right shunt should be electively closed. Surgical repair of an ASD is a safe and widely accepted procedure with negligible mortality. However, it is associated with morbidity, discomfort and a thoracotomy scar[2,3]. As an alternative to surgery, transcatheter closure of an ASD has been developed[4,5]. The authors initially reported their experience of transcatheter closure of atrial septal defect using the Amplatzer™ Septal Occluder with intermediate term follow-up[6,7]. The result of successful transcatheter closure with surgery was also compared[3]. Conventional methods for evaluation of the ASD include transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE). Recently, a study revealed that as many as 41 out of 240 patients were excluded from transcatheter closure of ASD by using transthoracic and transesophageal echocardiogram[8]. However, only 144 patients had successful closure. The location, size of the defect, and age of the patient are the major determining factors indicating whether surgical correction or transcatheter closure by a device is preformed[9]. Newer techniques for evaluation of the ASD anatomy are the three dimensional echocardiography performed using a TEE probe[10,11], intracardiac ultrasound[12,13] and magnetic resonance imaging[14-16]. Three dimensional images were constructed to simulate the ASD view as seen by a surgeon, however, it still requires TEE which poses a small but potentially life threatening risk with some discomfort[17,18]. Intracardiac ultrasound is not currently available in Thailand. Visualization of the ASD by cardiac MRI using the spin-echo technique is well established, as is the use of dynamic imaging with a gradient-echo technique to visualize the ASD shunt flow. Investigators have also compared the apparent ASD size in spin-echo images with measurement by other methods and during surgery[14-16]. The objectives of this study were to determine whether cardiac magnetic resonance imaging (MRI) is an accurate non-invasive technique for defining the morphology of atrial septal defects (ASD) and to compare this technique with measurement of the ASD by transesophageal echocardiogram, a transcatheter balloon sizing technique and the final device size.

METHOD

Patients

Patients with a secundum ASD were evaluated with transthoracic or transesophageal two-

dimensional color Doppler echocardiography from August 2000 to December 2001. Patients who met the criteria for transcatheter closure of the ASD (isolated secundum ASD, large left to right shunt with a ratio of pulmonary to systemic blood flow or Qp : Qs > 1.5:1, and a distance of > 5 mm from the margins of the defect to the surrounding organ) were enrolled in the study. Patients who were excluded from transcatheter closure were patients who had associated congenital heart defect (s) which required cardiac surgery, had other types of ASD (sinus venosus or ostium primum).

Measurement of the ASD

Since the majority of ASD are not circular, the authors defined the measurement of the largest diameter (Fig. 1) obtained by each technique as the major axis, and likewise, the smallest diameter obtained in the same patients as the minor axis. The distance of the surrounding atrial septal rims was defined as the distance measured which corresponded to each of the four rims as follows (Fig. 1A-1D): 1) Anterior superior (AS) rim is the rim adjacent to the aortic valve, 2) The anterior inferior (AI) rim is the rim adjacent to the tricuspid valve, 3) The posterior superior (PS) rim is the rim adjacent to the superior vena cava and 4) The posterior inferior (PI) rim is the rim adjacent to the inferior vena cava.

Transesophageal echocardiographic (TEE) measurement

Two-dimentional and color Doppler echocardiograms were recorded using an Agilant 5500 echocardiographic machine with TEE probe (Agilant Technologies, Andover, MA, USA). Conventional cross-sectional studies of the atrial septum were performed using a standard view[19]. All of the TEE measurements were performed within one month of the transcatheter closure. For the TEE measurement a Pediatric bi-plane probe (9 mm in diameter) was used for children smaller than 20 kg and an adult multiplane probe in larger sized patients.

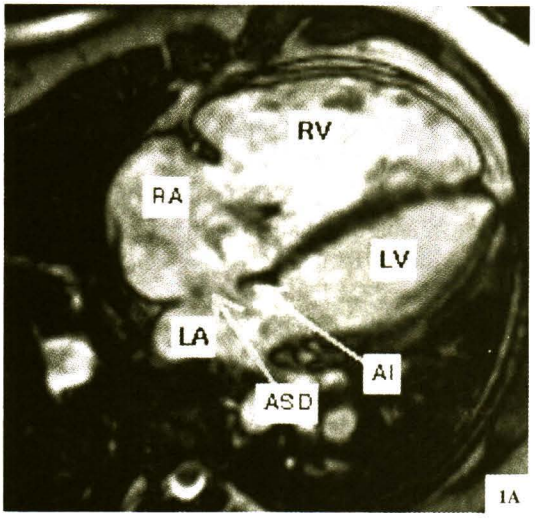


Fig. 1A. Cardiac MRI of an ASD showing a four chamber view.

ASD = Atrial septal defect, RA = Right atrium, LA = Left atrium, RV = Right ventricle, LV = Left ventricle, AI = Anterior inferior rim.

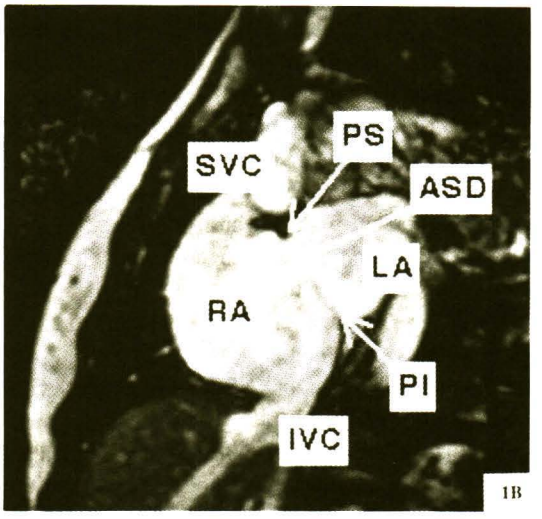


Fig. 1B. Cardiac MRI of an ASD showing a modified short axis view and saggital view of the atrial septum with the right atrium to the left of the picture.

ASD = Atrial septal defect, RA = Right atrium, LA = Left atrium, SVC = Superior veva cava, IVC = Inferior veva cava, PS = Posterior superior rim, PI = Posterior inferior rim.

Magnetic resonance imaging

The MRI studies were performed on a Philips 1.5T whole body MR scanner (NT Intera release 7 with Master gradient). A series of breath-holding multislice, multiple heart phase gradient echo sequence covering the whole atrium was performed in different planes in order to measure the size of the ASD size measurement (2D TFE, multi-slice, prospective triggering, 350 mm Field of view, 256x256 image matrix, 8 mm slice thickness with zero slice gap, flip angle 25 degrees, 15 heart phases, TR 9.1 msec, TE 4.5 msec, 1 signal average). Firstly, four chamber views were performed which would provide the AI rim measurement (Fig. 1A). Next, modified short axis views (Fig. 1B) were done to obtain the PS and PI rim measurement. Thereafter, transaortic views (Fig. 1C), comparable to the short axis view on the transthoracic echocardiogram, were performed to provide the AS rim measurement. The size of the ASD was measured in all the above views during the early diastolic filling period when the ASD shunt flow was maximal (approximately 400 msec after R wave). Finally, a flow-sensitive gradient-echo pulse sequence was performed in the enface view (Fig. 1D-1F), to provide a spatial orientation of the ASD, its change in size and shape during the cardiac cycle, and it's relation to vital adjacent structures, such as the tricuspid valves, the coronary sinus and the great veins (2D FFE, retrospective gating, 300 mm Field of view, 128 x 256 image matrix, 6 mm slice thickness, flip angle 30 degrees, 30 heart phases, TR 20 msec, TE 6.5 msec, 4 signal averages, 80-100 cm/sec phase-contrast velocity).

Balloon-size measurement

A detailed description of the transcatheter closure technique has been explained previously [6,7]. As a brief summary, the patients were intubated and placed under general anesthesia. A complete hemodynamic evaluation was performed. An angiographic picture was taken in the right pulmonary vein to delineate the anatomy of the ASD. An exchange 260 cm, J-tipped guide wire was placed into the end hole catheter in the left upper pulmonary

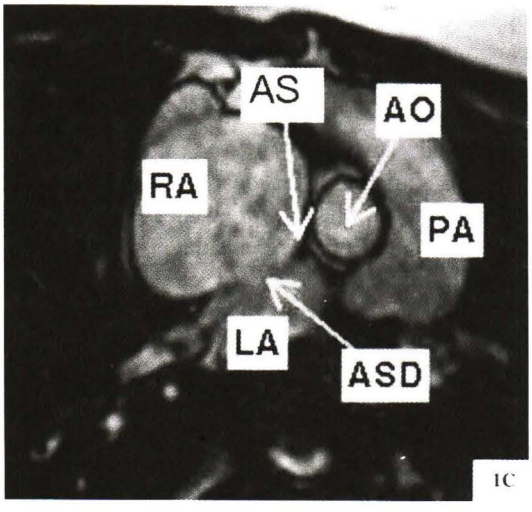


Fig. 1C. Cardiac MRI of an ASD transaortic view comparable to a parasternal short axis view of an echocardiogram.

ASD = Atrial septal defect, RA = Right atrium, LA = Left atrium, PA = Pulmonary artery, Ao = Aorta, AS = Anterior superior rim.

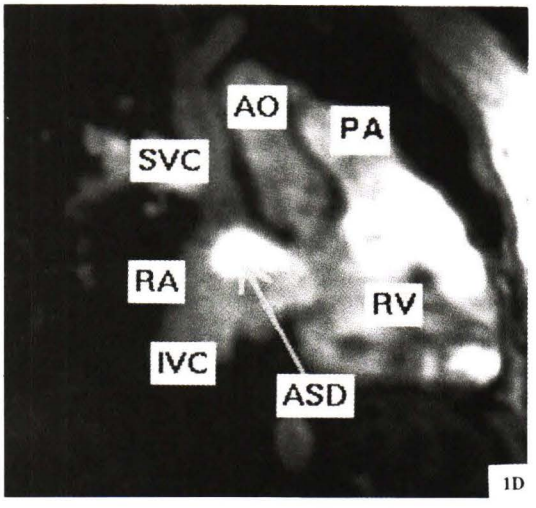
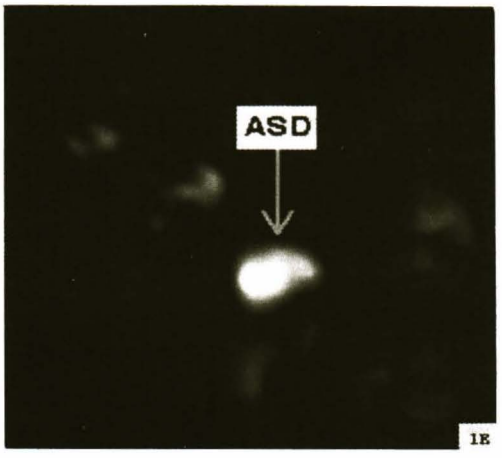


Fig. 1D. Cardiac MRI of an ASD (enface view of the ASD).

ASD = Atrial septal defect, RA = Right atrium, RV = Right ventricle, SVC = Superior veva cava, IVC = Inferior veva cava, PA = Pulmonary artery, Ao = Aorta.



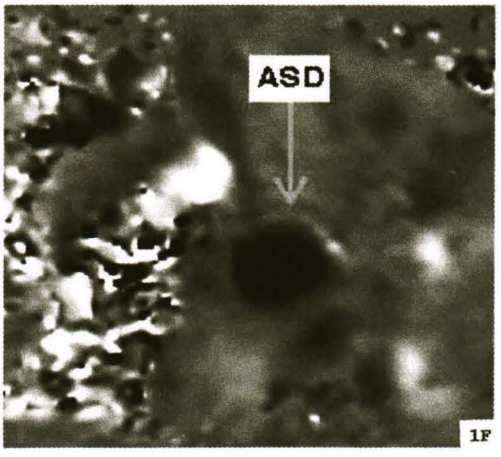


Fig. 1E, 1F. Cardiac MRI of ASD flow sensitive gradient-echo pulse sequence showing companion view of the en-face view

ASD = Atrial septal defect.

vein to exchange with a balloon occlusion catheter (Occlusion balloon from MediTech, Boston Scientific, Boston, USA). This balloon catheter was inflated with various increments of diluted contrast and was then pulled across the ASD to determine the stretched diameter. The distance spanning the waist of the balloon was taken to be the balloon-size diameter of the ASD.

Transcatheter closure of the ASD

The Amplatzer™ Septal Occluder(3,5-7) (AGA Medical Corp., Golden Valley, MN, USA) is constructed from Nitinol (nickel and titanium) wires, tightly woven into two flat buttons (discs) with 4 mm connection waists. Its size varies from 4 mm to 38 mm. The device was selected to be the same size or 1 mm smaller than the stretched diameter. Under fluoroscopic and TEE guidance, the left atrial disc was deployed and pull gently against the atrial septum which were both felt and observed by TEE. Once its position was optimal, the device was released by counterclockwise rotation of the delivery cable.

Device implantation and cardiac MRI measurement were performed using a research protocol approved by the Ethical Committee on Clinical Investigation of the Faculty of Medicine Siriraj Hospital. The Amplatzer™ Septal Occluder was approved by the U.S. Food and Drug Administration. Informed parental or patient consent was obtained for each patient.

Statistical analysis

Variables were described as mean ± standard deviation where appropriate. Pearson correlation coefficients (r) were calculated to determine the strength of association between different parts of the ASD measurements. Sample linear requisition equations were performed to estimate the device size from the MRI and from the TEE. A p-value < 0.05 was considered significant.

RESULTS

There were 37 patients who had a secundum ASD and met the established criteria for atrial septal defect closure during the study period. There were 22 patients who had complete transcatheter closure. All patients had cardiac MRI and complete closure of the ASD by transcatheter method without complications. Ten patients are on the waiting list for transcatheter closure. Two patients were excluded due to unsuitable anatomy of the atrial septal rim

(very small posterior inferior rim). There were 15 female patients (68.6%). The mean age and standard deviation of the patients was 33.2±15.1 (8-67) years. The mean weight of the patients was 51.6±13.1 (20-99) kg. The atrial septal defect major axis measurement was 24.9±6.4 mm by cardiac MRI and 20.8±5.6 mm by TEE measurement respectively. The demographic and hemodynamic data are shown in Table 1. The average degree of left to right shunt (the calculated ratio of pulmonary to systemic blood flow; Qp : Qs) was 3.1:1. The transcatheter balloon measurement of the ASD was 25.2±6.9 (11-36) mm and the device closure size was 24.8±6.6 (11-36) mm.

Correlation of the ASD measurement (using the major axis) by both cardiac MRI and TEE to the device closure size were performed. The correlation coefficient of the ASD diameter measured by cardiac MRI to device closure size was $r = 0.796$ ($p < 0.001$); TEE measurement to device closure size; $r = 0.769$ ($p < 0.001$) respectively. As expected, the balloon sizing method showed the highest correlation coefficient to device closure size ($r = 0.993$, $p < 0.001$).

The regression formula showing the predicted device closure size from cardiac MRI was 1.5 + (1.02 x MRI size (mm)), $r^2 = 63$ per cent, $p < 0.001$ when compared to the regression formula from TEE measurement which was 7 + (0.85 x TEE size (mm)), $r^2 = 59$ per cent, $p < 0.001$.

The atrial septal rim could not be measured by the transcatheter balloon-sizing method. The measurements of the atrial septal rims were performed only by TEE and cardiac MRI. These rims were divided into four different rims as in the method section. The authors compared these measurements by cardiac MRI and TEE measurement as in Table 2. There was poor correlation between the methods for measurement of the AS rim ($r = 0.052$) and, AI rim ($r = 0.276$). There was fair correlation between the methods for measurement of the PS and PI rim ($r = 0.704$ and $r = 0.679$ respectively).

Table 1. Demographic data of patients who had cardiac MRI, TEE, transcatheter balloon sizing and device closure of the atrial septal defect.

Variable	Mean ± SD
Age (yrs)	26.3 ± 15.7
Weight (kg)	51.6 ± 13
Height (cm)	156.3 ± 12
ASD diameter by MRI-major axis (mm)	24.9 ± 6.4
ASD diameter by MRI-minor axis (mm)	18.5 ± 5.4
ASD diameter by TEE-major axis (mm)	20.8 ± 5.6
ASD diameter by TEE-minor axis (mm)	17.2 ± 4.7
Balloon sizing (mm)	25.2 ± 6.9
Device size (mm)	25.4 ± 6.7
RVSP (mmHg)	42.8 ± 20.6
Calculated Qp : Qs	3.1 ± 1.3

ASD = atrial septal defect, MRI = magnetic resonance imaging, TEE = transesophageal echocardiogram, RVSP = right ventricular systolic pressure, Qp : Qs = degree of pulmonary blood flow to systemic blood flow calculated by cardiac catheterization.

DISCUSSION

Successful transcatheter closure of secundum ASD using an Amplatzer™ Septal Occluder in

Table 2. Measurement of the atrial septal defect rim by both cardiac MRI and TEE methods.

	Minimum (mm)	Maximum (mm)	Mean (mm)	Std. Deviation
MRI measurement AS	0.00	9.70	6.5286	3.1492
MRI measurement AI	10.60	29.30	20.0400	4.7452
MRI measurement PS	7.80	24.20	15.4333	4.7098
MRI measurement PI	9.80	26.10	17.6133	5.7079
TEE measurement AS	4.00	7.00	5.8000	1.6432
TEE measurement AI	11.00	18.00	14.7500	2.8723
TEE measurement PS	15.00	24.00	18.0000	4.2426
TEE measurement PI	10.00	21.00	15.2500	5.5603

MRI = magnetic resonance imaging, TEE = transesophageal echocardiogram,
AS = anterior septal rim, AI anterior inferior rim, PS = posterior septal rim, PI = posterior inferior rim.
Descriptive Statistics

more than 6000 patients worldwide including in our institute has been reported[20]. In each patient who is a candidates for transcatheter closure, the diagnosis of ASD requires confirmation. The imaging of an ASD by transthoracic echocardiogram may present diagnostic difficulty; 1) False-positive diagnoses caused by "signal dropout" when the ultrasound beam did not produce an image of the atrial septum in the perpendicular direction. 2) Optimal imaging cannot be obtained in some patients with chest deformities or other acoustic impediments. Accurate evaluation of the size, location and adjacent structure of an ASD is very important in the selection of patients for further management[9]. Conventionally transesophageal echocardiogram has been the mainstay of evaluation and screening patients who are candidate for transcatheter closure. However, this technique can not easily be applied in a young child. The risk of aspiration, airway obstruction and esophageal lacerations are not uncommon in young children[17,18]. Also, this technique causes considerable discomfort and requires good cooperation even in adult patients. Visualization of an ASD by cardiac MRI with spin-echo in conjunction with dynamic imaging by gradient echo technique is well established[14-16]. However, there are few systematic studies to report ASD measurement by cardiac MRI in patients with ASD. The authors compared the measurement of the ASD diameter and atrial septal rim by different techniques, including TEE, cardiac MRI, and the transcatheter balloon size method with final device size closure.

As expected, transcatheter balloon-sizing measurement of the ASD was highly correlated with the device closure size, since most of the selected devices were the same size for transcatheter closure or 1-2 mm larger. When the authors compared the correlation between cardiac MRI and TEE to balloon sizing or device closure size, an acceptable range of correlation between both non-invasive methods was found. Cardiac MRI appeared to have better correlation with balloon size measurement and to the final device size when compared to TEE.

The cardiac MRI is a relatively new method to evaluate intracardiac lesions and can accurately measure the ASD size and surrounding anatomy. It is easy to perform (generally lasts 30 to 45 minutes). It provides more detailed information, with higher resolution, about atrial septal morphology without using any contrast material as shown in Fig. 1E to 1F. There was poor correlation between the measurement of the AS rim (close to the aorta) and the AI rim (close to the mitral valve). Since the AS rim in the majority of the presented ASD patients was very small (0- 9.7 mm), it is to be expected that there will be poor agreement between the measurements by both methods. The average AI rim (close to the tricuspid valve) in the presented patients was 20±4.7 mm (10.6-29.3 mm) which is quite generous. Early in the authors' experience, there was some concern regarding a small anterior superior rim (close to the aorta). However, this problem was overcome by using a prebent delivery long sheath. Two out of 37 patients were initially excluded because of a very small posterior inferior rim (close to the inferior vena cava). Initial experience revealed that a patient with a small posterior inferior rim is a poor candidate for transcatheter closure(7). This rim is best visualized by cardiac MRI in a short axis view (Fig. 1B). All of patients in this study who had complete closure had a posterior inferior rim more than 10 mm. Two patients who were excluded had rims which measured 6.8 and 7 mm respectively. The authors believe that the key to success for transcatheter closure method is an adequate posterior inferior rim, which has to be more than 5 mm longer than what is generally recommended.

SUMMARY

The authors demonstrated the capability of the cardiac MRI in assessing ASD morphology and anatomy for transcatheter closure of the ASD with an Amplatzer™ Septal Occluder. Cardiac MRI can help to evaluate the following information about the ASD 1) Type and location of the defect, 2) Size of the defect, 3) Direct visualization of the atrial septum anatomy. This detailed information provided a safer and more effective application of the ASD occluder. Cardiac MRI is also a non-invasive test which can be performed comfortably in an acceptable time. Further studies should be performed to evaluate the results of using cardiac MRI alone as a screening tool for patients who are candidates for transcatheter closure of the ASD.

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การวัดขนาดรู atrial septal defect เพื่อประเมินผู้ป่วยในการปิดรูรั่วทางการตรวจสวนหัวใจโดยใช้ Cardiac Magnetic Resonance Imaging

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ที่มา : ผลการปิดรูรั่วผนังกั้นห้องหัวใจด้านบนโดยการสวนหัวใจขึ้นอยู่กับ ขนาด ตำแหน่ง และ อายุของผู้ป่วย ในบางครั้งการตรวจผู้ป่วยโดยใช้การตรวจคลื่นเสียงสะท้อนหัวใจความถี่สูงทางหน้าอก หรือทางหลอดอาหาร (transesophageal echocardiogram : TEE) นั้นยังไม่สามารถให้ข้อมูลที่ชัดเจนได้

วัตถุประสงค์ : การศึกษานี้รายงานผลการเปรียบเทียบการวัดขนาดและตำแหน่งของรูรั่วนี้โดยวิธีต่างกัน

วิธีการ : ผู้ป่วยที่ได้รับการวินิจฉัยว่ามีรูรั่วผนังกั้นห้องหัวใจด้านบน ชนิด secundum atrial septal defect (ASD) และมีขนาดของ left to right shunt มากพอจะได้รับการตรวจสวนหัวใจ ขนาดของ ASD จะถูกวัดโดย Transesophageal echocardiogram (TEE), cardiac magnetic resonance imaging และ balloon occlusion catheter F โดยเปรียบเทียบกับขนาด device size ของอุปกรณ์ Amplatzer™

ผลการรักษา : ผู้ป่วยจำนวน 22 รายได้รับการประเมินรูรั่วและปิดรูรั่ว โดยมีอายุเฉลี่ย 33.2±15.1 (8-67) ปี น้ำหนักโดยเฉลี่ยคือ 51.6±13.1 (20-99) ขนาดเฉลี่ยของ ASD ที่วัดได้จาก MRI คือ 24.9±6.4 มม. และจาก TEE คือ 20.8±5.5 มม. จาก balloon sizing คือ 25.2±6.9 (11-36) มม. และขนาดของ device คือ 24.8±6.6 (11-36) มม. Correlation efficient ของ cardiac MRI ต่อ device closure size คือ r = 0.784 ($p < 0.001$. SE = 4.78) เมื่อเทียบกับของ TEE ต่อ device closure size r = 0.761 ($p = 0.001$, SE = 4.22)

สรุป : เราพบว่าการใช้ cardiac magnetic resonance imaging นั้นสามารถให้ข้อมูลในด้านของขนาด ตำแหน่งของรูรั่วระหว่างผนังกั้นห้องหัวใจด้านบนได้โดยสามารถใช้เป็นแนวทางในการตรวจประเมินเพื่อใช้ในการพิจารณาผู้ป่วยเพื่อเข้ารับการรักษาปิดรูรั่วผนังกั้นห้องหัวใจด้านบนโดยการสวนหัวใจได้

คำสำคัญ : การตรวจทางคลื่นแม่เหล็กไฟฟ้า, รูรั่วผนังกั้นห้องหัวใจด้านบน

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