Iatrogenic Atrial Septal Defect

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The number of left atrial transcatheter procedures performed via a transseptal (TS) approach has grown exponentially over the last 2 decades.[1] Persistent iatrogenic atrial septal defects (iASD) after structural TS interventions are not uncommon especially when larger TS sheaths are used (25%–50% with 22 Fr sheaths).[2–5] The optimal management strategy of postprocedural iASD is currently unknown. In the absence of societal recommendations with regards to iASD, the decision to close iASD and the timing of the closure pose a clinical dilemma to the interventionalist caring for these patients. We present 2 cases of iASD after TS transcatheter mitral valve repair/implantation and discuss the challenges in the management of such patients.

Case Presentation

Two patients were seen in consultation by the Mayo Clinic structural heart service:

Ms K: An 81-year-old female admitted with decompensated biventricular heart failure. She had hypertension, atrial fibrillation, systolic heart failure (left ventricular ejection fraction=42%), a permanent pacemaker, and a history of mitral valve replacement with a 33 mm St Jude EPIC prosthesis and tricuspid valve repair. On examination, she was a slender woman (5′0″, 49 kg). Heart rate was 72 bpm, blood pressure was 129/83 mm Hg, and oxygen saturation was 92% on room air. Auscultation revealed a prominent thrill at the apex radiating across her chest and a loud 6/6 apical holosystolic murmur. Jugular veins were distended, and rales were heard at both lung bases. Moderate peripheral pitting edema was also noted. Echocardiography showed a degenerative mitral prosthesis with a flail leaflet and severe mitral regurgitation (MR). It also showed severe right ventricular enlargement with moderately depressed right ventricular function. No thrombus or evidence of endocarditis was present. The heart team evaluation concluded that the patient was at high risk for redo mitral valve replacement (Society of Thoracic Surgeons [STS] score=10%). She then underwent a successful antegrade TS mitral valve in valve implantation with a 29-mm Sapien S3 valve. To facilitate delivery of the S3 valve, the septum was dilated with a 15 mm Z-Med Balloon (B. Braun Inc, Melsungen, Germany; Figure 1A). After the procedure, the left atrial V wave decreased from 51 to 26 mm Hg (Figure 1D), and there was no residual MR. However, there was a residual atrial septal defect measuring 7×5 mm by transesophageal echocardiography (TEE) with a predominant left to right shunt (Figure 1B and 1C).

Mr J: An active 89-year-old male who was evaluated in the outpatient setting for worsening dyspnea. He has history of hypertension, remote deep venous thrombosis, anemia, and chronic kidney disease stage 3 (estimated glomerular filtration rate=31 mL/min per 1.73 m2). On examination, the patient was obese (5′5″, 103 kg), had bradycardic (49 bpm), and had a normal blood pressure 126/78 mm Hg. There was a 4/6 holosystolic apical murmur. Echocardiography documented normal left ventricular ejection fraction of 62% and a flail mitral valve posterior leaflet with severe MR. The right ventricle was mildly dilated with mildly reduced systolic function. Because of his age and renal insufficiency, he was not deemed to be a candidate for mitral valve surgery. He underwent a successful transcatheter mitral valve repair (TMVR) with one MitraClip (Abbott Vascular, Santa Clara, CA). After the procedure, the MR decreased from severe to mild–moderate, and the left atrial V wave decreased from 60 to 40 mm Hg (Figure 2C). A small residual atrial septal defect measuring 3×4 mm with left to right shunt was noted (Figure 2A and 2B).

Discussion

Dr Sarraf: Both patients are left with an iASD after a sucessful mitral valve therapeutic procedure. Should we be concerned about these residual defects, or do they usually close spontaneously?

Dr Holmes: Historically, the majority of residual iASD following transcatheter TS interventions have been thought to close spontaneously and therefore have not been routinly closed. However, there is growing evidence that iASDs which have resulted from placement of larger diameter devices could persist beyond 6 months after TS procedures (Table 1).[2–7] With the substantial increase in the number of patients with valvular and arrhythmic disorders who are being treated with transcatheter TS procedures (Table 2), persistent iASDs are an increasing concern.

Dr Sarraf: Are these residual iASD associated with adverse clinical outcomes?

Dr Alkhouli: The available data are scarce and inconclusive. There are multiple case reports of the deleterious effects of iASD (hypoxemia, heart failure, and systemic embolization).[8–15] There is only one single-center prospective study that suggested a possible negative impact of persistent iASD on right ventricular function, dyspnea, and mortality after TMVR

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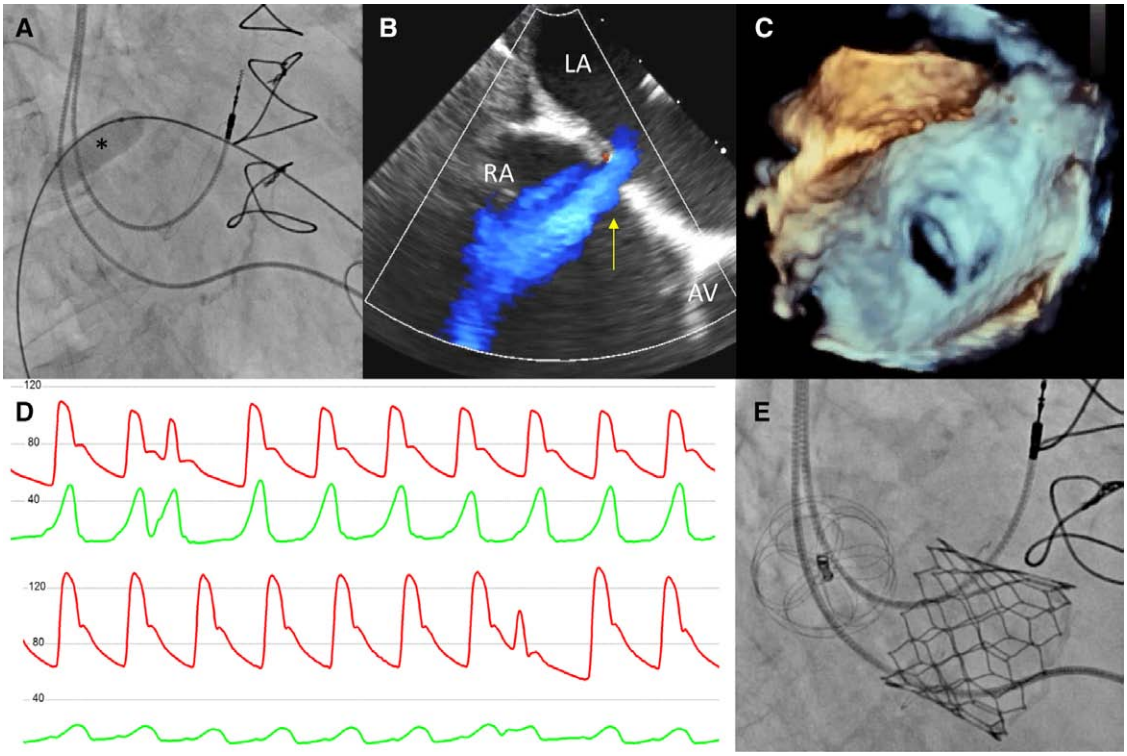

Figure 1. Iatrogenic atrial septal defect (iASD) after mitral valve in valve placement. **A**, Atrial septostomy: a still frame image of a balloon atrial dilatation of the intra-atrial septum before valve in valve placement. A 15×40-mm Z-Med II balloon was used (asterix). **B**, Transesophageal echo assessment of the residual iASD: a large iASD with left to right shunt is noted (yellow arrow). **C**, 3-Dimensional transesophageal echocardiography reconstruction of the iASD showing the irregular shape of the defect. **D**, Hemodynamic assessment of aortic (red) and left atrial pressure (green) before (top rows) and after (lower rows) the mitral valve in valve placement. The left atrial pressure decresed significantly after the valve implantation. **E**, Percutanous iASD closure with a 25 mm Cardioform septal occluder. The 29 mm Sapien S3 valve is also seen in the mitral position. AV indicates aortic valve; LA, left atrium; and RA, right atrium.

with MitraClip.[3] However, in this study, patients with persistent iASD had longer procedures (82.4±39.7 versus 68.9±45.5 minutes; *P*=0.05) and had somewhat higher degrees of residual MR (95.5% versus 88.5% with residual MR grade >II; *P*=0.35) compared with those who had spontaneous closure of the iASD. The iASD might have been related to a more challenging anatomy/procedure or might have been a marker of a higher degree of residual MR and left atrial pressure. An association between higher residual MR and persistent iASD after MitraClip procedures has been suggested by Smith et al.[2] Other studies have evaluated the effect of iASD on clinical outcomes, but were underpowered due to the very low incidence of adverse events (Table 1).[2,4–7]

Dr Sarraf: In the absence of an immediate deterioration requiring urgent iASD closure (eg, right to left shunt with hypoxemia), when should we consider iASD closure?

Dr Holmes: Unfortunately, there are currently no guidelines to aid with the management of iASD. Desaturation due to right to left shunting is probably the strongest indication to close an iASD during the index procedure. If oxygen desaturation is noted after removing the TS sheath, and is found to be related to the iASD, then immediate closure is indicated.[14–17] The causal relationship between oxygen desaturation and the iASD can be confirmed with the improvement in oxygen saturation with balloon occlusion of the defect and sometimes even with readvancement of the large TS sheath across the defect.[15]

Besides this indication, it is reasonable to consider elective iASD closure in selected patients who are at high future risk for right ventricular overload and/or systemic embolization (paradoxical thrombus). It is also clinically reasonable to consider iASD closure in patients who suffer a cryptogenic stroke and are found to have persistent iASD. In our first case, Ms K was at particularly high risk for right ventricular overload given her large left to right shunt and her baseline severe right ventricular dysfunction. In addtion, she also has permenant pacemaker leads which may increase her risk for paradoxial embolism.[18] I would therefore consider percutaneous iASD closure in this patient. A suggested algorithm for the assessment and management of iASD is illustrated in Figure 3.

Dr Sarraf: Is there a role for routine invasive hemodynamic assessment of iASD in the cath lab?

Dr Alkhouli: A detailed hemodynamic study at baseline and after the intervention would be very helpful when considering iASD closure for several reasons: (1) calculation of baseline pulmonary vascular resistence would aid in avoiding closure in patients with irreversible severe pulmonary hypertension (pulmonary vascular resistence >2/3 systemic vascular resistence).[19] (2) Shunt volume/fraction calculations after the intervention could identify patients with very large left to right shunts (QP/QS >2) who might require a more aggressive follow up and in whom a lower threshold for iASD closure should be considered. (3) When continuous left atrial presure monitoring is not available, pulmonary capillary wedge

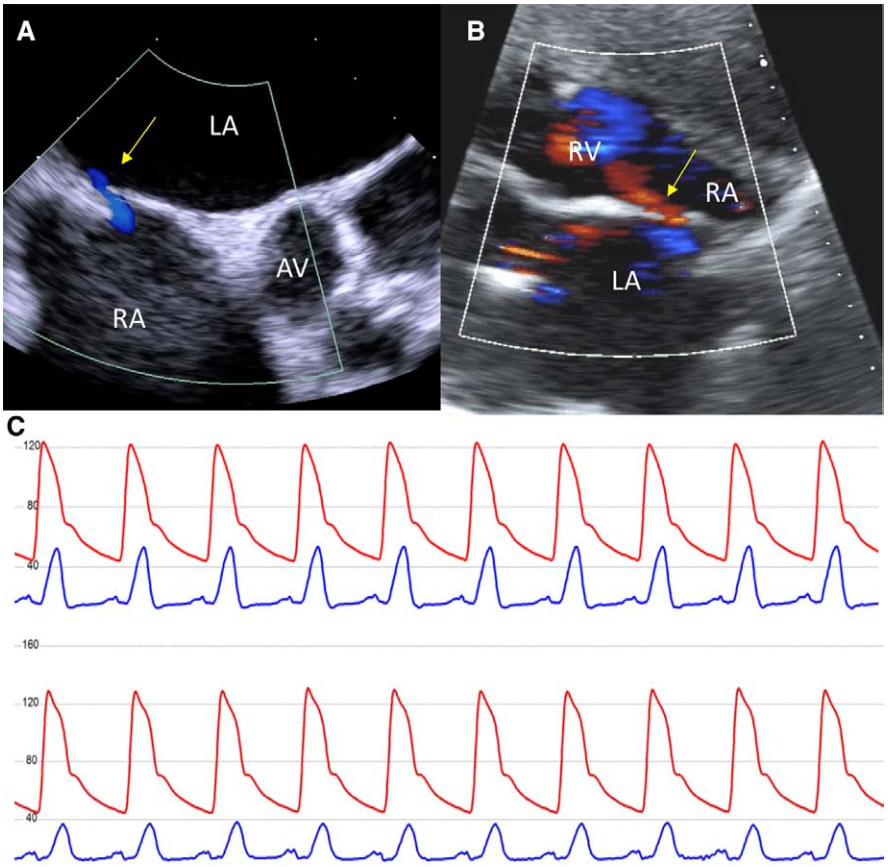

Figure 2. Iatrogenic atrial septal defect (iASD) after transcatheter mitral valve repair. **A**, Transesophageal echo assessment of the residual iASD: a small iASD with left to right shunt is noted (yellow arrow). **B**, Transthoracic echo (subcostal view) at 1 month showing a persistent small iASD with small shunt. Hemodynamic assessment of aortic (red) and left atrial pressure (blue) before (top rows) and after (lower rows) the mitral valve in valve placement. The left atrial pressure decresed after the mitral valve repair but remained significantly elevated. AV indicates aortic valve; LA, left atrium; and RA, right atrium.

pressure measurement before and after the TS procedure would identify those patients with high postprocedural pulmonary capillary wedge pressure that might be better served with conservative management of the iASD. Given the low incidence of iASD after TS with sheath <12 Fr in diameter, I would reserve this comprehensive assessment for patients who undergo TS procedures with large-bore sheaths/guides (>12 Fr).[2]

Dr Sarraf: The issue of closure of the iASD is complex. Some data suggest an increased risk of serious acute left ventricular dysfunction leading to pulmonary edema immediately after closure of left to right shunts from an ASD in elderly patients with significant LV diastolic dysfunction.[20,21] Should we be concerned about this risk in our patients?

Dr Alkhouli: Congenital defects are different than iASD. With the former, the heart is subject to a life-long conditioning

Table 1. A Summary of Studies on Persistent iASD Following Transseptal Structural Heart Procedures

Study	Procedure	Sheath Size, Fr	iASD Incidence	Follow Up, m	Detection Method	Diameter, mm	Echo Parameters	Clinical Events
Yoshida et al[5]	PBMV	14	3/15 (20%)	6	TEE	1.1	NR	None
Ishikura et al[7]	PBMV	14	2/46 (4.4%)	12	2D TTE	NR	NR	None
Devarakonda et al[6]	PBMV	14	21/110 (19%)	12	3D TTE	5.4±3.1	NR	None
Singh et al[4]	LAA Closure	14	14/253 (7%)	12	2D TEE	<3 (50%)	NR	No Δ in stroke
Smith et al[2]	TMVR	22	8/30 (27%)	12	2D TTE	6.6±3.1	No Δ in RVD	None
Schueler et al[3]	TMVR	22	33/66 (50%)	6	2D TEE	4.3×3.8	↑ RVSP, RAD, RVD	↑Death, HF

Δ indicates change; 2D, 2-dimenstional; 3D, 3-dimentional; Fr, french; HF, heart failure; iASD, iatrogenic atrial septal defects; LAA, left atrial appendage; NR, not reported; PBMV, percutaneous balloon mitral valvuloplasty; RAD, right atrial dimension; RVD, right ventricular dimension; RVSP, right ventricular systolic pressure; TEE, transesophageal echo; TMVR, transcatheter mitral valve repair; and TTE, transthoracic echo.

Table 2. Characteristics of Structural Procedures Using a Transseptal Access Approach

Procedure	Catheter Size	Septostomy Required	Patients Characteristics
Hemodynamic Study	7–9 Fr	No	Variable
PVL closure	8 Fr	No	Prior sternotomy Severe MR, LAH
PV stenting	8–9 Fr	No	Afib, prior TS procedure
RF PVI	8 Fr±8 Fr	No	Afib, ±LA enlargment
CB PVI	12 Fr±8 Fr	No	Afib, ±LA enlargment
LAA closure	14 Fr	No	Afib, ±LA enlargment
PBMV	12 Fr	No	LAH, ±LA enlargment
Mitral VinV	16–18 Fr	Yes	Prior sternotomy, LAH
pLVAD	22 Fr	Possible	LAH, cardiogenic shock
TMVR	22 Fr	Possible	LAH, LA enlargment

CB indicates cryoballoon; Fr, french; LA, left atrium; LAA, left atrial appendage; LAH, left atrial hypertension; MR, mitral regurgitation; PBMV, percutaneous balloon mitral valvuloplasty; pLVAD, percutaneous left ventricular assist device; PV, pulmonary vein; PVI, pulmonary vein isolation; PVL, paravalvular leak; RF, radiofrequency; TMVR, transcatheter mitral valve repair; TS, transseptal puncture; and VinV, valve in valve.

process, and hence, sudden closure of these defects may lead to acute decompensation in patients with significant diastolic dysfunction and/or elevated left-sided filling pressures. iASDs are more acute phenomena, and therefore, the risk of decompensation upon their closure should be much less. However, if there is any concern about clinical deterioration after iASD closure, a balloon occlusion test may help to identify high-risk patients for postclosure heart failure. This procedure involves temporary closure of the defect with a soft AMPLATZER Sizing Balloon (AGA Medical, Plymouth, MN). During this time, pulmonary capillary wedge pressure or left atrial pressures are monitored. If temporary occlusion of the iASD with the sizing balloon result in significant elevation in mean left atrial pressures (>10 mmHg), closing the defect is not recommended.[22] Mr J has severely elevated left atrial pressure despite the reduction in his MR (Figure 2C). The iASD in this patient might be a useful pop-off route for his elevated filling pressures. In addition, his residual iASD is small and his right ventricular function is preserved, minimizing the risk of right-sided overload if the left to right shunt is not closed. In this patient, I would not close the iASD immediately at the time of the index procedure but would repeat a transthoracic echocardiography (TTE) in 3 to 6 months.

Dr Sarraf: Are there any procedural or patient's characteristics that are associated with a higher chance of having a persistent iASD?

Dr Holmes: The available data do not provide strong evidence that any particular patient factor is associated with higher probability of iASD persistence. Elevated left atrial pressure was suggested as a negative predictor of spontaneous closure after left atrial appendage closure with the Watchman device and after TMVR with the MitraClip device.[2,4] In terms of procedural characteristics, the size of the TS sheath seems to be a key factor in determining the likelihood of iASD

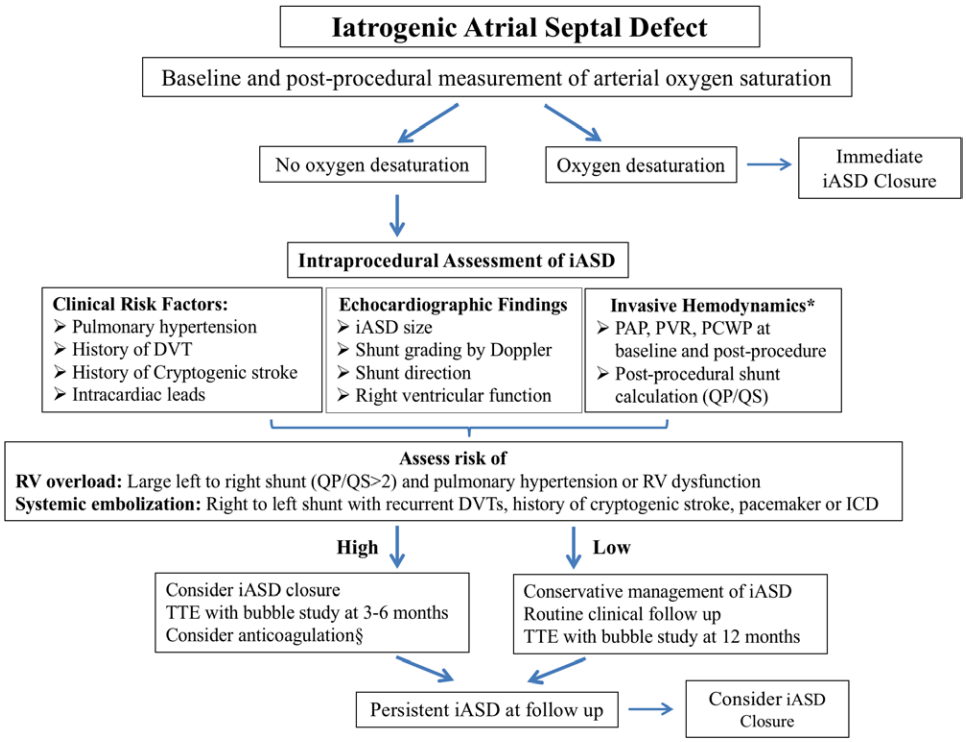

Figure 3. A suggested algorithm for the assessment and management of iatrogenic atrial septal sefects. DVT indicates deep venous thrombosis; iASD, iatrogenic atrial septal defect; ICD, implantable cardioverter defibrillator; PAP, pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; PVR, pulmonary vascular resistence; QP/QS, pulmonary to systemic blood flow ratio; RV, right ventricle; and TTE, transthoracic echocardiogram. *For procedures using a transseptal sheath size >12 French. §If the patient is at high risk for systemic embolization (recurrent DVTs, history of cryptogenic stroke) and the defect is not closed during the index procedure.

persistence versus spontaneous closure. Structural heart interventions that utilize TS sheaths ≤14 Fr are associated with a very high rate of spontaneous closure (80%–90%), while those that utilize TS >20 Fr are associated with lower rates of spontaneous closure (50%–75%; Table 1).

Dr Sarraf: Does the access location on the interatrial septum predict the likelihood of spontaneous iASD closure?

Dr Holmes: Pulmonary vein isolation procedures that are performed via an inferior limbus puncture are associated with lower incidence of acute iASD compared with those performed via a fossa ovalis puncture.[23,24] However, many structural interventional procedures require a specific access location on the septum for successful execution of the procedure. For example, TMVR requires a TS puncture that is located posteriorly and superiorly on the fossa ovalis about 4 cm above the mitral valve annulus. Similarly, TS mitral valve in valve implantation and left atrial appendage closure require positerior and inferior fossa ovalis puncture site. Therefore, the possibility of utilizing a non–fossa ovalis access may be limited to a small number of specific structural procedures.

Dr Sarraf: A certain percentage of these patients may require a second TS procedure. Would the need to recross the septum be hampered with the presence of septal occluder device?

Dr Alkhouli: Certainly. The presence of a septal occluder device will complicate recrossing attempts and this issue should be considered before closing an iASD. In most cases, a second TS puncture can be performed adjacent to the ASD closure device. However, in some patients, puncture through the ASD closure device might be necessary which while possible is technically challenging and associated with significantly longer procedure time.[25,26]

Dr Sarraf: What are your preferred septal occluder device for iASD closure?

Dr Holmes: There are 2 commercially available atrial septal defect closure devices: The GORE Cardioform Septal Occluder (W.L Gore and Associates, Flagstaff, AZ) and the AMPLATZER Atrial Septal Occluder (AGA Medical, Plymouth, MN). I prefer the Cardioform device because it is softer and more compliant than the AMPLATZER device and because there have not been any reports of cardiac erosion with this device. However, the Cardioform septal occluder is limited to treating defects <15 to 18 mm. Although uncommon, larger iASD would need to be treated with an AMPLATZER. There are also emerging bioabsorbable septal occluders that could potentially be utilized in these cases in the future. The CARAG septal occluder (CARAG-S Engineering, Baar, Switzerland) showed promising acute and early follow-up results in a small first-in-man series.[27] A clinical trial is currently ongoing to evaluate the safety and effectiveness of this device (https://www.clinicaltrials.gov: NCT01960491). If bioabsorable septal occluders are proven safe and effective, they may become the occluders of choice for iASD closure as they might preserve future access to the left atrium.

Dr Sarraf: Are there any technical considerations specific to closing iASD?

Dr Alkhouli: Sizing iASD is not always straightforward as these defects often have irregular boders and/or edge tearing, and their true dimensions may be underestimated with 2D imaging.[28] We prefer to obtain 3D imaging of the septum when possible to avoid undersizing or oversizing of the defect. Balloon sizing is also an option in equivocal cases. Otherwise, the iASD closure procedure is performed in a similar manner to congenital ASD closure.

Dr Sarraf: If the decision is to not close the iASD, how often do we image these patients and what imaging tools do we choose?

Dr Holmes: The ideal test for postoperative surveillance of iASD should be noninvasive or minimally invasive and should provide an accurate assessment of the iASD size and the interatrial shunt. TTE is readily available and noninvasive but has limited accuracy in detecting and measuring iASD.[29] Studies that used TTE for the follow up of iASD yielded lower rates of persistent iASD compared with those that used TEE.[2,3,5] Real-time 3D technology has proven to be superior to 2D imaging in accurately assessing the dimensions of iASD with both TTE and TEE.[6,28] I would start with an enhanced TTE (ie, TTE with agitated saline contrast and valsava meanuves ±3D). If the study is negative and I am still concerned (for example, in case of unexplained worsening heart failure), I would then proceed to TEE±right heart catheterization.

Outcomes

Ms K: Following her succesful mitral valve in valve implantation, the patient underwent percutaneous closure of the iASD (Figure 1E). A 25-mm Cardioform septal occluder device was placed with trivial residual shunt seen on TEE. She was discharged home on day 2 and has done very well at 2-month follow-up.

Mr J: After undergoing TMVR with the MitraClip device, the decision was made to observe the iASD clinically and with a follow-up TTE at 6 months. At 1 month follow up, Mr J increased his 6-minute walk distance from 213 m to 278 m and had only mild residual exertional dyspnea.

Disclosures

None.

References

1. McGinty PM, Smith TW, Rogers JH. Transseptal left heart catheterization and the incidence of persistent iatrogenic atrial septal defects. *J Interv Cardiol*. 2011;24:254–263. doi: 10.1111/j.1540-8183.2011.00630.x.
2. Smith T, McGinty P, Bommer W, Low RI, Lim S, Fail P, Rogers JH. Prevalence and echocardiographic features of iatrogenic atrial septal defect after catheter-based mitral valve repair with the MitraClip system. *Catheter Cardiovasc Interv*. 2012;80:678–685. doi: 10.1002/ccd.23485.
3. Schueler R, Öztürk C, Wedekind JA, Werner N, Stöckigt F, Mellert F, Nickenig G, Hammerstingl C. Persistence of iatrogenic atrial septal defect after interventional mitral valve repair with the MitraClip system: a note of caution. *JACC Cardiovasc Interv*. 2015;8:450–459. doi: 10.1016/j.jcin.2014.10.024.
4. Singh SM, Douglas PS, Reddy VY. The incidence and long-term clinical outcome of iatrogenic atrial septal defects secondary to transseptal catheterization with a 12F transseptal sheath. *Circ Arrhythm Electrophysiol*. 2011;4:166–171. doi: 10.1161/CIRCEP.110.959015.
5. Yoshida K, Yoshikawa J, Akasaka T, Yamaura Y, Shakudo M, Hozumi T, Fukaya T. Assessment of left-to-right atrial shunting after percutaneous mitral valvuloplasty by transesophageal color Doppler flow-mapping. *Circulation*. 1989;80:1521–1526.

6. Devarakonda SB, Mannuva BB, Durgaprasad R, Velam V, Akula VS, Kasala L. Real Time 3D Echocardiographic Evaluation of Iatrogenic Atrial Septal Defects After Percutaneous Transvenous Mitral Commissurotomy. *J Cardiovasc Thorac Res*. 2015;7:87–95. doi: 10.15171/jcvtr.2015.20.
7. Ishikura F, Nagata S, Yasuda S, Yamashita N, Miyatake K. Residual atrial septal perforation after percutaneous transvenous mitral commissurotomy with Inoue balloon catheter. *Am Heart J*. 1990;120:873–878.
8. Zanchetta M, Onorato E, Rigatelli G, Dimopoulos K, Pedon L, Zennaro M, Maiolino P. Use of Amplatzer septal occluder in a case of residual atrial septal defect causing bidirectional shunting after percutaneous Inoue mitral balloon valvuloplasty. *J Invasive Cardiol*. 2001;13:223–226.
9. Harikrishnan S, Titus T, Tharakan JM. Septal defects after percutaneous mitral valvotomy–all are not innocent. *J Am Soc Echocardiogr*. 2005;18:183–184. doi: 10.1016/j.echo.2004.08.009.
10. Nakao M, Ch'ng JK, Sin YK, Chua YL, Lee CY. Acquired right-to-left shunt through an atrial septal perforation with cyanosis after percutaneous transvenous mitral commissurotomy. *J Thorac Cardiovasc Surg*. 2008;135:690–691. doi: 10.1016/j.jtcvs.2007.10.038.
11. Pitcher A, Schrale RG, Mitchell AR, Ormerod O. Percutaneous closure of an iatrogenic atrial septal defect. *Eur J Echocardiogr*. 2008;9:294–295. doi: 10.1016/j.euje.2006.09.006.
12. Sur JP, Pagani FD, Moscucci M. Percutaneous closure of an iatrogenic atrial septal defect. *Catheter Cardiovasc Interv*. 2009;73:267–271. doi: 10.1002/ccd.21768.
13. Agrifoglio M, Trabattoni D, Rossi F, Alamanni F, Bartorelli A, Biglioli P. Percutaneous closure of iatrogenic atrial septal defect due to implantation of a left-left "Tandem Heart" ventricle assistance device in a postcardiotomy cardiac failure: six-year follow-up. *J Cardiovasc Surg (Torino)*. 2012;53:270–272.
14. Losi MA, Strisciuglio T, Stabile E, Castellano G, de Amicis V, Saccenti A, Maresca G, Santoro C, Izzo R, Barbato E, Esposito G, Trimarco B, Rapacciuolo A. Iatrogenic atrial septal defect (iASD) after MitraClip system delivery: The key role of PaO2/FiO2 ratio in guiding post-procedural iASD closure. *Int J Cardiol*. 2015;197:85–86. doi: 10.1016/j.ijcard.2015.06.026.
15. Aznaouridis K, Hobson N, Rigg C, Bragadeesh T. Emergency percutaneous closure of an iatrogenic atrial septal defect causing right-to-left shunt and severe refractory hypoxemia after pulmonary vein isolation. *JACC Cardiovasc Interv*. 2015;8:e179–e181. doi: 10.1016/j.jcin.2015.04.023.
16. McCready JW, Moon JC, Chow AW. Right to left shunt following radiofrequency catheter ablation of atrial fibrillation in a patient with complex congenital heart disease. *Europace*. 2010;12:289–290. doi: 10.1093/europace/eup353.
17. Huntgeburth M, Müller-Ehmsen J, Baldus S, Rudolph V. Postinterventional iatrogenic atrial septal defect with hemodynamically relevant left-to-right and right-to-left shunt as a complication of successful percutaneous mitral valve repair with the MitraClip. *Int J Cardiol*. 2013;168:e3–e5. doi: 10.1016/j.ijcard.2013.05.018.
18. Vaidya VR, DeSimone CV, Asirvatham SJ, Chandra VM, Noheria A, Hodge DO, Slusser JP, Rabinstein AA, Friedman PA. Implanted endocardial lead characteristics and risk of stroke or transient ischemic attack. *J Interv Card Electrophysiol*. 2014;41:31–38. doi: 10.1007/s10840-014-9900-4.
19. Warnes CA, Williams RG, Bashore TM, Child JS, Connolly HM, Dearani JA, Del Nido P, Fasules JW, Graham TP Jr, Hijazi ZM, Hunt SA, King ME, Landzberg MJ, Miner PD, Radford MJ, Walsh EP, Webb GD. ACC/AHA 2008 Guidelines for the Management of Adults with Congenital Heart Disease: Executive Summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (writing committee to develop guidelines for the management of adults with congenital heart disease). *Circulation*. 2008;118:2395–2451. doi: 10.1161/CIRCULATIONAHA.108.190811.
20. Schubert S, Peters B, Abdul-Khaliq H, Nagdyman N, Lange PE, Ewert P. Left ventricular conditioning in the elderly patient to prevent congestive heart failure after transcatheter closure of atrial septal defect. *Catheter Cardiovasc Interv*. 2005;64:333–337. doi: 10.1002/ccd.20292.
21. Masutani S, Senzaki H. Left ventricular function in adult patients with atrial septal defect: implication for development of heart failure after transcatheter closure. *J Card Fail*. 2011;17:957–963. doi: 10.1016/j.cardfail.2011.07.003.
22. Ewert P, Berger F, Nagdyman N, Kretschmar O, Dittrich S, Abdul-Khaliq H, Lange P. Masked left ventricular restriction in elderly patients with atrial septal defects: a contraindication for closure? *Catheter Cardiovasc Interv*. 2001;52:177–180.
23. Knecht S, Wright M, Lellouche N, Nault I, Matsuo S, O'Neill MD, Lomas O, Deplagne A, Bordachar P, Sacher F, Derval N, Hocini M, Jaïs P, Clémenty J, Haïssaguerre M. Impact of a patent foramen ovale on paroxysmal atrial fibrillation ablation. *J Cardiovasc Electrophysiol*. 2008;19:1236–1241. doi: 10.1111/j.1540-8167.2008.01260.x.
24. Rich ME, Tseng A, Lim HW, Wang PJ, Su WW. Reduction of iatrogenic atrial septal defects with an anterior and inferior transseptal puncture site when operating the cryoballoon ablation catheter. *J Vis Exp*. 2015:e52811. doi: 10.3791/52811.
25. Santangeli P, Di Biase L, Burkhardt JD, Horton R, Sanchez J, Bailey S, Zagrodzky JD, Lakkireddy D, Bai R, Mohanty P, Beheiry S, Hongo R, Natale A. Transseptal access and atrial fibrillation ablation guided by intracardiac echocardiography in patients with atrial septal closure devices. *Heart Rhythm*. 2011;8:1669–1675. doi: 10.1016/j.hrthm.2011.06.023.
26. Li X, Wissner E, Kamioka M, Makimoto H, Rausch P, Metzner A, Mathew S, Rillig A, Richard Tilz R, Fürnkranz A, Chen Q, Zhang Q, Liu Q, Zhou S, Kuck KH, Ouyang F. Safety and feasibility of transseptal puncture for atrial fibrillation ablation in patients with atrial septal defect closure devices. *Heart Rhythm*. 2014;11:330–335. doi: 10.1016/j.hrthm.2013.11.011.
27. Sievert SB, Mellmann A, Bernhard J, Gafoor S. First human use and intermediate follow-up of a septal occluder with a bioresorbable framework. Paper presented at: EuroPCR 2015; May 2015; Paris.
28. Saitoh T, Izumo M, Furugen A, Tanaka J, Miyata-Fukuoka Y, Gurudevan SV, Tolstrup K, Siegel RJ, Kar S, Shiota T. Echocardiographic evaluation of iatrogenic atrial septal defect after catheter-based mitral valve clip insertion. *Am J Cardiol*. 2012;109:1787–1791. doi: 10.1016/j.amjcard.2012.02.023.
29. Silvestry FE, Cohen MS, Armsby LB, Burkule NJ, Fleishman CE, Hijazi ZM, Lang RM, Rome JJ, Wang Y. Guidelines for the echocardiographic assessment of atrial septal defect and patent foramen ovale: from the American Society of Echocardiography and Society for Cardiac Angiography and Interventions. *J Am Soc Echocardiogr*. 2015;28:910–958.

KEY WORDS: atrial septal defect ■ iatrogenic disease ■ mitral valve ■ structural heart disease ■ transseptal puncture

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Iatrogenic Atrial Septal Defect

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