Supplementary material

Grygier M, Sabiniewicz R, Smolka G, et al. Percutaneous closure of atrial septal defect: a consensus document of the joint group of experts from the Association of Cardiovascular Interventions and the Grown-Up Congenital Heart Disease Section of the Polish Cardiac Society. Kardiol Pol. 2020; 78: 1066-1083. doi:10.33963/KP.15629

I. Transesophageal echocardiography of ASD

Standard evaluation of the septum begins with midesophageal four chamber view at 0º and should be performed with increments of 15°-30° to obtain the complete view of the septum. Apart from 2D imaging, it's important to applied also color Doppler with velocity reduction to 35–40 cm/sec. This adjustment enables visualization of small defects and fenestrations or flow through the PFO.

With the use of 2D imaging defect diameter should be obtained at least at 0°, 45°, 90°, 135° to approximate the shape as well as the size and morphology of the rims - *Figure S1 A, B, C, F.* Round defect is recognized when its minimal and maximal dimension differ by max. 1 mm. Lack of aortic rim or tissue deficiency in surrounding of the vena cava superior carries a risk of erosion and tamponade or intracardiac fistula after device closure.. In case of absent aortic rim it is advisable not to oversize the occluder more than 2mm to diameter measured during balloon sizing.

Recommended views during ASD II assessment

Lower esophageal view:

- the most important issue is the assessment of the distance between the defect and the coronary sinus - *Figure S1D*

Midesophageal view:

- 0°-30° which is the midesophageal four chamber view enables to obtain the distance between ASD and anterior mitral valve leaflet defined as mitral rim - *Figure S1A*
- 30°-70°- short-axis view demonstrates aortic rim (anterior–superior), visibility of the posterior rim is usually of worse quality. Facilitates imaging of spatial relations when ASD and PFO are both present - *Figure S1B*

- 70°-120°- bicaval view demonstrates drainage of vena cava superior (superior – posterior rim) and vena cava inferior (inferior – posterior rim) as well as the roof of right atrium and drainage of right superior pulmonary vein - Figure S1C. This view is used for detection of superior sinus venosus defects - *Figure S3 B,C*

- 120°-150°- long-axis view - is important for evaluating the extent of the defect and occluder location on the septum during percutaneous procedure.

The upper esophageal view:

- 0°- 45°- upper esophageal short-axis view – used to image upper part the septum, drainage of right pulmonary veins to right atrium, aorta - *Figure S1 E*

II. 3D imaging

It is advisable to obtain 3D data in several acquisitions of different views with comprehensive presentation of the defect and surrounding structures. Apart from images focused on the defect, wide-angled acquisition of septum surrounding structures is recommended. As the septum (except in special cases of excessively mobile aneurysm) is a stable structure, the frame rate does not have to be high, usually FPS about 8-12 is sufficient.

Multi-D (X-plane)- visualization using two perpendicular views is also very useful and quick methods for verification of ASD morphology - Figure S2 A, B.

Additional imaging with color Doppler is necessary especially in case of thin septum. That enables to differentiate the presence of second defect with the presence of flow in the color doppler from only apparent lack of continuity of the septum in 2D and 3D, without flow. 3D imaging is extremely useful in assessing the size of oval defects – Figure 2 E, F. It is pivotal in case of multifenestrated ASD as provides the spatial relationships of the defects and enables to assess the feasibility of percutaneous procedure and its planning - *Figure S4 A, B, C.* Recorded images can be evaluated in postprocessing. This allows to shorten the examination and subsequent assessment of dimensions, shape, dynamics with the use of available software. Comprehensive analysis of defect should include the shape (round, oval, irregular, etc.), minimal and maximal size, orifice area. The measurements should be taken in end-systole of the atrium. Due to the dynamics of the defect size, the systolic dimension and percentage of its change in size should also be provided – Figure S2 C, D. Figure S3 demonstrates examples of different defects not suitable for percutaneous closure.

III. TEE assessment during procedure of percutaneous ASD closure

The most frequent modality used for monitoring of ASD closure is TEE. During the procedure, the patient should be sedated with good TEE probe tolerance. In rare cases of difficult and long procedures, to increase comfort and reduce the risk of aspiration, general anesthesia may be considered. Measurement of the defect is the crucial part of the procedure conditioning selection of occluder size. It may be performed in TEE and with the use of sizing balloon. Nevertheless it is also guided with a color doppler TEE, the so-called stop flow method - *Figure S5 E, F*. This particular technique reduces the risk of floppy septum stretching. The measurement should be taken both in TEE and fluoroscopy and the final dimension of the occluder is recommended to be maximally 2 mm larger than the obtained dimension. Greater oversizing increases the risk of erosion. During the procedure, TEE provides visualization of guidewires, catheters and occluder and their spatial relation to the surrounding structures – Figure S4 D, E, F. Just at the first stage of the procedure, TEE is dedicated to verify the level of passage through the septum - Figure S*5 A, B, C, D* - especially important in the case of multifenestrated defects. After crossing the septum the guidewire should be preferably located in the left upper pulmonary vein (LUPV) and not in thin-walled LAA, what should be ruled out.

The left atrial occluder disc is usually opened deeply in the left atrium, usually close to the LUPV and than slowly withdraw to the septum. As it reaches the septum the right atrial disc of the occluder is opened - *Figure S6 A, B, C, D, E, F*. Before releasing the occluder, it is crucial to verify its position and appropriate capture of all the rims with the discs - *Figure S7 A, B, C, D*. It may be challenging in case of thin, floppy and excessively mobile septum. Presentation of posterior rims may be difficult in TEE, however 3D imaging might be helpful (Figure S7 F) as well as Minnesota maneuver (push-pull maneuver; the "Minnesota wiggle") enables to verify the stability of the occluder's position. It is obligatory to assess the presence of residual shunt before releasing the occluder. Usually tension of the delivery system causes deflection of right atrial disc with trivial shunt through the device disappearing after occluder release (Figure S7 E), whereas flow at the edge of the device may indicate that the occluder is undersized. It is necessary to re-verify the position of the occluder and its relation to the surrounding structures including especially atrioventricular valves and residual shunt after device release. Pericardium should be verified, trivial effusion may occur generally after long procedures, nevertheless it should be monitored due to the risk of tamponade.

IV. Short review of the devices for ASD closure available in Poland

The Amplatzer Septal Occluder (ASO) (Abbott - USA)

The ASO is currently the most widely used ASD device on the market with excellent safety and sustained efficacy results in pediatric and adult patients alike. It is both FDA and CE approved. The ASO consists of two nitinol woven discs connected by a waist designed to occlude the ASD. The inner parts of the device are covered with an ePTFE membrane. The device is self-expandable and self-centering, and fully recapturable and repositionable if necessary. The size of device is determined by dimensions of the central waist. The available sizes range from 4 to 40 mm., with 1.0 mm increments from 4 to 20 mm and 2.0 mm increments from 20 to 40 mm. The Amplatzer device is available in twenty-six sizes. The device is connected with the delivery system by a micro thread. The delivery systems range from 6 to 12F [71]. The ASO "cribriform" is a specially designed non-self-centering device for multi-fenestrated defects with 4 available sizes from 18 to 40 mm. Nonetheless, the serious complication of cardiac perforation/erosion has been reported with the estimated incidence of 0.19% [72].

ASO is regarded as a "gold-standard" device for many newer devices. All Amplatzer-like occluders are very similar in shape, dimensions, delivery system structure and implantation technique [73,74]. To minimize serum nickel release, the occluders have different protective layers: titanium oxide (Occlutech), titanium nitride (Cera), pre-oxidized nitinol (Hyperion) and platinum (Cocoon). Some devices (Amplatzer-like occluders) require larger delivery sheaths. This may increase the risk of vascular complications, especially in pediatric patients.

Figulla Flex II ASD Occluder (FSO) (Occlutech GmbH – Germany)

The device has a couple of important structural innovations. There is no stainless steel hub on the left atrial disc. This modification makes the tip of the device soft and atraumatic which reduced trauma risk and risk of clot formation, it also changes the geometry of the left disc [75]. The delivery system is completely different. The unique ball-connection between the pusher and the occluder increases the flexibility of the device and its adaptability to the septal anatomy. The titanium oxide-coated nitinol wires provide superior biocompatibility and reduce nitinol release. The device is available in twenty different sizes from 4 to 40 mm. The delivery systems range from 7 to 12F, they are slightly larger than in ASO devices. A fenestrated device for closure of ASD with pulmonary hypertension is available on an order-

made basis. The largest study with FSO, the IRFACODE study, showed a 98% success rate in 1395 patients and a 97.3% complete closure rate at 1 year [76].

Cera, CeraFlex (CSO) (Lifetech Scientific Co – China)

They are the different generation of the devices made by Liftech Co. Same in design as the ASO, this occluder is made from titanium nitride-coated nitinol wire. In contrast to the ASO, the two discs of the CSO consist of less metal, and the bioceramic titanium nitride coating on the disc surface potentially minimizes the risk of thrombus formation, causes less nickel ion elution, and facilitates endothelial tissue growth [77]. The last generation CeraFlex device is preloaded as a package. This device has couple of shared features with FSO; a coated surface of nitinol-wire, flexible connection between the device and delivery cable, and no hub on left atrial disk. The Cera is available in nineteen sizes ranging from 6 to 42 mm. The delivery system ranges from 7 to 14F. The CeraFlex is available with limited number of sizes.

Cocoon Septal Occluder (Vascular Innovations Co - Thailand)

The device is similar in design to the Amplatzer device. It is made from nitinol wire mesh nanocoated with platinum to prevent the release of nickel. The platinum coating also provides superior biocompatibility and prevents corrosion. The device is available in seventeen sizes from 8 to 40 mm (in 2.0 mm increments) and requires a 6 to 14F delivery system. European multicenter study reported an excellent results with procedural success rate of 100% and no complication in 92 patients. This device has been described as softest and lightest currently available device with less metal-to-septum ratio than other devices [78].

Hyperion (Lepu Medical Co - China)

Amplatzer-like device with pre-oxidized nitinol wires. The device is available in sizes ranging from 6 to 42 mm in 2 mm increments (nineteen different sizes). Delivery sheaths range from 8 to 14F.

MemoPart Atrial Septal Defect Occlusion Device (Shanghai Shape Memory Alloy Co, Shanghai - China)

The device is available in twenty-six different sizes from 6 to 42 mm. Delivery sheaths range from 8 to 14F.

Nit-Occlud ASD-R (NOA-R) (PFM Medical – Germany)

This is a double-disc, self-expandable, self-centering device; however, the device characteristics are quite different from other nitrol-mesh devices. The device was made of one piece of nitinol wire without any connecting elements. NOA-R has reduced amount of metal on the left atrial disc without clamping or screwing hub on either side of the atrial discs and has a "reverse configuration" of the single-nitinol-layer on the left atrial disc. Device retrieval could be more difficult because of the no-hub design. The release mechanism is unique as it is "snare-like", which includes a central locking wire and a pusher with a distal wire noose [79]. A total of 12 sizes are available from 8 to 30 mm. with 2.0 mm increments, and the delivery sheath sizes range from 8 to 14F. This is a preloaded device. The device is dedicated to closure ASD smaller than 18 mm. The device is no longer available on the market.

Ultrasept II ASD Occluder (Cardia Mineapolis – USA)

The device has a unique design. The nitinol wire frame forms two sails with a self-centering mechanism. There is a reduced amount of nitinol in the device. The dual articulating sails along with the patented self-centering mechanism allow for a super-low profile of the device. Fractures of the nitinol wire frame have been reported in previous-generation devices, where the nitinol wire frame was covered by a polyvinyl alcohol (PVA) membrane. Because of perforation incidence, this membrane was replaced with a Gore-tex patch in the last generation of the devices [80]. The device is available in fifteen sizes ranging from 6 to 34 mm in 2.0 mm increments. Delivery sheaths range from 9 to 11F.

Helex Septal Occluder (HSO), Gore Cardioform Septal Occluder (GSO) (W.L. Gore and Associates Inc.- USA)

HSO – the previous generation of the device was composed of single nitinol wire helical frame covered with expanded polytetrafluoroethylene (ePTFE) membrane. The GSO – next generation of the device is a non-self-centering double disk device composed of single platinum filled nitinol wire framework covered with ePTFE membrane. The GSO is preloaded as a package of the device and whole delivery system. There are 4 device sizes from 15 to 30 mm with 5.0 mm increments. It is not suitable for defects over 18 mm due to the non-self-centering feature. Currently the device is not available on the Polish market.

V. References:

1. Baumgartner H, De Backer J, Babu-Narayan SV et al. 2020 ESC guidelines for the management of adult congenital heart disease. Eur Heart J. 2020; doi:10.1093/eurheartj/ehaa554
2. Stout KA, Daniels CJ, Aboulhosn JA, et al. 2018 AHA/ACC Guideline for the Management of Adults With Congenital Heart Disease : a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. J Am Coll Cardiol. 2018; 73: e81-192
3. Oster M, Bhatt A, Zaragoza-Macias E, et al. Interventional therapy versus medical therapy for secundum atrial septal defect: a systematic review (part 2) for the 2018 AHA/ACC guideline for the management of adults with congenital heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. J Am Coll Cardiol. 2018; 73: 1579-95
4. Silversides CK, Dore A, Poirier N, et al. Canadian Cardiovascular Society 2009 consensus conference on the management of adults with congenital heart disease: shunt lesions. Can J Cardiol. 2010; 26: e70-79
5. Marelli AJ, Ionescu-Ittu R, Mackie AS, et al.Life time prevalence of congeital heart disease in the general population from 2000 to 2010. Circulation. 2014; 130: 749–56
6. Perloff JK. Surgical closure of atrial septal defect in adults. N Engl J Med. 1995; 333: 513–4
7. Gatzoulis MA, Freeman MA, Siu SC, et al. Atrial arrhythmia after surgical closure of atrial septal defects in adults. N Engl J Med. 1999; 340: 839–46
8. Campbell M. Natural history of atrial septal defect. Br Heart J. 1970; 32: 820–6.
9. Hirayama-Yamada K, Kamisago M, Akimoto K, et al. Phenotypes with GATA4 or NKX2.5 mutations in familial atrial septal defect. Am J Med Genet A 2005; 135: 47-52.
10. McElhinney DB, Geiger E, Blinder J, et al. NKX2.5 mutations in patients with congenital heart disease. J Am Coll Cardiol 2003; 42: 1650-5.
11. Rakhmanov Y, Maltese PE, Zulian A, et al. Genetic testing for atrial septal defect. The EuroBiotech Journal. 2018; DOI: 10.2478/ebtj-2018-0035
12. Chaix MA, Andelfinger G, Khairy P Genetic testing in congenital heart disease: A clinical approach. World J Cardiol 2016; 8: 180-191
13. Murphy JG, Gersh BJ, McGoon MD, et al. Long-term outcome after surgical repair of isolated atrial septal defect. Follow-up at 27 to 32 years. N Engl J Med. 1990; 323:

1645–50

14. Silvestry FE, Cohen MS, Armsby LB, Burkule NJ et al 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: 910-58.
15. Rana BS Echocardiography guidance of atrial septal defect closure J Thorac Dis 2018; 10(Suppl 24): S2899-S2908
16. Bechis MZ, Rubenson DS, Price MJ. Imaging Assessment of the Interatrial Septum for Transcatheter Atrial Septal Defect and Patent Foramen Ovale Closure. Intervent Cardiol Clin 2017; 6: 505–524
17. Meier B, Gloekler S, Dénéréaz D, et al. Percutaneous Repair of Sinus Venosus Defect With Anomalous Pulmonary Venous Return. Eur Heart J 2014; 35: 1352-1358
18. Grewal J, Majdalany D, Syed I, et al. Three dimensional echocardiographic assessment of right ventricular volume and function in adult patients with congenital heart disease: comparison with magnetic resonance imaging. J Am Soc Echocardiogr. 2010; 23: 127–33.
19. Kilner PJ, Geva T, Kaemmerer H, et al. Recommendations for cardiovascular magnetic resonance in adults with congenital heart disease from the respective working groups of the European Society of Cardiology. Eur Heart J 2010; 31: 794–805.
20. Festa P, Ait-Ali L, Cerillo AG, et al. Magnetic resonance imaging is the diagnostic tool of choice in the preoperative evaluation of patients with partial anomalous pulmonary venous return. Int J Cardiovasc Imaging. 2006; 22: 685–93.
21. van der Linde D, Rossi A, Yap SC, et al. Ascending aortic diameters in congenital aortic stenosis: cardiac magnetic resonance versus transthoracic echocardiography. Echocardiography. 2013; 30: 497–504.
22. Puchalski MD, Williams RV, Askovich B, et al. Assessment of right ventricular size and function: echo versus magnetic resonance imaging. Congenit Heart Dis. 2007; 2: 27–31.
23. Bonello B, Kilner PJ. Review of the role of cardiovascular magnetic resonance in congenital heart disease, with a focus on right ventricle assessment. Arch Cardiovasc Dis. 2012; 105: 605–13.
24. Stout KK, Daniels CJ, Aboulhosn JA, et al. 2018 AHA/ACC Guideline for the Management of Adults With Congenital Heart Disease: A Report of the American

College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. Circulation. 2019; 139: e698–e800.

25. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. N Engl J Med. 2007; 357: 2277–84.
26. Barron AJ, Wensel R, Francis DP, et al. The role for cardiopulmonary exercise testing in patients with atrial septal defects: A review. Int J Cardiol. 2012; 161: 68–72.
27. Galie N, Humbert M, Vachiery J-L et al. 2015 ESC/ERS Guidelines for the diagnosis and treatment of pulmonary hypertension. Eur Heart J. 2016; 37: 67-119
28. Kurzyna M, Araszkiewicz A, Błaszczak P et al. Summary of recommendations for haemodynamic and angiographic assessment of the pulmonary circulation. Joint statement of Polish Cardiac Society's Working Group on Pulmonary Circulation and Assocaition of Cardiovascular Intervention. Kardiol Pol. 2015; 73: 63-68
29. Kurzyna M, Araszkiewicz A, Błaszczak P et al. Standardy hemodynamicznej i angiograficznej oceny krążenia płucnego. Kardiol Pol. 2014; 72 Suppl IV: 45-64
30. Simmoneau G, Montani D, Celermajer DS, et al. Haemodynamic definitions and updated clinical classification of pulmonary hypertension. Eur Resp.J. 2019; 53 : 180-191
31. Bergsta A, van Dijk RB, Hillege HL, Lie KI, Mook GA. Assumed oxygen consumption based on calculation from dye dilution cardiac output: an improved formula. Eur Heart J. 1995; 16: 698-703
32. Murray G. Closure of defects in cardiac septa. Ann Surg. 1948; 128: 843-853.
33. Burkhart HM, Suri RM. Minimally invasive video assisted surgical closure of secundum atrial septal defect. Ann Cardiothorac Surg. 2017; 6: 60-63.
34. King TD, Mills NL. Nonoperative closure of atrial septal defects. Surgery. 1974; 75: 383-388.
35. Amin Z, Hijazi ZM, Bass JL, et al. Erosion of Amplatzer septal occluder device after closure of secundum atrial septal defects: review of registry of complications and recommendations to minimize future risk. Catheter Cardiovasc Interv. 2004; 63: 496-502.
36. Takaya Y, Akagi T, Kijima Y, et al. Functional Tricuspid Regurgitation After Transcatheter Closure of Atrial Septal Defect in Adult Patients: Long-Term Follow-Up. JACC Cardiovasc Interv. 2017; 10: 2211-2218.
37. Humenberger M, Rosenhek R, Gabriel H, et al. Benefit of atrial septal defect closure in adults: impact of age. European Heart Journal. 2011; 32: 553–560.

38. Attie F, Rosas M, Granados N, et al. Surgical treatment for secundum atrial septal defects in patients 40 years old. A randomized clinical trial. J Am Coll Cardiol. 2001; 38: 2035–2042.
39. Rosas M, Zabal C, Garcia-Montes J, et al. Transcatheter versus surgical closure of secundum atrial septal defect in adults: impact of age at intervention. A concurrent matched comparative study. Congenit Heart Dis. 2007; 2: 148–155.
40. Salehian O, Horlick E, Schwerzmann M, et al. Improvements in cardiac form and function after transcatheter closure of secundum atrial septal defects. J Am Coll Cardiol. 2005; 45: 499–504.
41. Majunke N, Bialkowski J, Wilson N, et al. Closure of atrial septal defect with Amplatzer septal occlude in adults. Am J Cardiol 2009; 103: 550-4
42. Jategaonkar S, Scholtz W, Schmidt H, et al. Percutaneous Closure of Atrial Septal Defects Echocardiographic and Functional Results in Patients Older Than 60 Years Circulation: Cardiovascular Interventions. 2009; 2: 85–89.
43. Fuse S, Tomita H, Hatakeyama K, Kubo N, Abe N. Effect of size of a secundum atrial septal defect on shunt volume. Am J Cardiol. 2001; 88: 1447-50.
44. Ewert P, Berger F, Nagdyman N, et al. Masked left ventricular restriction in elderly patients with atrial septal defects: a contraindication for closure? Cath Cardiovasc Interv. 2001; 52: 177–180.
45. Masutani S, Taketazu M, Mihara C, et al. Usefulness of early diastolic mitral annular velocity to predict plasma levels of brain natriuretic peptide and transient heart failure development after device closure of atrial septal defect. Am J Cardiol. 2009; 104: 1732-6.
46. Tomai F, Ando G, De Paulis R, et al. Real-time evaluation of the hemodynamic effects of atrial septal defect closure in adults with left ventricular dysfunction. Catheter Cardiovasc Interv. 2005; 64: 124-6.
47. Schubert S, Peters B, Abdul-Khaliq H, et al. Left ventricular conditioning in the elderly patient to prevent congestive heart failure after transcatheter closure of atrial septal defect. Catheter Cardiovasc Interv. 2005; 64: 333-7.
48. Gruner C, Akkaya E, Kretschmar O, et al. Pharmacologic preconditioning therapy prior to atrial septal defect closure in patients at high risk for acute pulmonary edema. J Interv Cardiol. 2012; 25: 505-12.
49. Peters B, Ewert P, Schubert S, et al. Self-fabricated fenestrated Amplatzer occluders for transcatheter closure of atrial septal defect in patients with left ventricular restriction: midterm results. Clin Res Cardiol. 2006; 95: 88-92.

50. Engelfriet PM, Duffels MG, Moller T, et al. Pulmonary arterial hypertension in adults born with a heart septal defect: the Euro Heart Survey on adult congenital heart disease. Heart 2007; 93: 682-7.
51. Vogel M, Berger F, Kramer A, et al. Incidence of secondary pulmonary hypertension in adults with atrial septal or sinus venosus defects. Heart 1999; 82: 30-3.
52. Craig RJ, Selzer A. Natural History and Prognosis of atrial septal defect. Circulation 1968; 37: 805-815
53. Jain S, Dalvi B. Atrial septal defect with pulmonary hypertension: when/how can we consider closure? J Thorac Dis. 2018; 10 (Suppl. 24): S2890-2898
54. Bruch L, Winkelmann A, Sonntag S et al. Fenestrated occluders for treatment of ASD in elderly patients with pulmonary hypertension and/or right heart failure. J Interv Cardiol. 2008; 21: 44-9.
55. Holzer R, Qi-Ling C, Hijazi ZM. Closure of moderately large atrial septal defect with self-fabricated fenestrated Amplatzer septal occludder in an 85-year-old patient with reduced diastolic elasticity of the left ventricle. Cath Cardiovasc Interv. 2005; 64: 513-518
56. Beghetti M, Galie N, Bonnet D. Can "inoperable" congenital heart defects become operable in patients with pulmonary arterial hypertension? Dream or reality? Congenit Heart Dis. 2012; 7: 3-11
57. Viswanathan S, Kumar RK. Assessment of Operability of Congenital Cardiac Shunts with Increased Pulmonary Vascular Resistance. Cath Cardiovasc Interv. 2008; 71: 665-70.
58. Tyc F, Suchodolski A, Rojczyk D et al. Transcatheter closure of atrial septal defect with Chinese and Thai nitinol wire mesh occluders in adult patients. Kardiol Pol 2020; 78; 68-70
59. Thomson J. Step-by-step closure of atrial septal defects. In: Butera F, Chessa M, Eicken A et al. Cardiac catheterization for congenital heart disease from fetal life to adulthood. Springer-Verlag Italia 2015: 421-448
60. Felice H, Chandran S, Bharma-Ariza P et al. Transcatheter Closure of Multiple Defects of the Atrial Septum: Technique and Follow-Up. International Journal of Clinical Medicine 2015; 6: 591-596
61. Fraisse A, Latchman M, Sharma SR et al. Atrial septal defect closure: indications and contra-indications. J Thorac Dis 2018; 10(Suppl 24): S2874-S2881

62. Se Yong Jung, Jae Young Choi, Transcathter closure of atrial septal defect: principles and available devices. J Thorac Dis. 2018; 10(Suppl 24): S2909–S2922
63. Hu Z, Zhang Y, Zhang T et al. Comparison of the Effectiveness and Safety of Single versus Dual Occluders for the Closure of Multiple Atrial Septal Defects. J. Interv Cardiol 2015; 27: E90-E97
64. Ohno N, Chaturvedi R, Lee KJ et al. Characteristics of secundum atrial septal defects not percutaneously closed. Cath Cardiovasc Interv 2015; 85: 234-239
65. Ostermayer SH, Srivastava S, Doucette H et al. Malattached Septum Primum and Deficient Septal Rim Predict Unsuccessful Transcatheter Closure of Atrial Communications. Cath Cardiovasc Interv 2015; 86: 1195–120
66. O'Byrne ML, Glatz AC, Sunderji S et al. Prevalence of deficient retro-aortic rim and its effects on outcomes in device closure of atrial septal defects. Pediatr Cardiol. 2014; 35: 1181–1190
67. Amedro P, Bayburt S, Assaidi A et al. Should transcatheter closure of atrial septal defects with inferior-posterior deficient rim still be attempted? J Thorac Dis 2019; 11: 708-716
68. Thakkar AN, Chinnadurai P, Breinholt JP et al. Transcatheter closure of a sinus venosus atrial septal defect using 3D printing and image fusion guidance. Cath Cardiovasc Interv. 2018; 92: 353-357
69. Krishnamoorthy KM, Gopalakrishnan A, Sivasankaran SS. Percutaneous Closure of Atrial Septal Defects with Deficient Rims. Cardiology 2016; 135: 48–49
70. King TD, Thompson SL, Steiner C, Mills NL. Secundum atrial septal defect. Nonoperative closure during cardiac catheterization. JAMA 1976; 235: 2506–9.
71. Chessa M, Carminati M, Butera G, et al. Early and late complications associated with transcatheter occlusion of secundum atrial septal defect. J Am Coll Cardiol 2002; 39: 1061–1065.
72. Crawford GB, Brindis RG, Krucoff MW, et al. Percutaneous atrial septal occluder devices and cardiac erosion: a review of the literature. Cath Cardiovasc Interv 2012; 80: 157-67.
73. Bialkowski J Percutaneous closure of atrial septal defect type II - a few remarks on the basis of my own experience Kardiol Pol 2017; 75: 1062-3

74. Tyc F, Suchodolski A, Rojczyk D, Galeczka M et al. Transcatheter closure of atrial septal defect with Chinese and Thai nitinol wire mesh occluders in adult patients. Kardiol Pol 2020; 78: 68-70
75. Halabi A, Hijazi ZM. A new device to close secundum atrial septal defects: First clinical use to close multiple defects in a child. Cath Cardiovasc Interv 2008; 71: 853–856.
76. Haas NA, Soetemann DB, Ates I, et al. Closure of Secundum Atrial Septal Defects by Using the Occlutech Occluder Devices in More Than 1300 Patients: The IRFACODE Project: A Retrospective Case Series. Cath Cardiovasc Interv 2016; 88: 571-81.
77. Zhang D, Zhang Z, Zi Z, et al. Fabrication of graded TiN coatings on nitinol occluders and effects on in vivo nickel release. *Biomed Mater Eng.* 2008; 18: 387-93.
78. Thanopoulos BD, Biasco L, Dardas P, et al. Catheter closure of atrial septal defects using the Cocoon septal occluder: preliminary results of a European multicenter study. Int J Cardiol 2014; 177: 418-22.
79. Peirone A, Contreras A, Ferrero A, et al. Immediate and short-term outcomes after percutaneous atrial septal defect closure using the new nit-occlud ASD-R device. Cath Cardiovasc Interv 2014; 84: 464-70.
80. Bozyel S, Sahin T, Dervis E, et al. A massive left-to-right shunt due to delayed spontaneous perforation of polyvinyl alcohol membrane of atrial septal occluder. Turk Kardiyol Dern Ars 2017; 45: 541-4.
81. Villablanca PA, Briston DA, Rodes-Cabau J, et al. Treatment options for the closure of secundum atrial septal defects: a systematic review and meta-analysis. Int J Cardiol 2017; 241: 149e-55.
82. Turner DR, Owada CY, Sang Jr CJ, et al. Closure of secundum atrial septal defects with the AMPLATZER septal occluder: a prospective, multicenter, post-approval study. Circ Cardiovasc Interv 2017; 10.
83. Jalal Z, Hascoet S, Baruteau AE, et al. Long-term complications after transcatheter atrial septal defect closure: a review of the medical literature. Can J Cardiol 2016; 32: 1315.e11e8.
84. Levi DS, Moore JW. Embolization and retrieval of the Amplatzer septal occluder. Cath Cardiovasc Interv 2004; 61: 543e7.
85. Hijazi Z.M.: Catheter closure of atrial septal and ventricular septal defects using the Amplatzer devices. Heart, Lung and Circulation 2003; 12: S63-S72.
86. DiBardino DJ, McElhinney DB, Kaza AK, et al. Analysis of the US Food and Drug administration manufacturer and user facility device experience database for adverse

events involving amplatzer septal occluder devices and comparison with the society of thoracic surgery congenital cardiac surgery database. J Thorac Cardiovasc Surg 2009; 137: 1334e41.

87. Abaci A, Unlu S, Alsancak Y, et al. Short and long term complications of device closure of atrial septal defekt and patent foramen ovale: meta-analysis of 28,142 patients from 203 studies. Cath Cardiovasc Interv 2013; 82: 1123e38.c
88. Moore J, Hegde S, El-Said H et al.: Transcatheter device closure of atrial septal defects. A safety review. J Am. Coll. Cardiol. 2013; 6: 433-442
89. Fillipone G, La Barbera G, Valentino F, et al. Transcatheter retrieval of Amplatzer Septal Occluder device embolized into the abdominal aorta. SAGE Open Med Case Rep. 2019; 7: 2050313X19842462.
90. Martínez-Quintana E, Rodríguez-González F. Risks Factors for Atrial Septal Defect Occlusion Device Migration. Int J Angiol 2016; 25: e63-5.
91. Deser SB, Demirag MK. Migration of an Atrial Septal Occluder Device with Formation of Abdominal Aortic Dissection. Ann Thorac Surg 2017; 103: e343-4
92. Poommipanit P, Amin Z. Considerations for ASD Closure. Understanding the devices and proper anatomic evaluation to prevent and manage possible complications. Cardiac interventions Today. March/April 2014
93. McElhinney DB, Quartermain MD, Kenny D et. Al. Relative Risk Factors for Cardiac Erosion Following Transcatheter Closure of Atrial Septal Defects. Circulation. 2016; 133: 1738–1746
94. Qureshi AM, Mumtaz MA, Latson L. Partial prolapse of a Helex device associated with early frame fracture and mitral valve perforation. Cath Cardiovasc Interv. 2009; 74:777-782.
95. Yang M-C, Wu J-R: Recent review of transcatheter closure of atrial septal defect. Kaohsiung J of Med. Sci. 2018; 34: 363-369.
96. Szkutnik M, Lenarczyk A, Kusa J, Bialkowski J. Symptomatic tachy- and bradyarythmia after transcatheter closure of interatrial communications with Amplatzer device. Cardiol J 2008; 15: 510-16
97. Krumsdorf U, Ostermayer S, Billinger K, et al.: Incidence and clinical course of thrombus formation on atrial septal defect and patient foramen ovale closure devices in 1,000 consecutive patients. J Am Coll Cardiol 2004; 43: 302-309.

98. Heredia J, Szkutnik M, Fiszer R et. al. Early neurological complications after transcatheter closure of atrial septal defect with nitinol wire mesh occluder. Kardiol Pol 2013; 71: 957-9
99. Bialkowski J, Pawlak S, Banaszak P. Incomplete endothelization of an Amplatzer septal occluder device followed by meningitis and late bacterial endocarditis. Cardiol Young 2016; 26: 808-810
100. Wertman B, Azarbal B, Riedl M, et al. Adverse events associated with nickel allergy in patients undergoing percutaneous atrial septal defect or patent foramen ovale closure. J Am Coll Cardiol. 2006; 47: 1226-1227.
101. Gordon BM, Moore JW. Nickel for your thoughts: survey of the Congenital Cardiovascular Interventional Study Consortium (CCISC) for nickel allergy. J Invasive Cardiol 2009; 21: 326 –9.
102. Bhattacharjya S, Sadasivan L Doraiswamy V, et al.: Prospective concurrent head-to head comparison of three different types of nitinol occluder device for transcatheter closure of secundum atrial septal defects. Eurointervention 2019; 15: e321-e328.
103. Hanslik A, Pospisil U, Salzer-Muhar U, et al. Predictors of spontaneous closure of isolated secundum atrial septal defect in children: A longitudinal study. Pediatrics 2006; 118: 1560–1565
104. Mcmahon Cj., Feltes TF., Fraley JK., et al. Natural history of growth of secundum atrial septal defects and implications for transcatheter closure. Heart 2002; 87: 256-259.
105. Petit CJ, Justino H, Pignatelli RH, et al. Percutaneous atrial septal defect closure in infants and toddlers: Predictors of success. Pediatr Cardiol 2013; 34: 220–225.
106. Wyss Y., Quandt D., Weber R., et al. Interventional Closure of Secundum Type Atrial Septal Defects in InfantsLess Than 10 Kilograms: Indications and Procedural Outcome. Journal of Interventional Cardiology 2016; 29: 646-653.
107. Lim DS, Matherne GP. Percutaneous device closure of atrial septal defect in a premature infant with rapid improvement in pulmonary status. Pediatrics 2007; 119: 398–400.
108. Knop M, Bialkowski J, Szkutnik M et. al. Transcatheter closure of atrial septal defect type 2 in children under three years of age. Kardiol Pol 2018; 76: 1257-62
109. Houeijeh A, Hascoët S, Bouvaist H, et al. Transcatheter closure of large atrial septal defects (ASDs) in symptomatic children with device/weight ratio ≥1. 5. Int J Cardiol. 2018; 267: 84–87.

110. Jala Z., Hascoët S., Gronier C., et al. Long-Term Outcomes After Percutaneous Closure of Ostium Secundum Atrial Septal Defect in the Young: A Nationwide Cohort Study. JACC Cardiovasc Interv. 2018; 11: 795-804.

111. Giardini A, Donti A, Formigari R, et al. Determinants of cardiopulmonary functional improvement after transcatheter atrial septal defect closure in asymptomatic adults. J Am Coll Cardiol 2004; 43: 1886-91.

112. Prochownik P, Przewłocki T, Podolec P et al. Improvement of physical capacity in patients undergoing transcatheter closure of atrial septal defects. Advances in Interventional Cardiology 2018; 14: 90-94.

113. Komar M, Przewłocki T, Olszowska M. et al. Conduction abnormality and arrhythmia after transcatheter closure of atrial septal defect. Circ J. 2014; 78: 2415-21.

114. Weiss B, Zemp L, Seifert B, Hess O. Outcome of pulmonary vascular disease in pregnancy: A systematic overview from 1978 through 1996. J Am Coll Cardiol 1998; 31: 1650-7.

115. Butera G, Carminati M, Chessa M et al. Percutaneous versus surgical closure of secundum atrialseptal defect: comparison of early results and complications. Am Heart J 2006; 151: 228 – 234.

116. Siu SC, Sermer M, Colman JM et al. Prospective multicenterstudy of pregnancy outcomes in women with heart disease. Circulation 2001; 104: 515 – 521.

117. Fischer G, Stieh J, Uebing A et al. Experience with transcatheter closure of secundum atrial septal defects using the Amplatzer septal occluder: a single centre study in 236 consecutive patients. Heart 2003; 89: 199 – 204.

118. Wilson W, Taubert KA, Gewitz M, et al. Prevention of infective endocarditis: Guidelines from the American Heart Association: A guideline from the American Heart Association Rheumatic Fever, Endocarditis, and Kawasaki Disease Committee, Council on Cardiovascular Disease in the Young, and the Council on Clinical Cardiology, Council on Cardiovascular Surgery and Anesthesia, and the Quality of Care and Outcomes Interdisciplinary Working Group. Circulation 2007; 116: 1736-54.

119. Fuertes Moure A, Meyer M, Häcker AL, et al. Health-Related Physical Fitness and Quality of Life in Children and Adolescents With Isolated Left-to-Right Shunt. Front Pediatr. 2019; 7: 488-494.

120. Bedard E, Dimopoulos K, Gatzoulis MA. Has there been any progress made on pregnancy outcomes among women with pulmonary arterial hypertension? Eur Heart J 2009; 30: 256-65.

121. Araszkiewicz A, Bartuś S, Demkow M et al. , Interventional closure of patent foramen ovale in prevention of thromboembolic events. Consensus document of the Association of Cardiovascular Interventions and the Section of Grown-up Congenital Heart Disease of the Polish Cardiac Society. Kard. Pol. 2019; 77: 1094-1105
122. Singh V, Badheka AO, Patel NJ, et al. Influence of hospital volume on outcomes of percutaneous atrial septal defect and patent foramen ovale closure: a 10-years US perspective. Catheter Cardiovasc Interv. 2015; 85: 1073-81.
123. Marmagkiolis K, Hakeem A, Cilingiroglu M, et al. The Society for Cardiovascular Angiography and Interventions Structural Heart Disease Early Career Task Force survey results: endorsed by the Society for Cardiovascular Angiography and Interventions. Catheter Cardiovasc Interv. 2012; 80: 706-711.
124. Herrmann HC, Baxter S, Ruiz CE, et al. SCAI Council on Structural Heart Disease. Results of the Society of Cardiac Angiography and Interventions survey of physicians and training directors on procedures for structural and valvular heart disease. Catheter Cardiovasc Interv. 2010; 76: E106-10.

VI. FIGURES:

Figure S1A

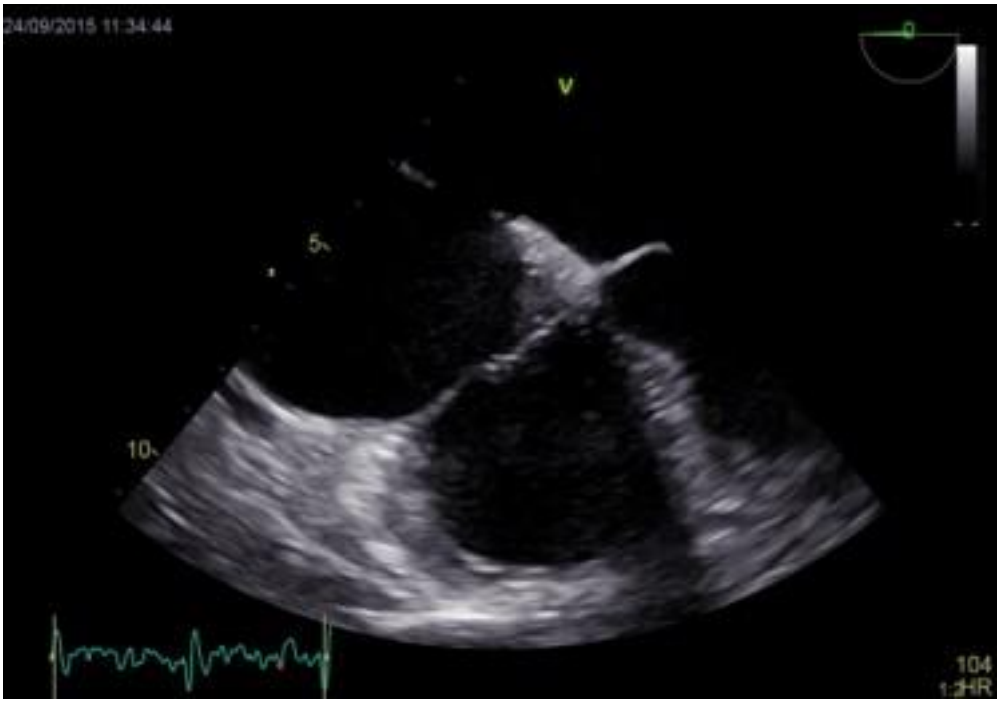


Figure S1B

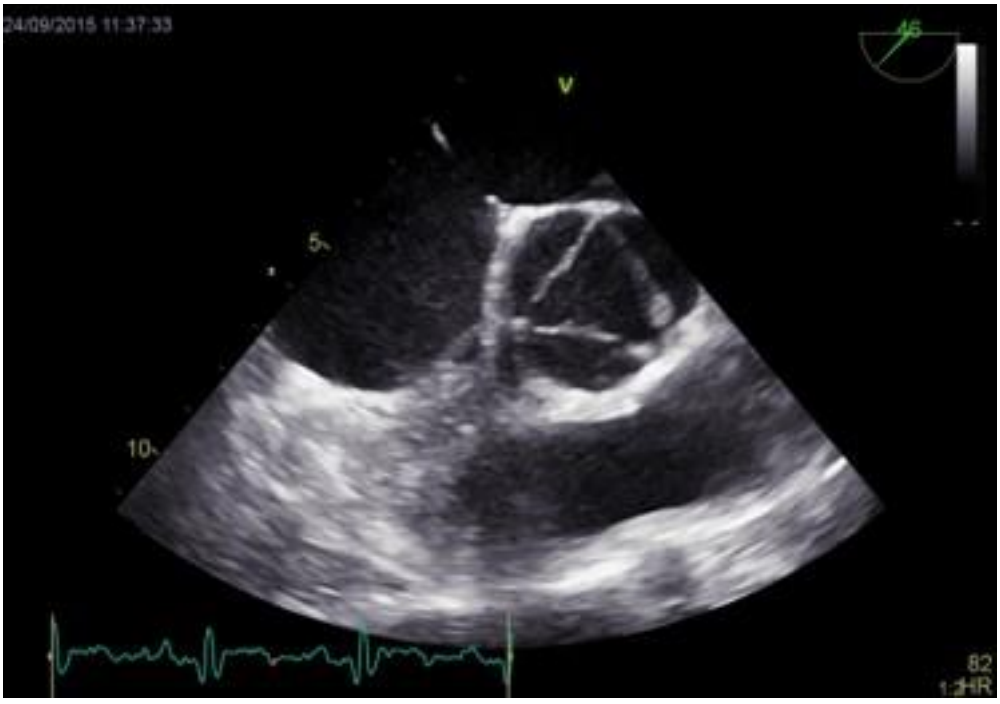


Figure S1C

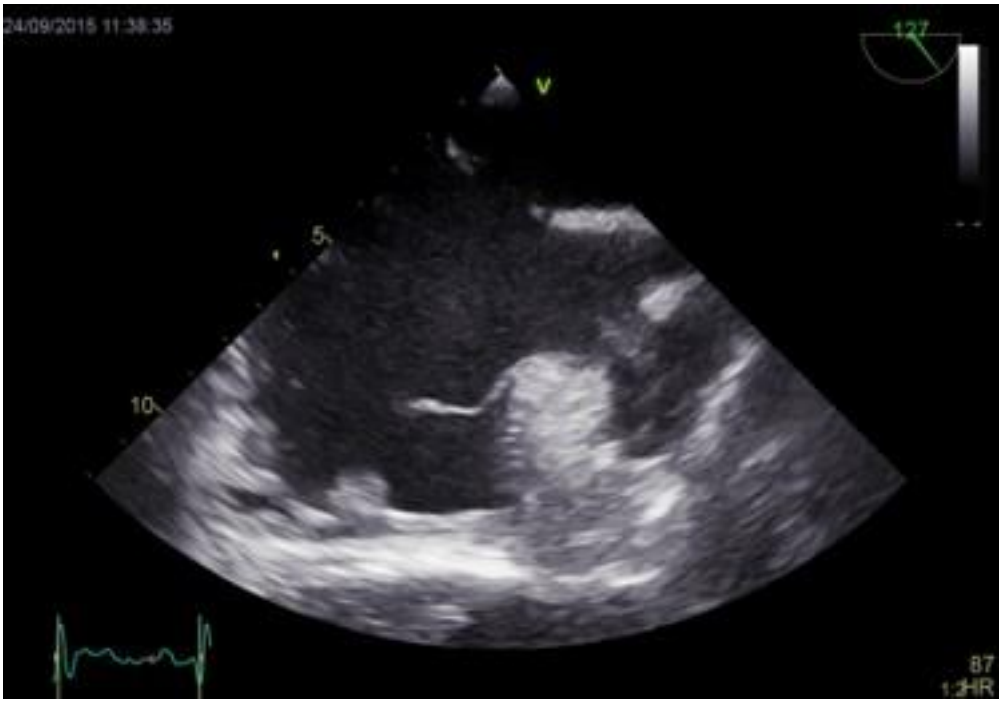


Figure S1D

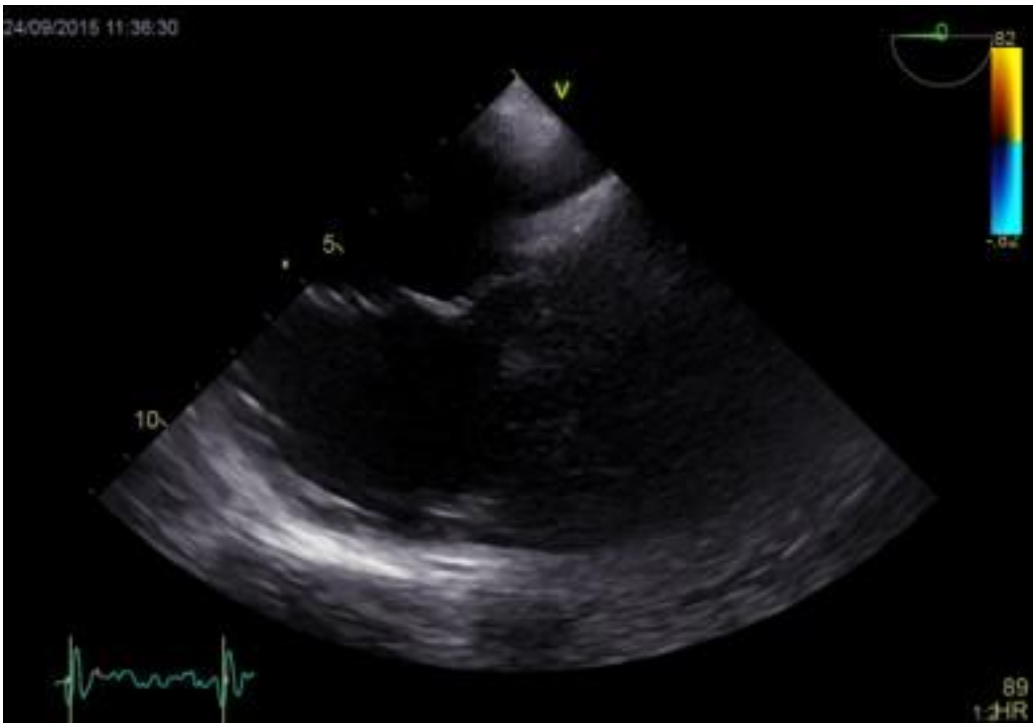


Figure S1E

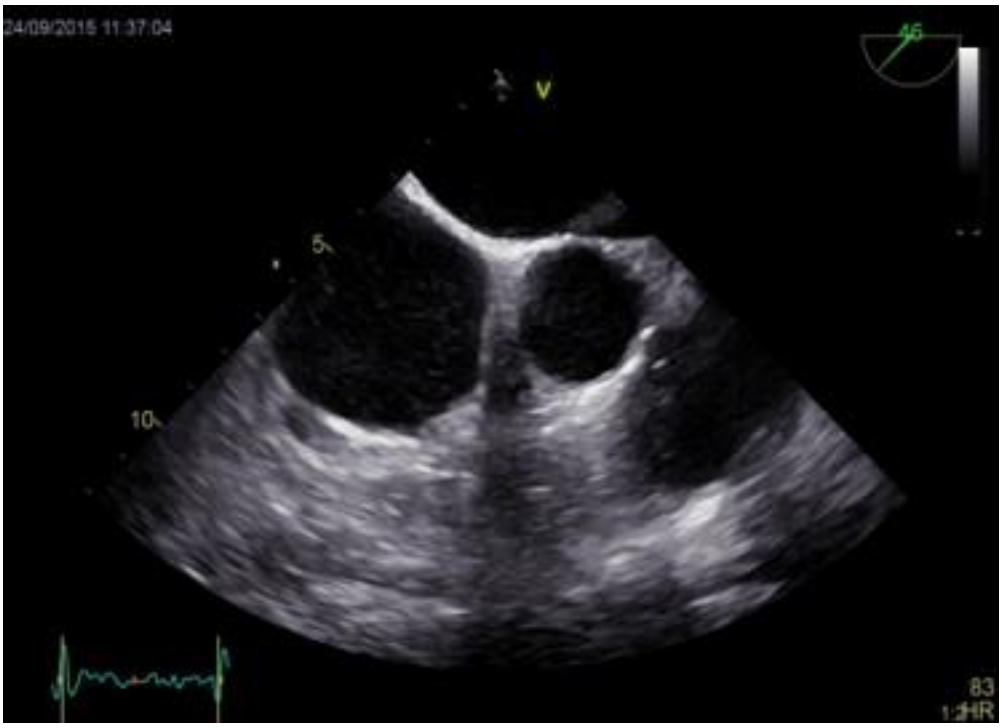


Figure S1F

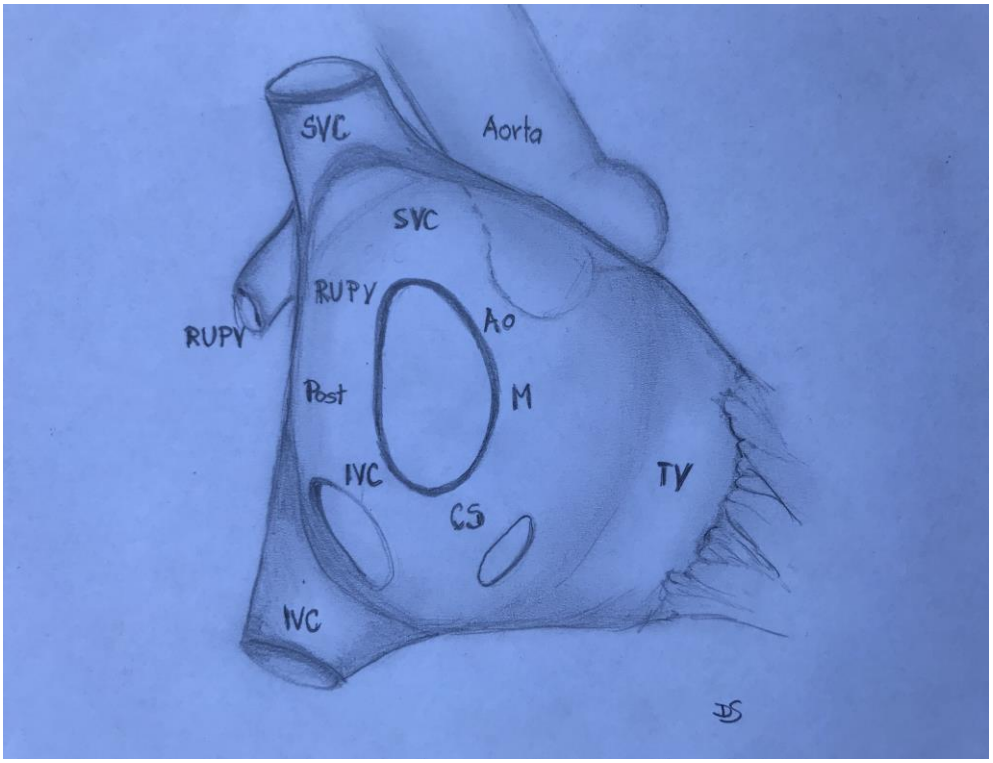


Figure S2A

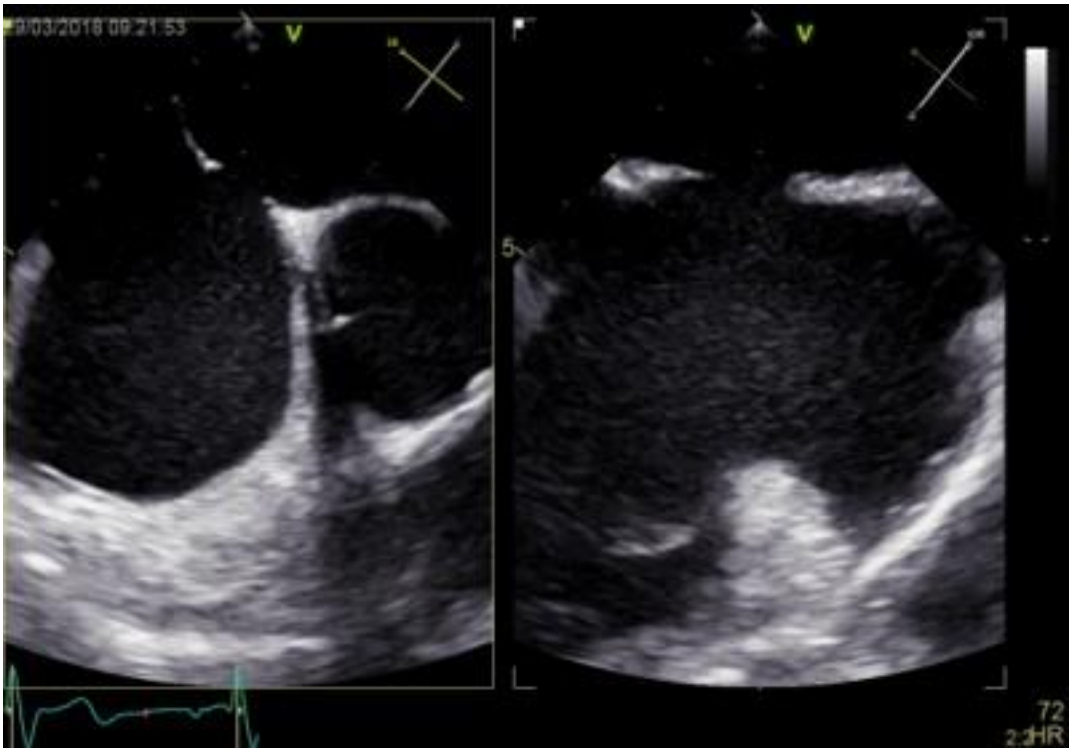


Figure S2B

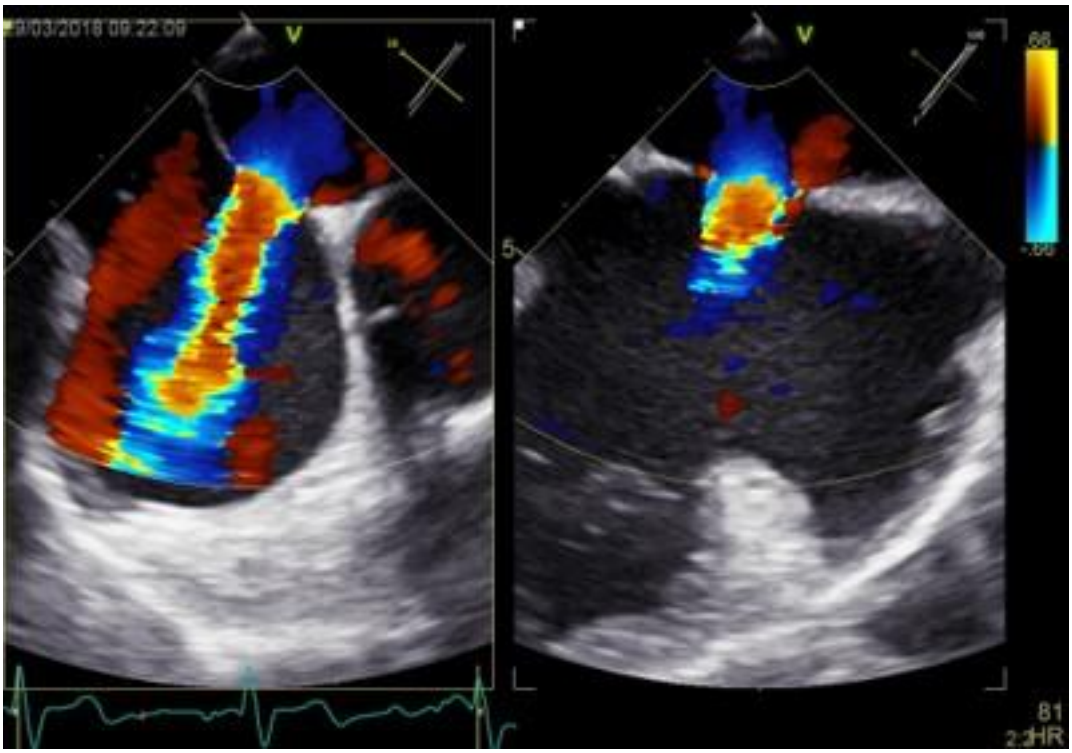


Figure S2C

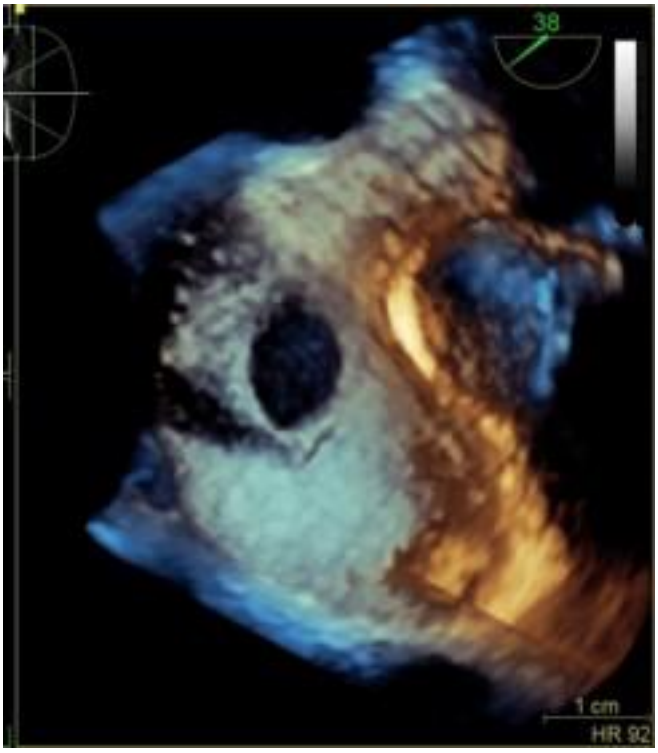


Figure S2D

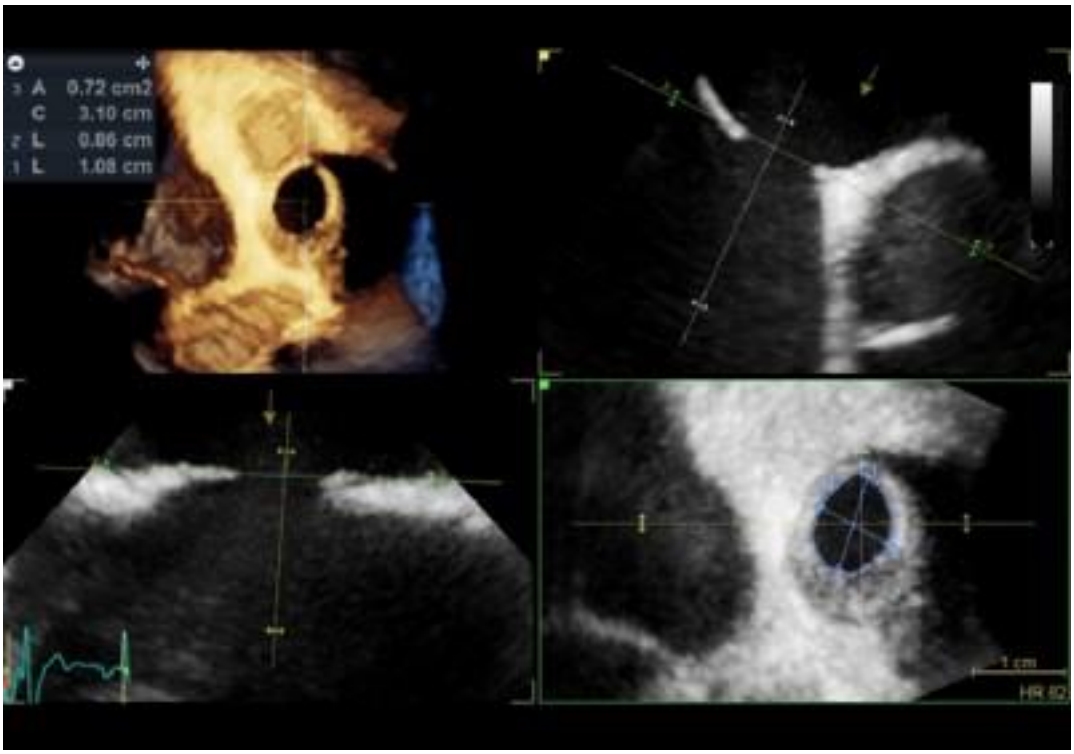


Figure S2E

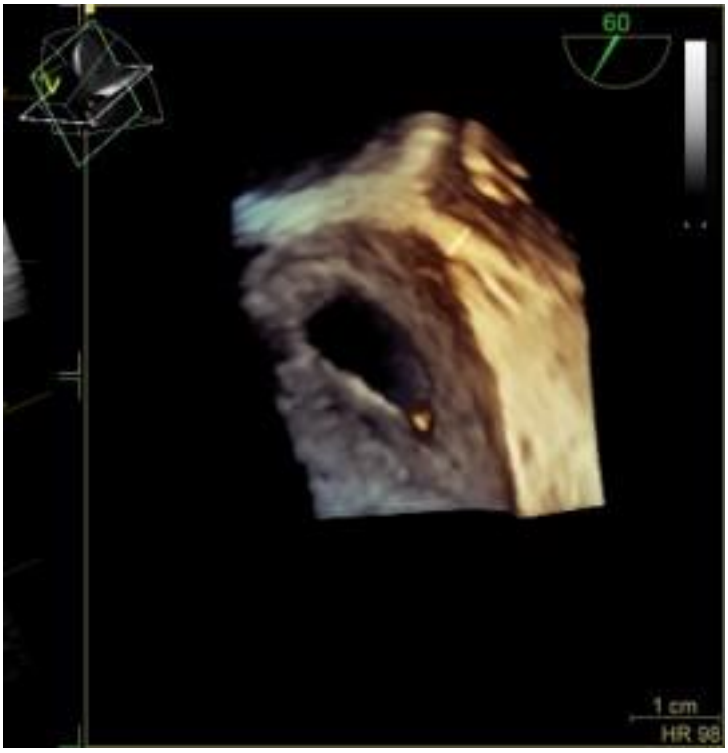


Figure S2F

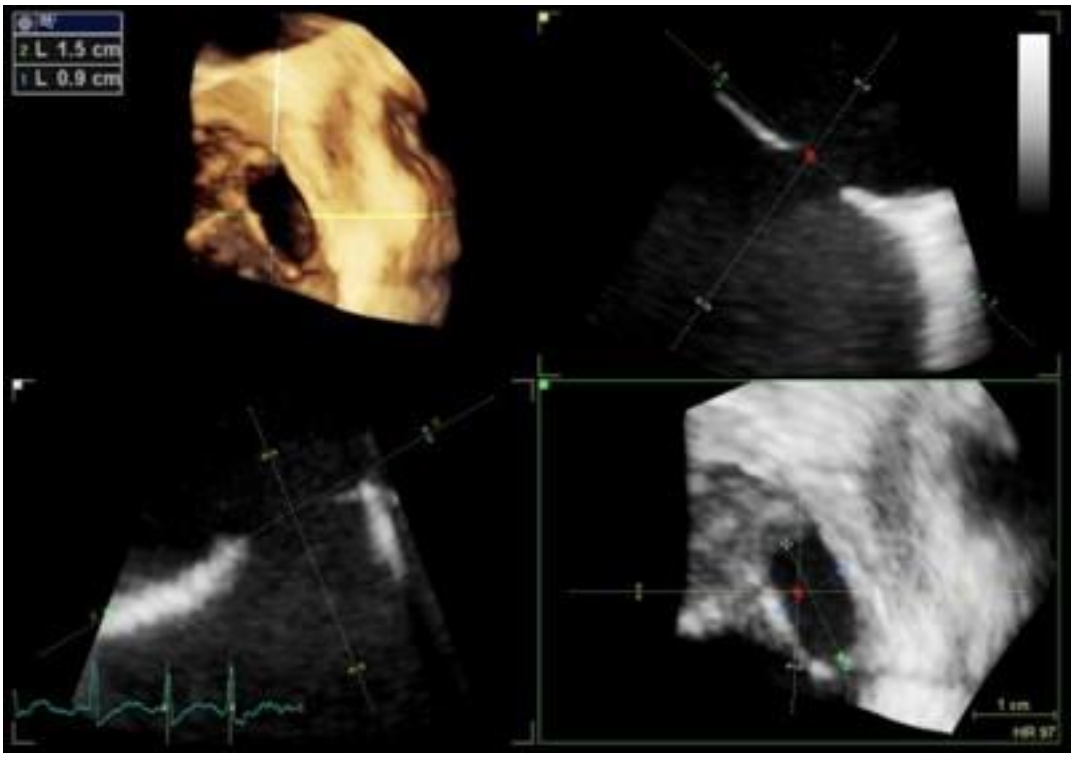


Figure S3A

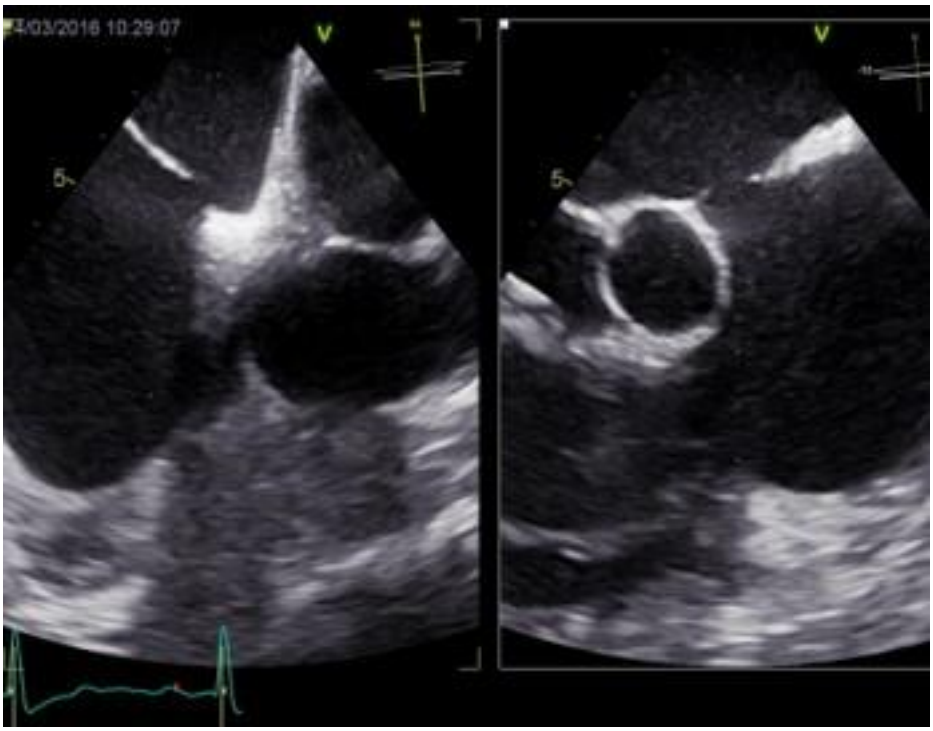


Figure S3B

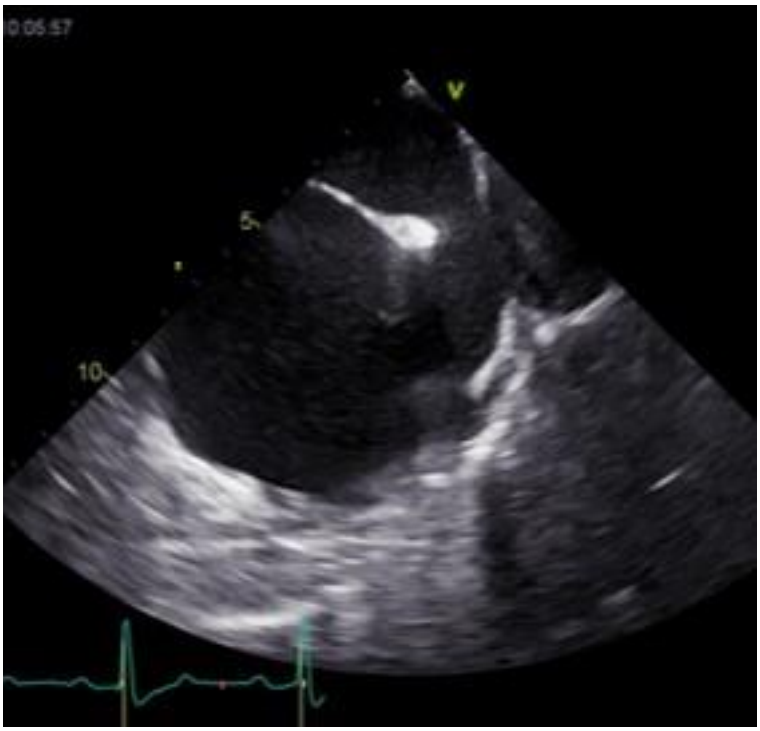


Figure S3C

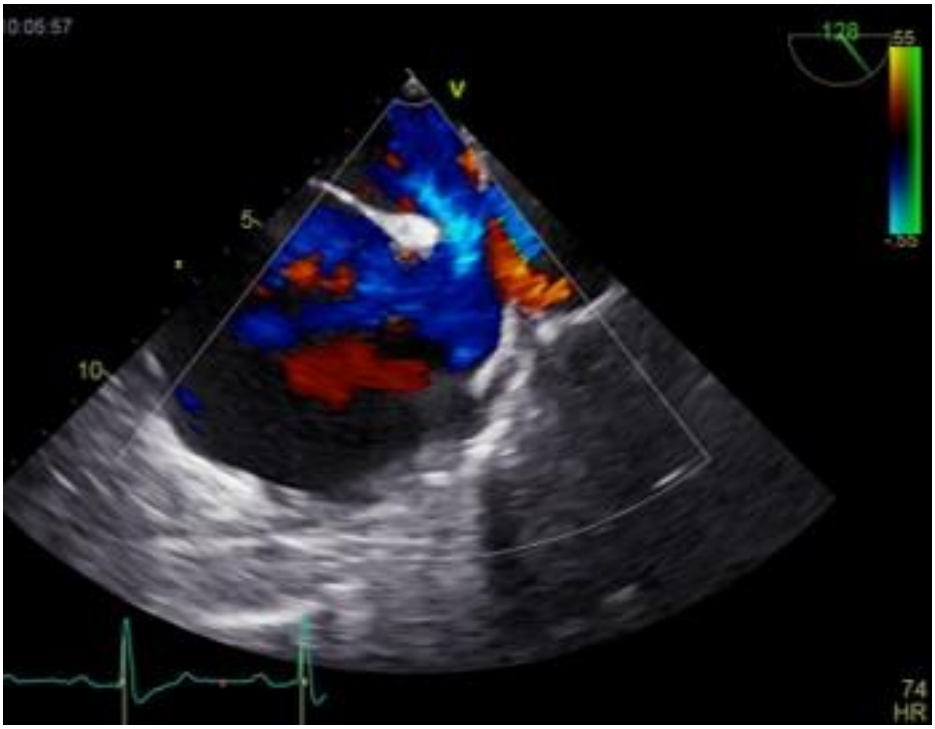


Figure S3D

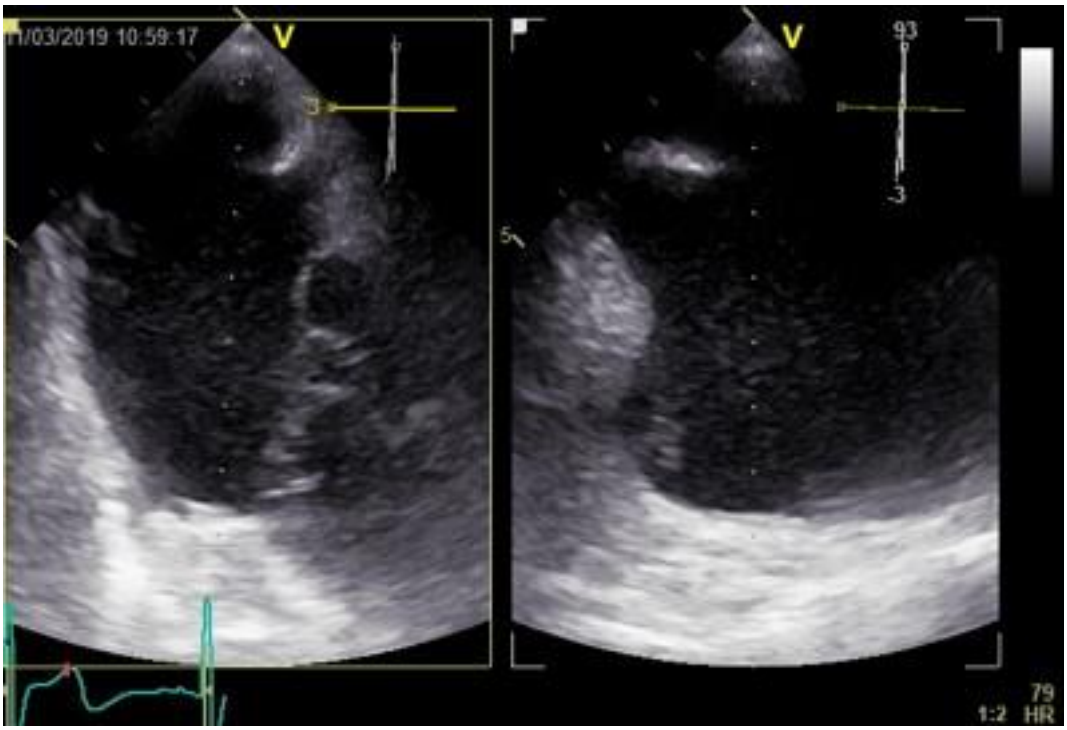


Figure S3E

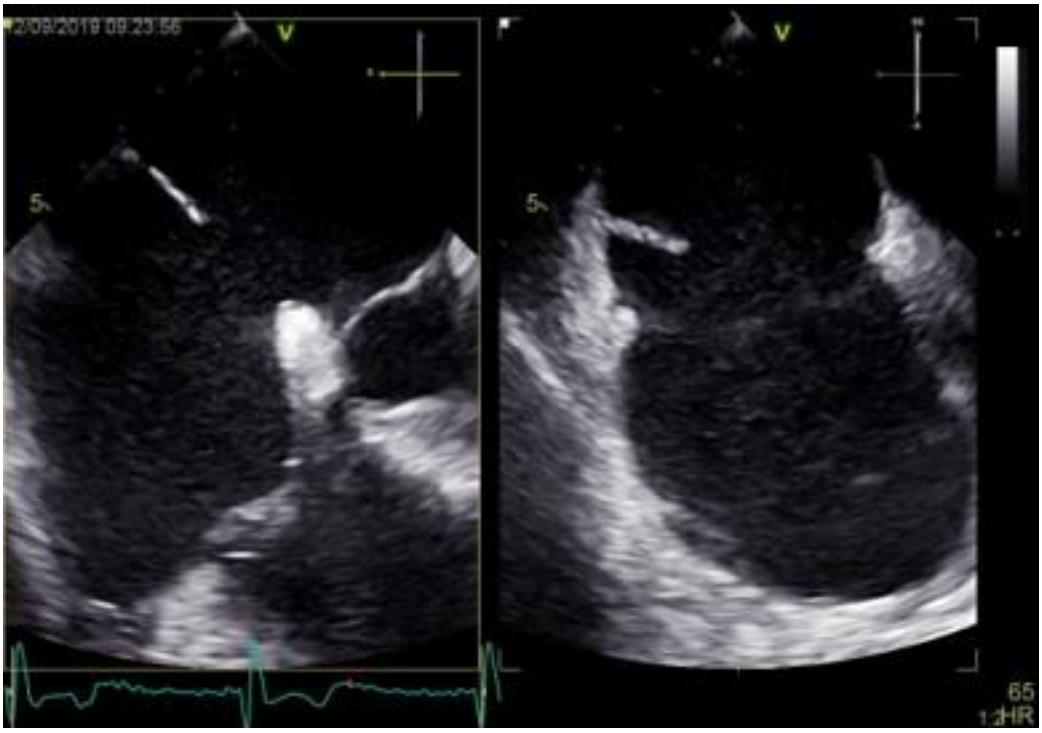


Figure S3F

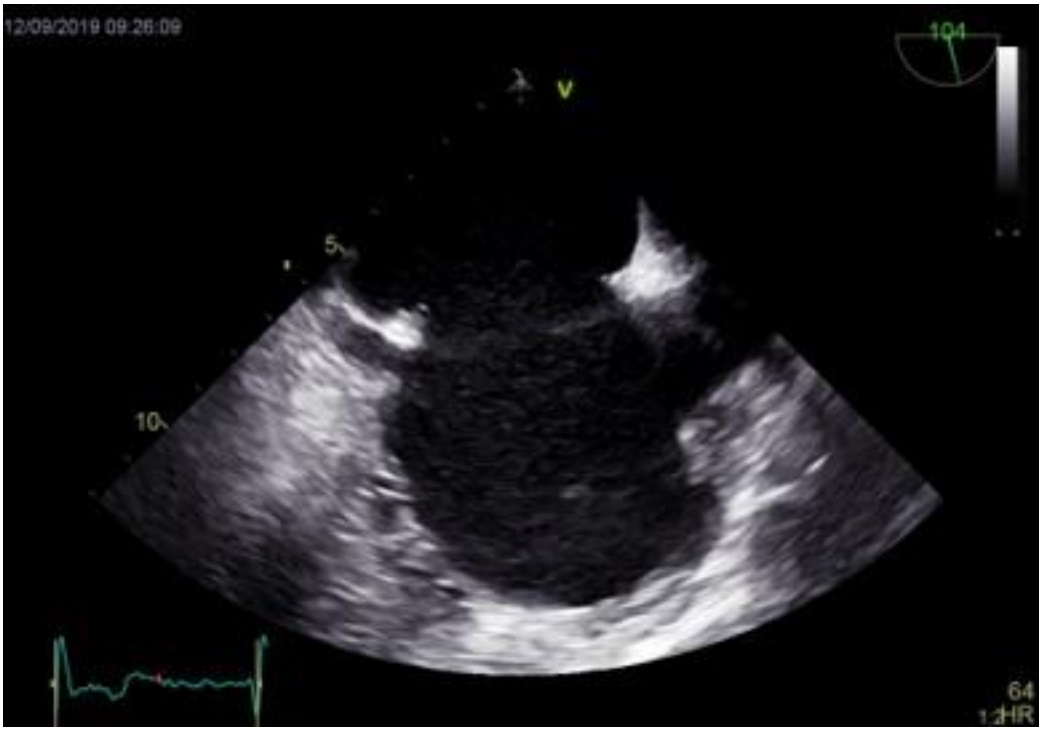


Figure S3G

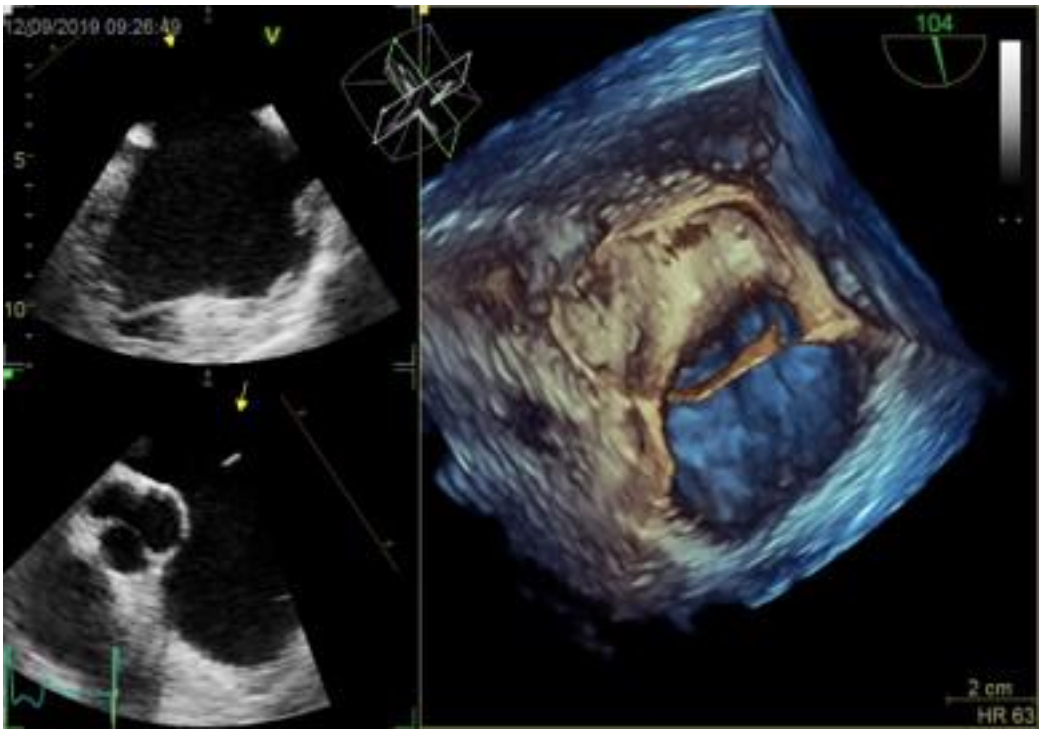


Figure S4A

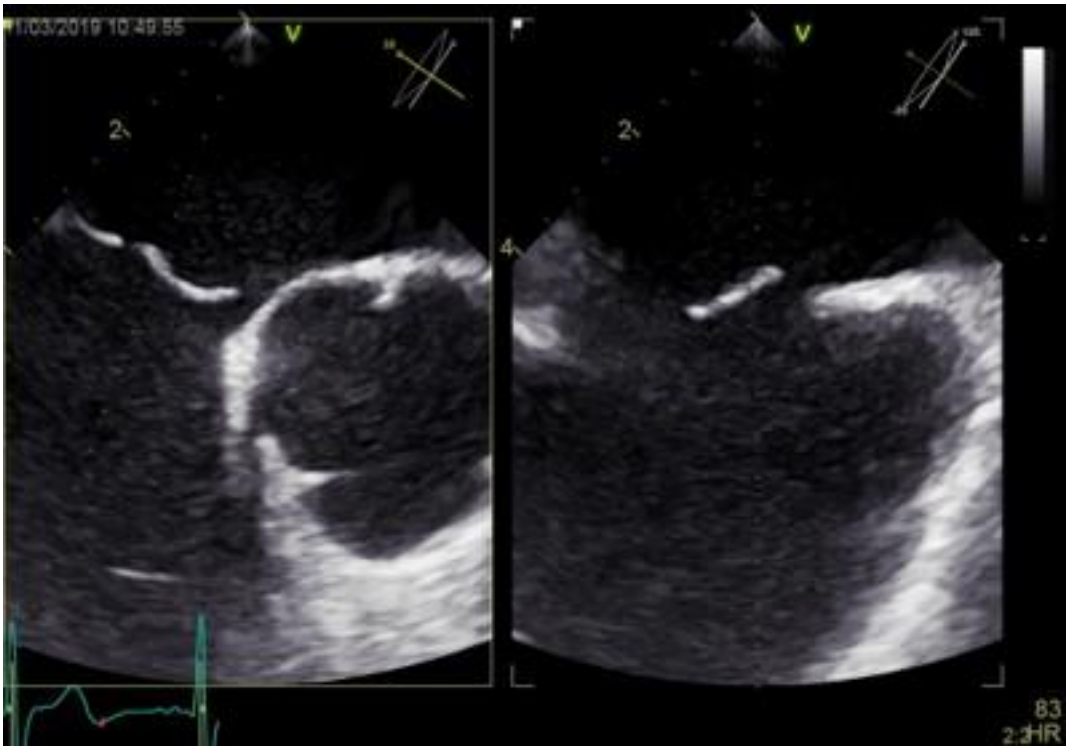


Figure S4B

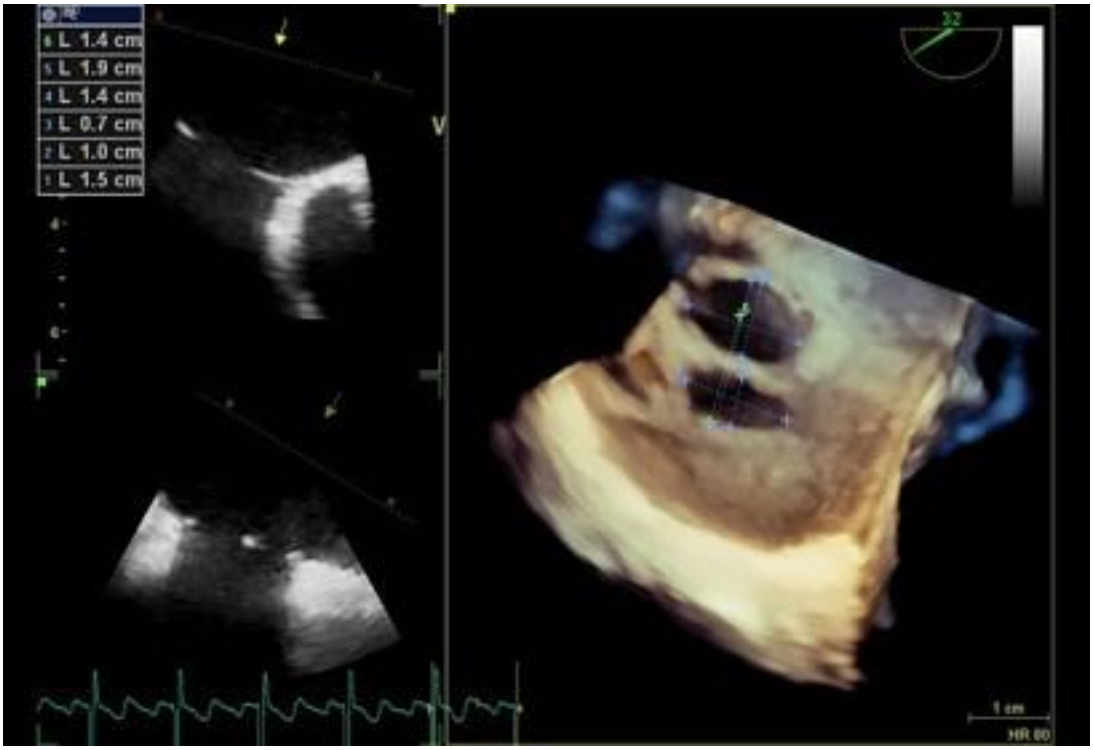


Figure S4C

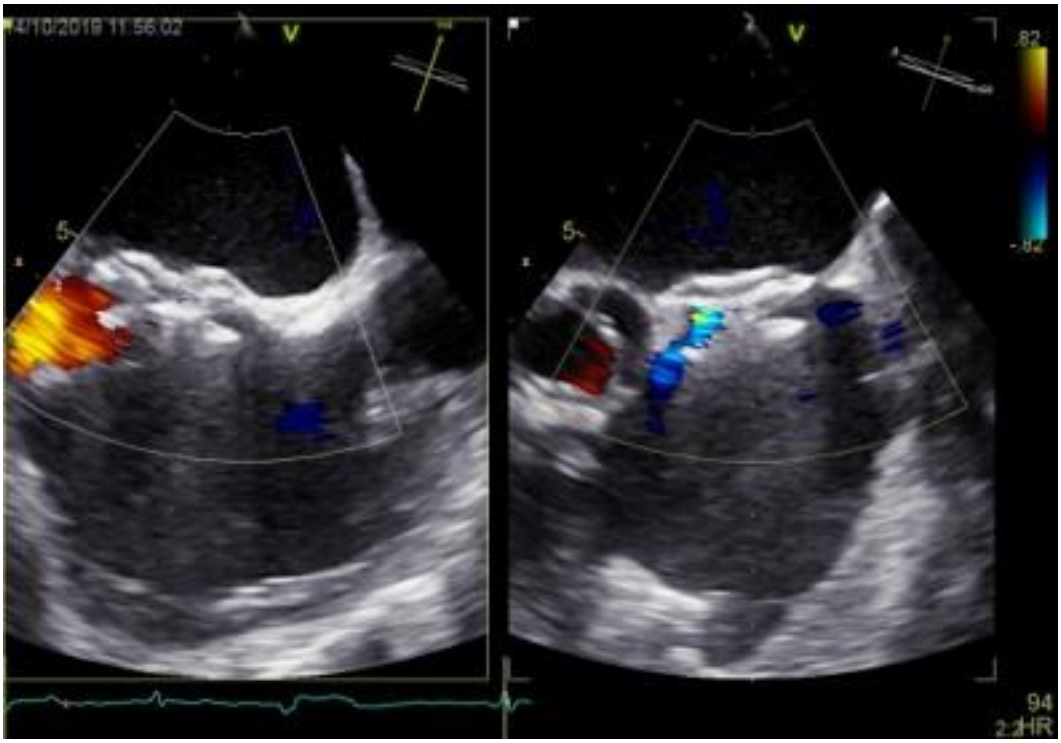


Figure S4D

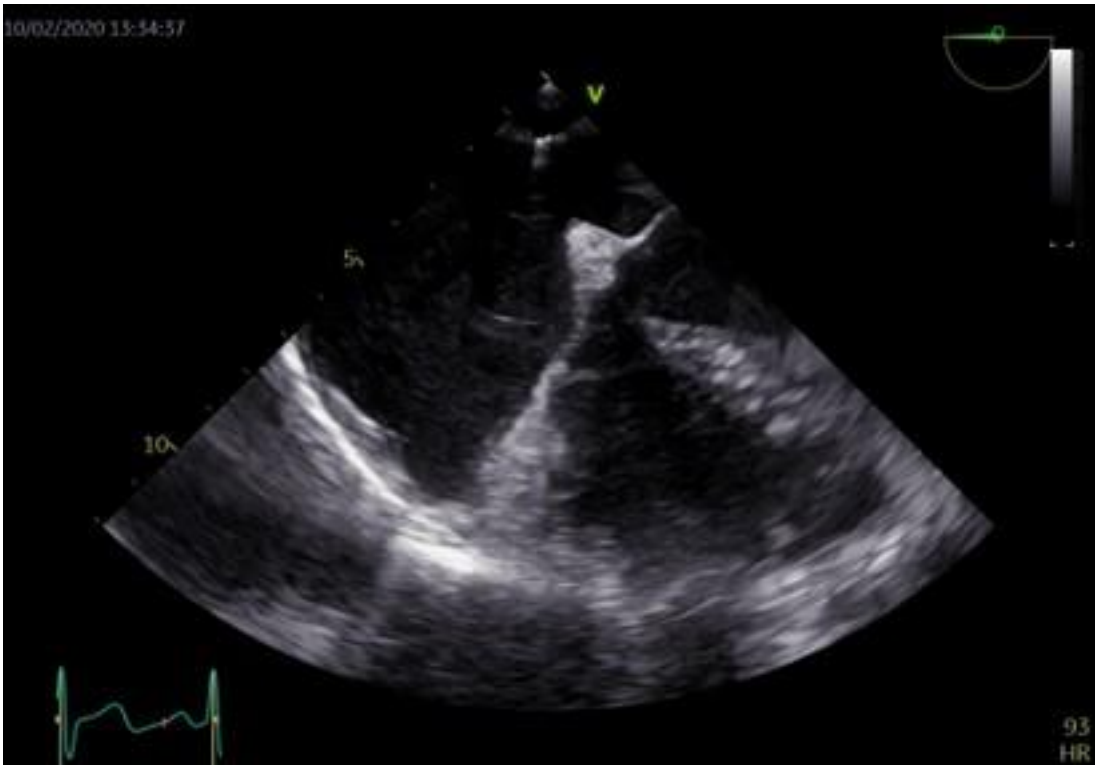


Figure S4E

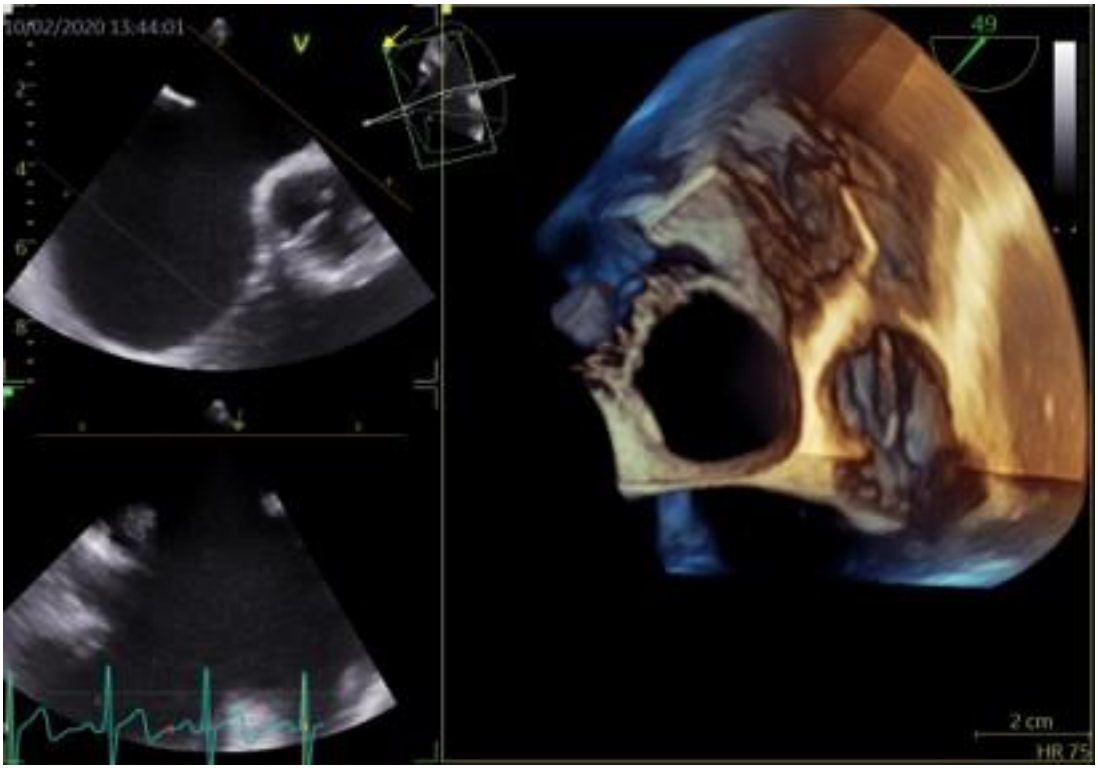


Figure S4F

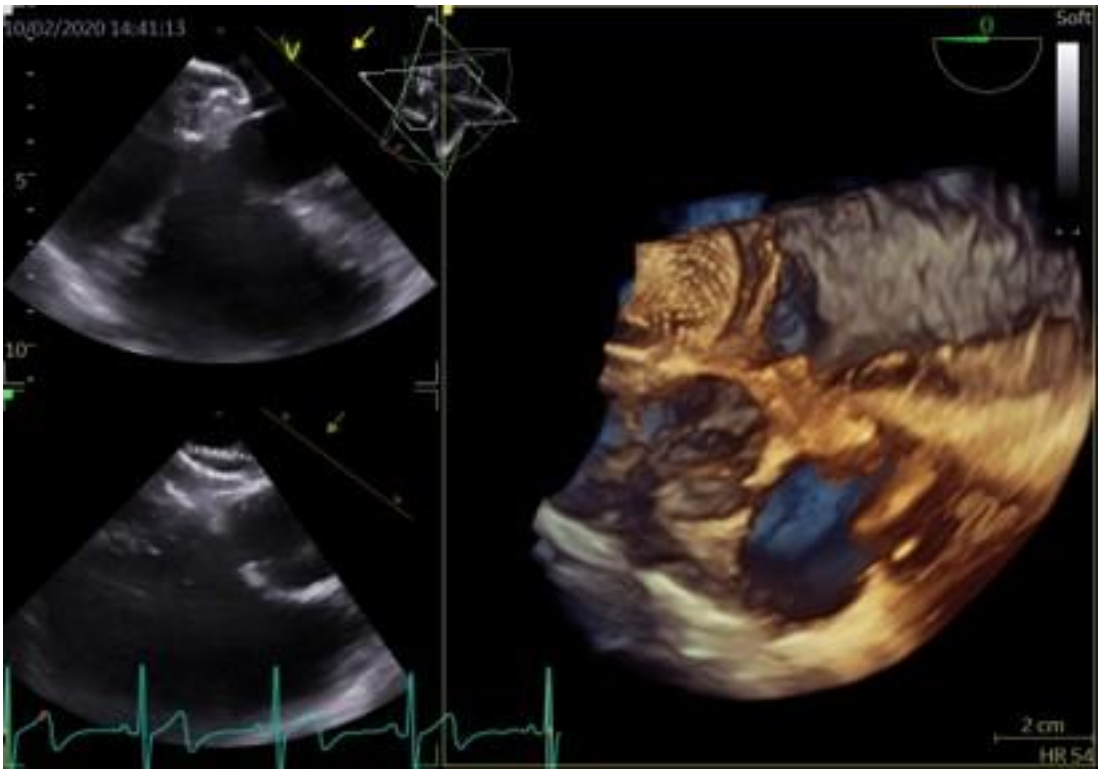


Figure S5A

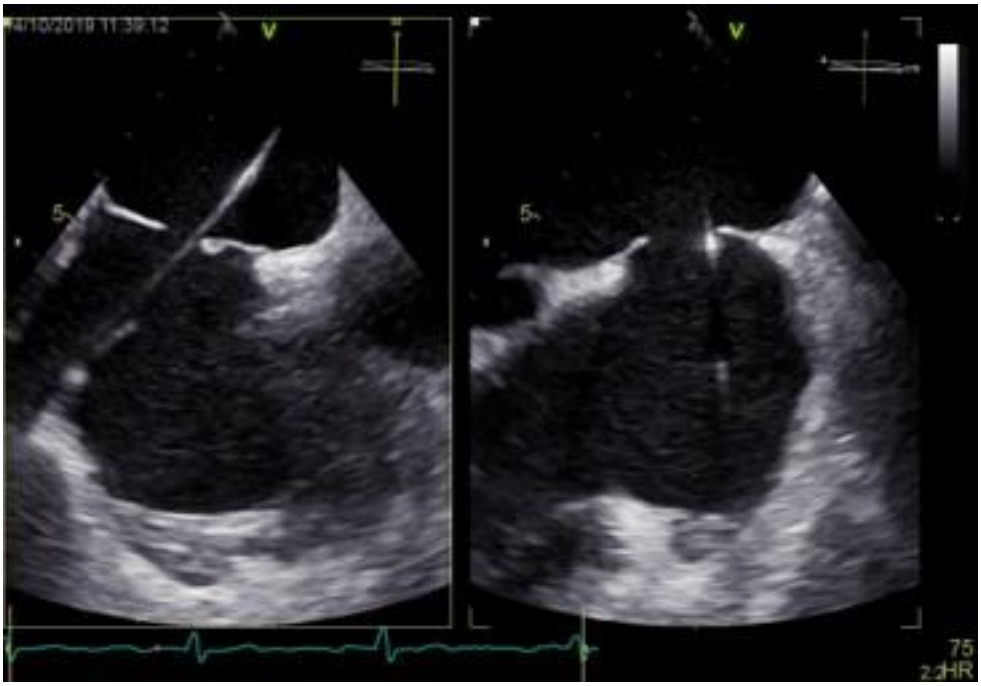


Figure S5B

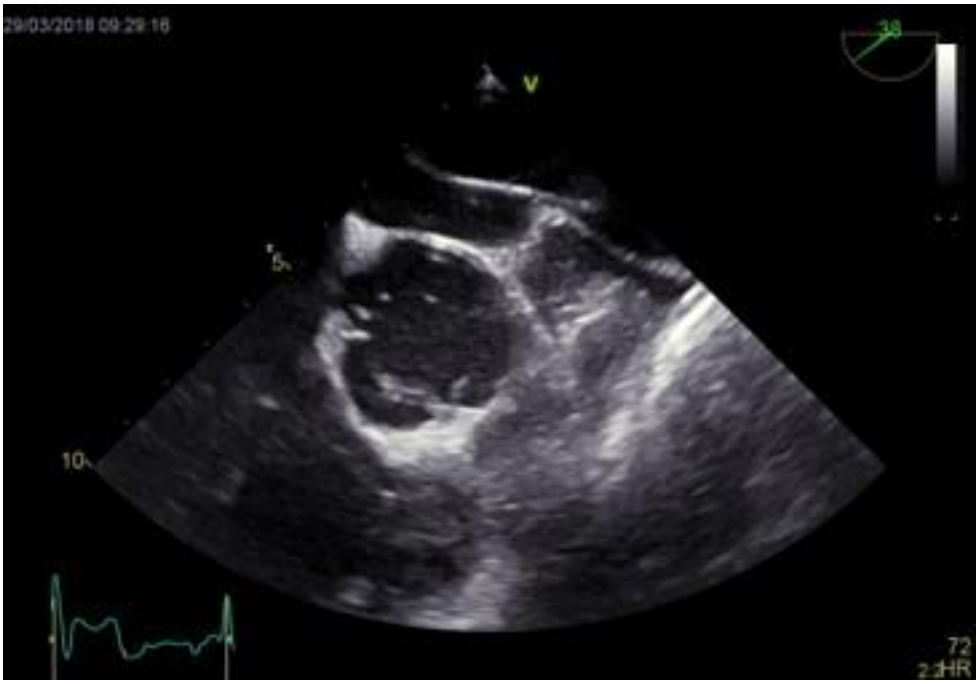


Figure S5C

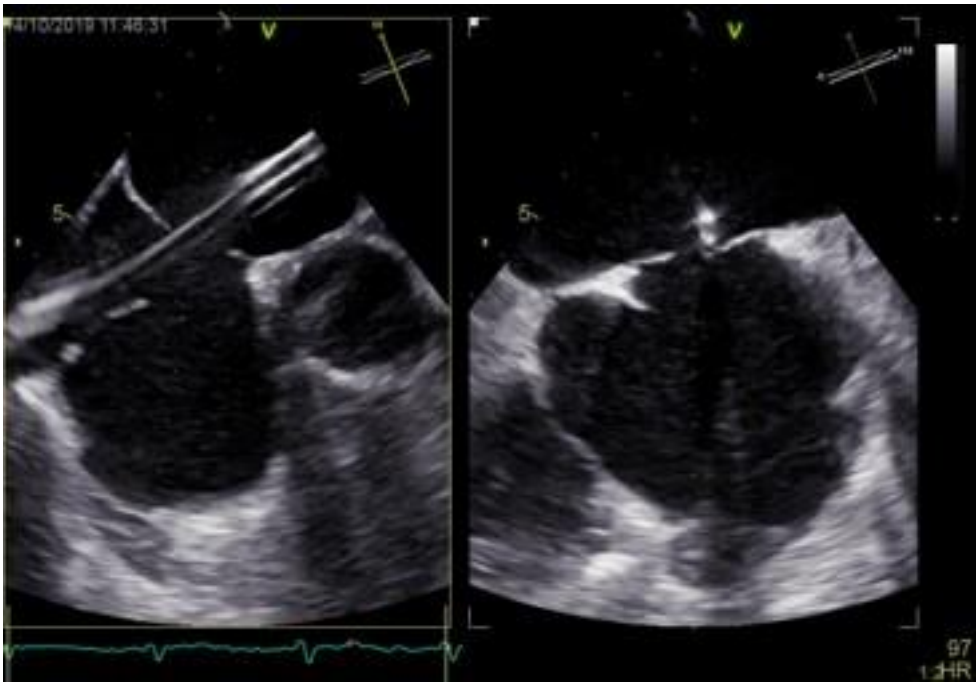


Figure S5D

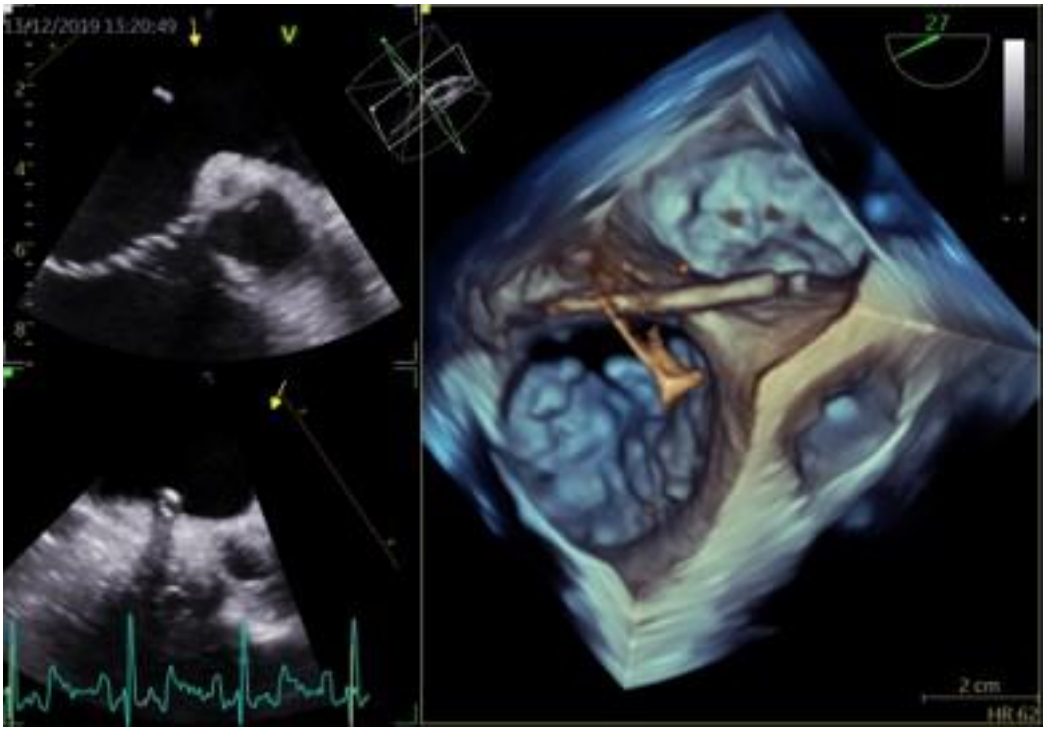


Figure S5E

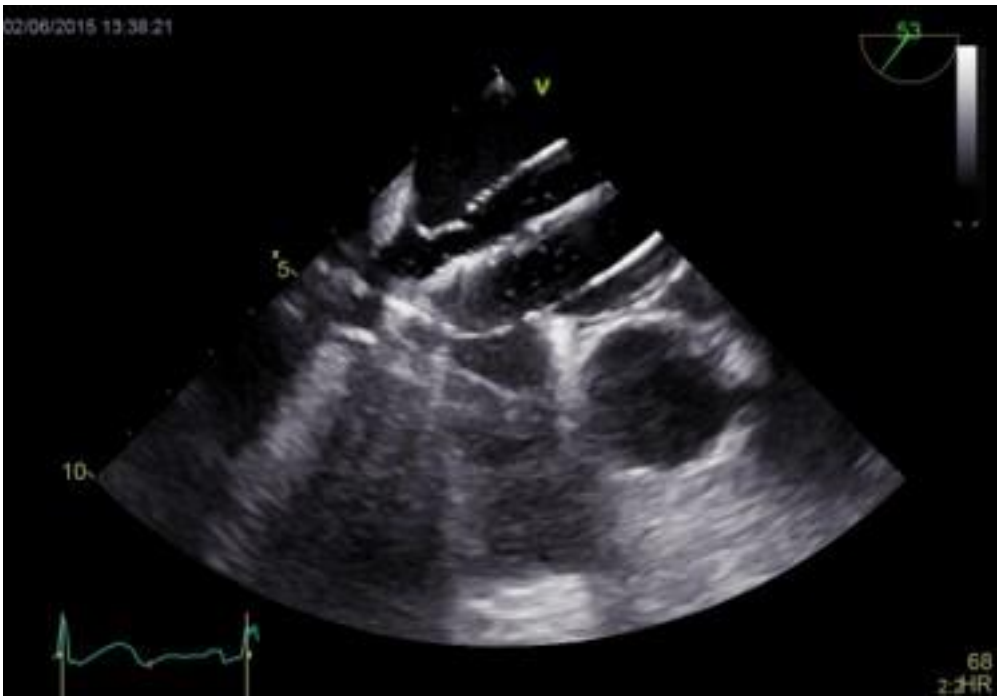


Figure S5F

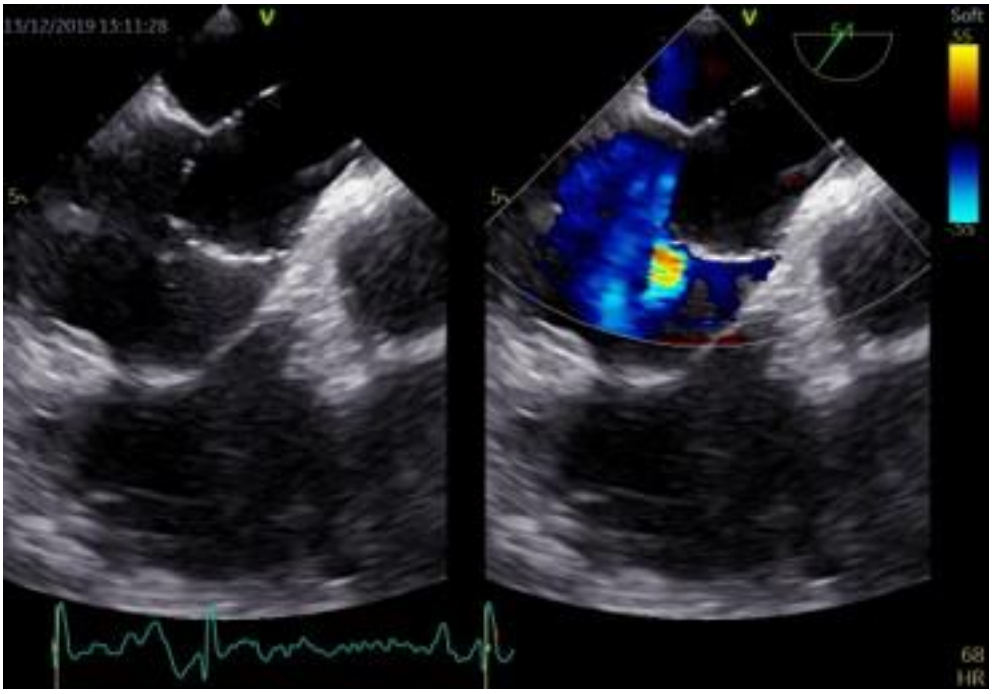


Figure S6A

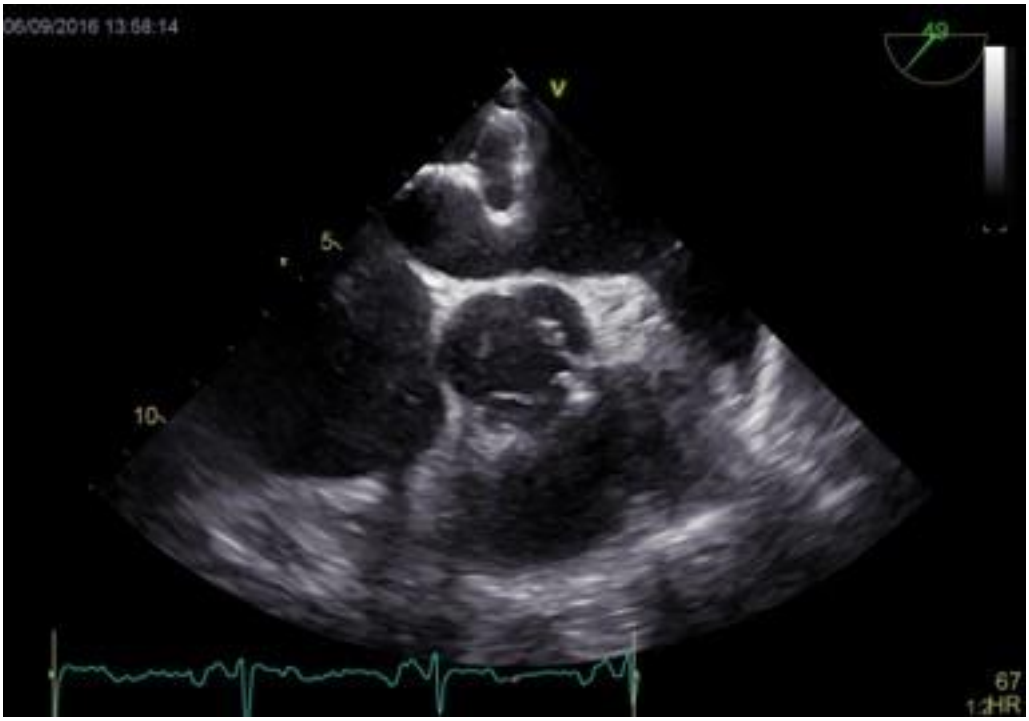


Figure S6B

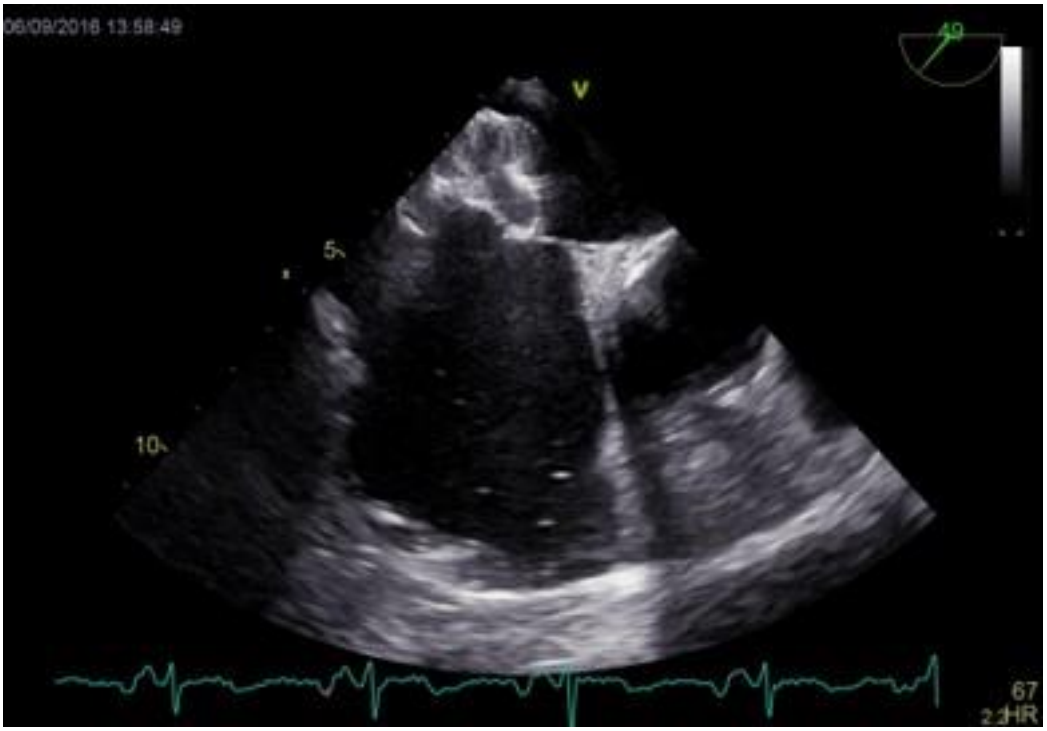


Figure S6C

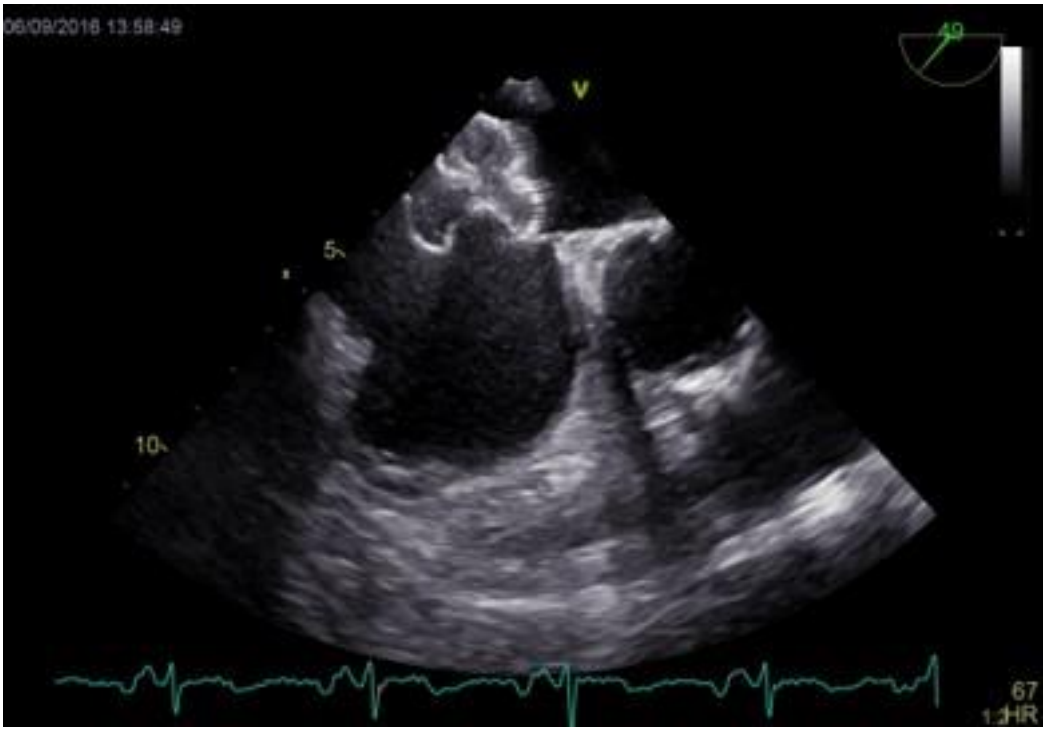


Figure S6D

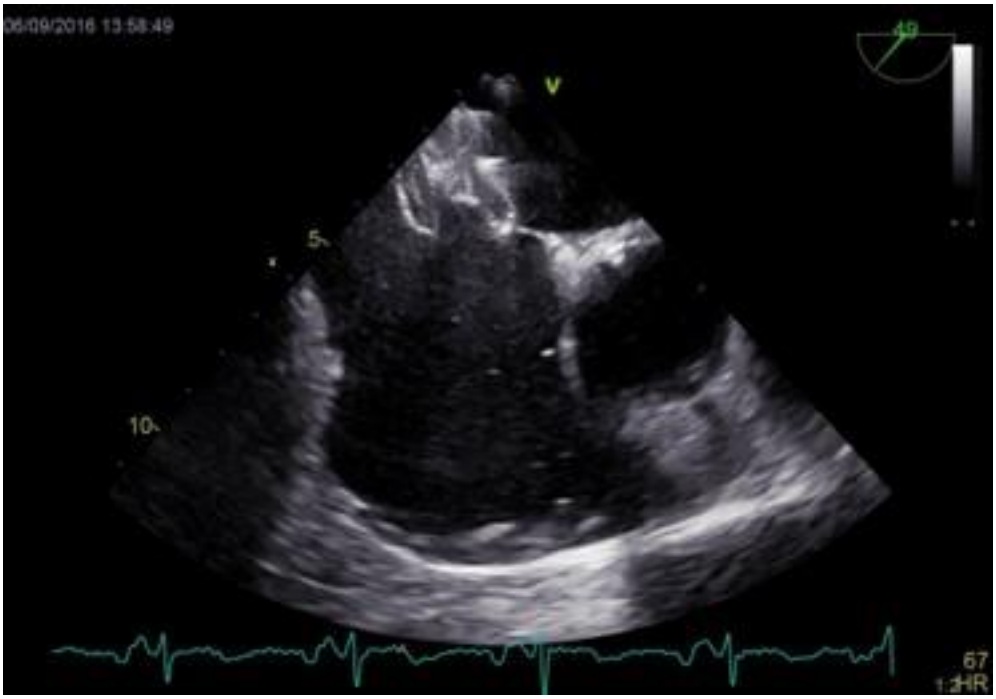


Figure S6E

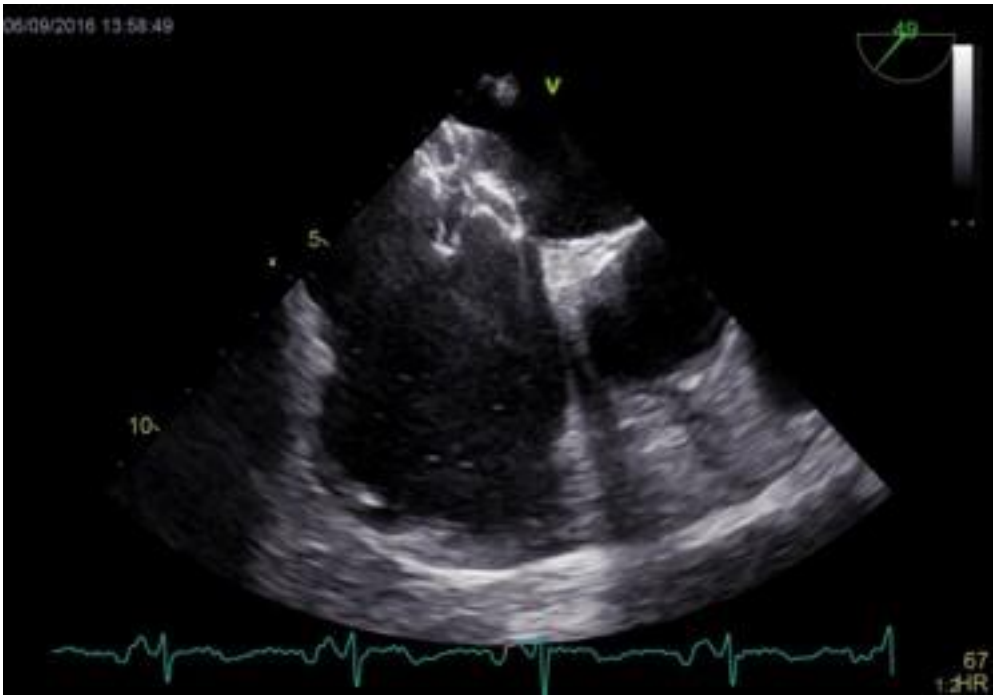


Figure S6F

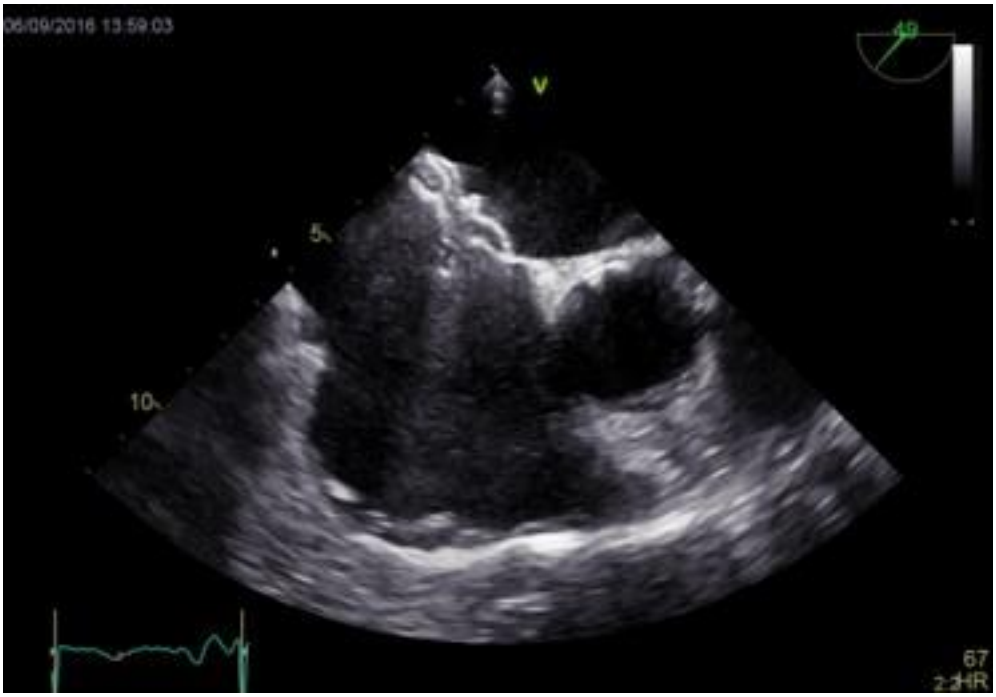


Figure S6G

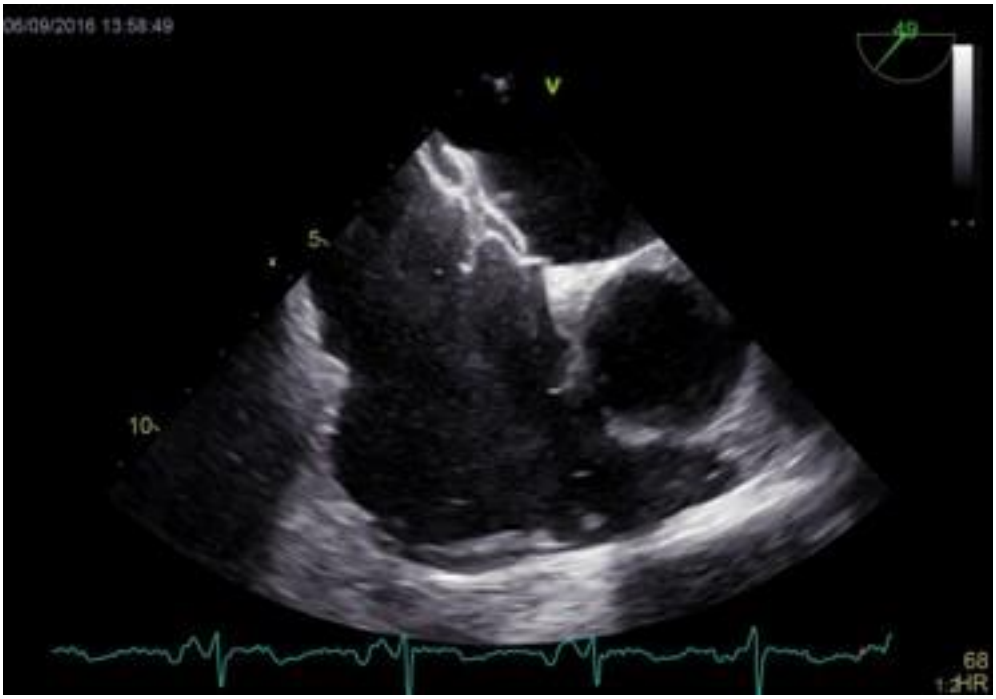


Figure S7A

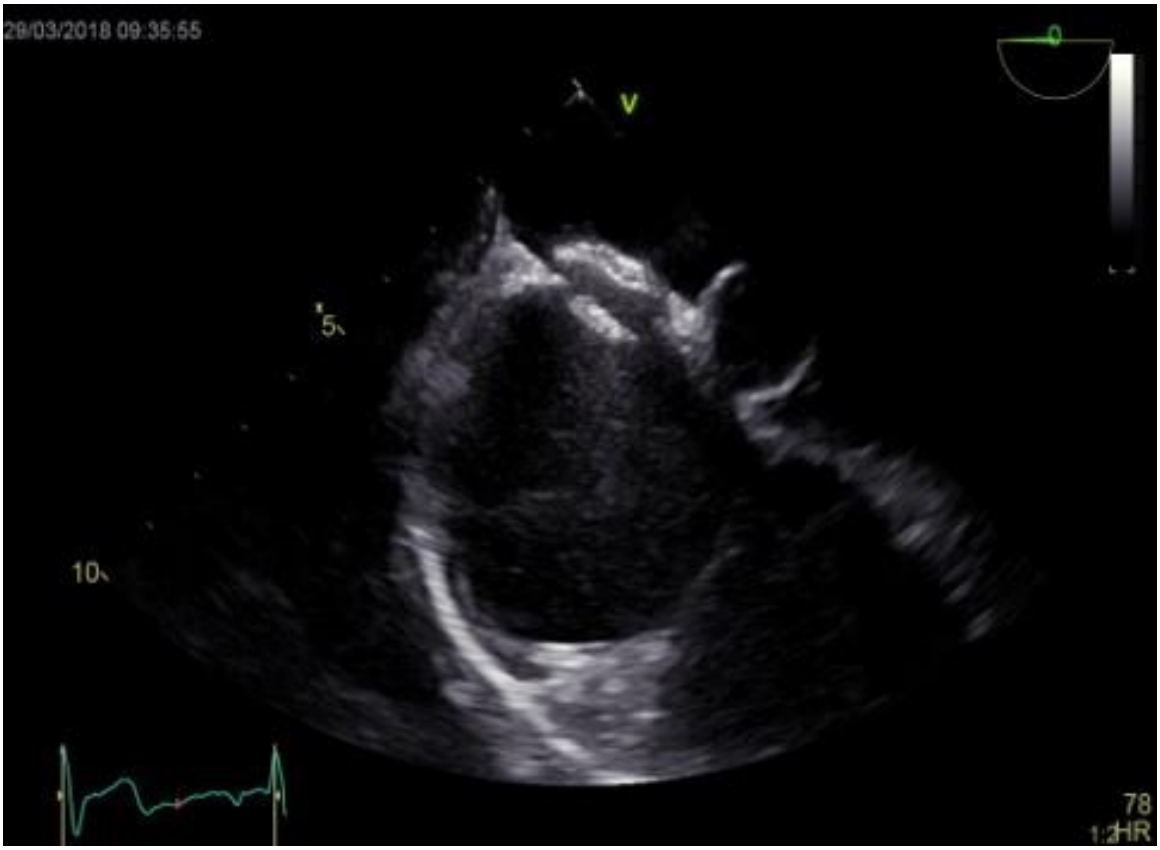


Figure S7B

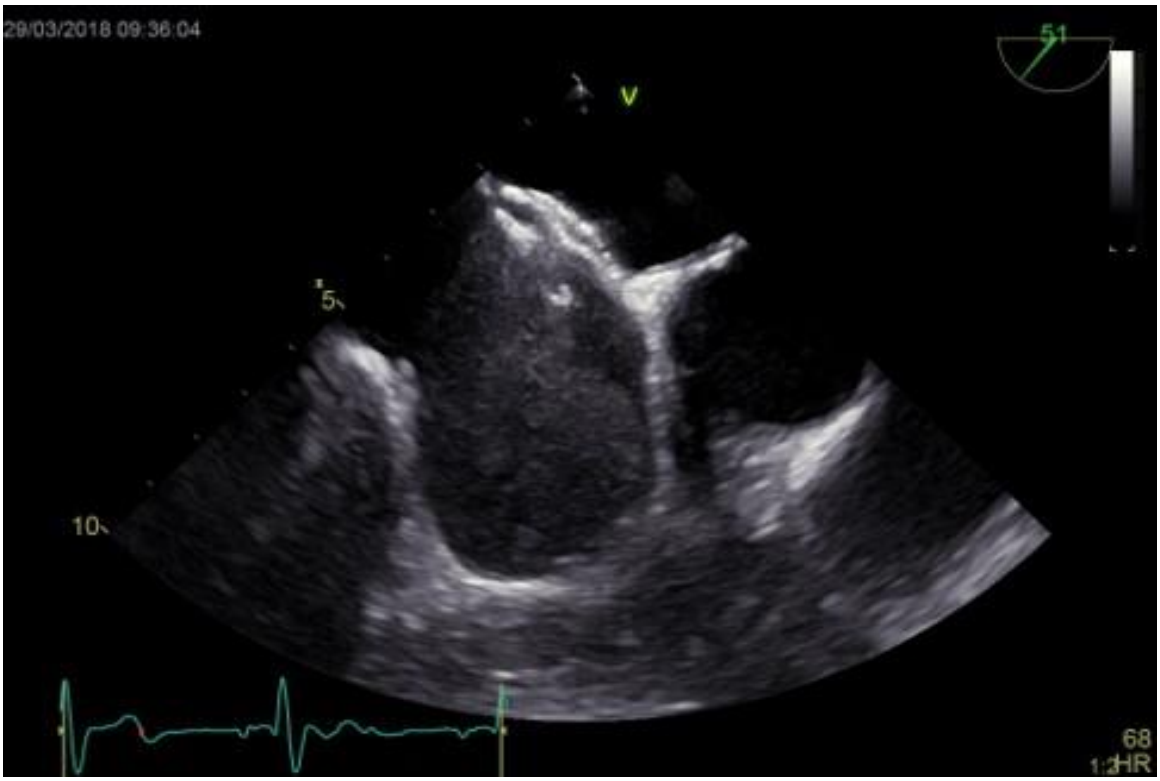


Figure S7C

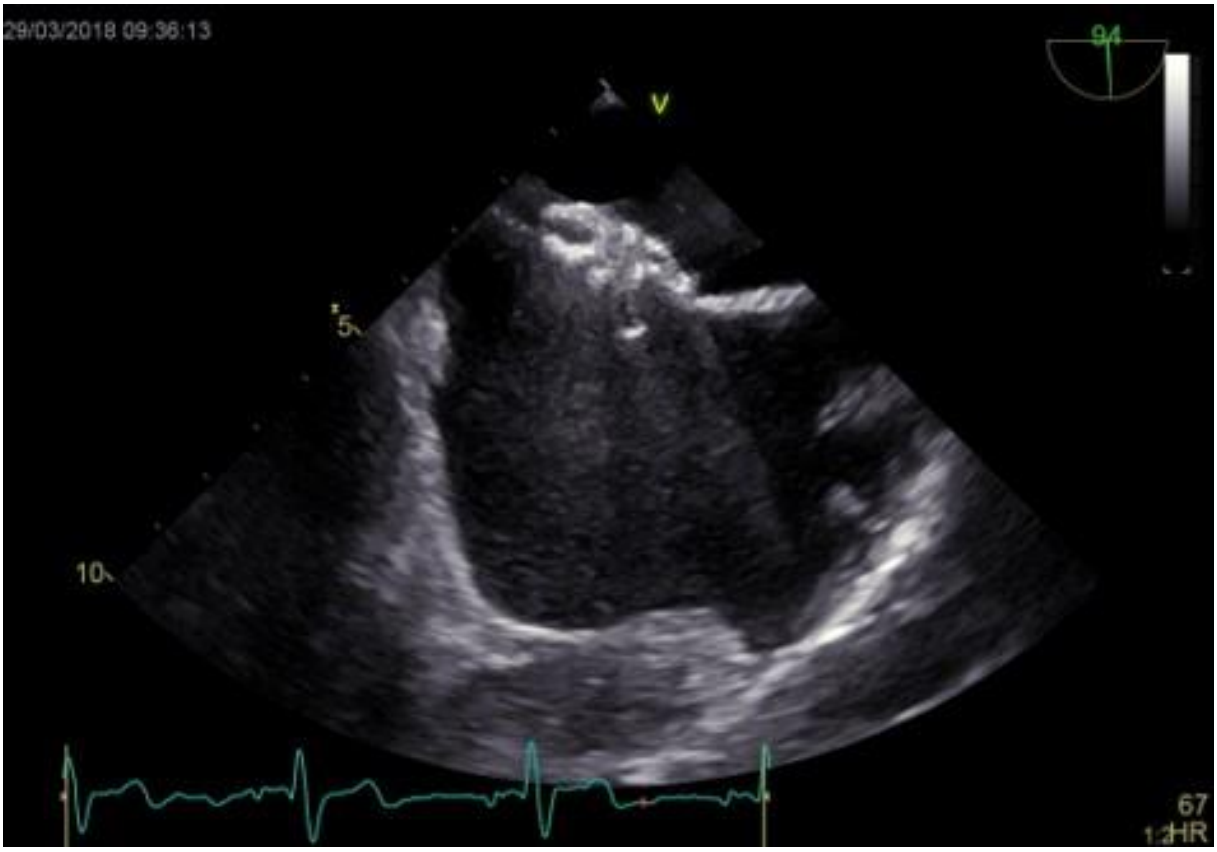


Figure S7D

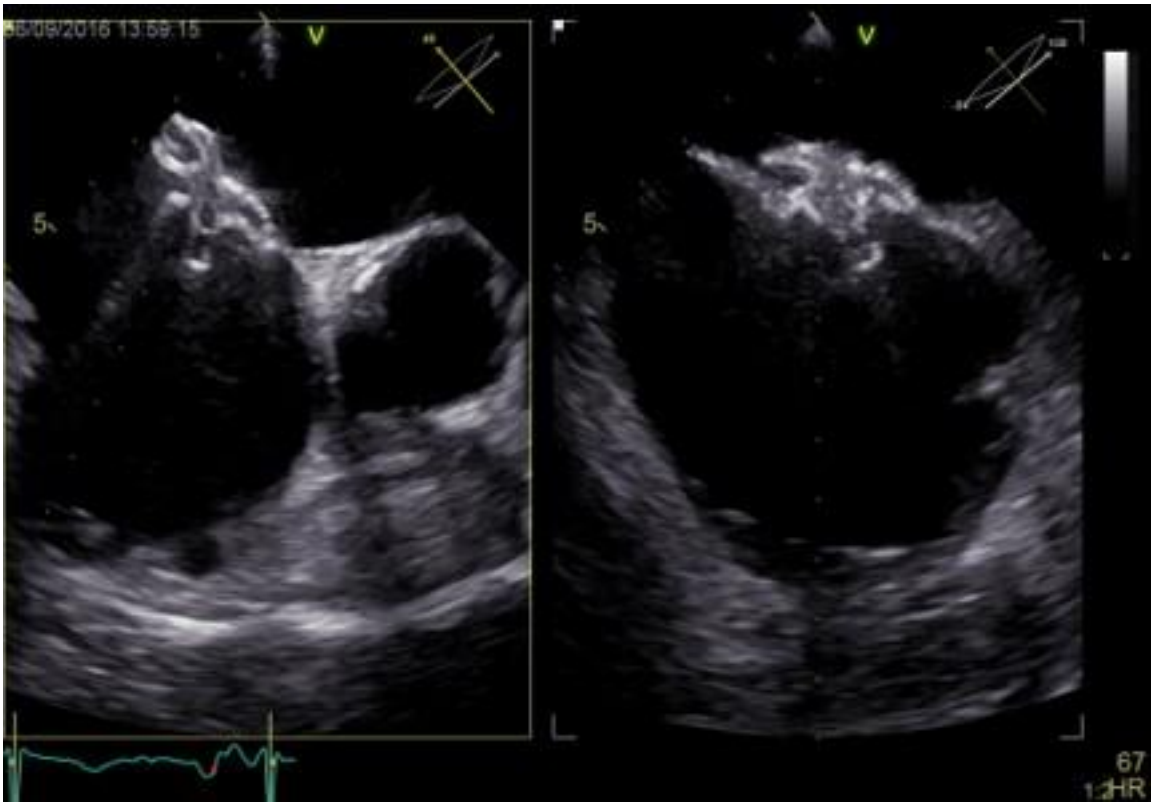


Figure S7E

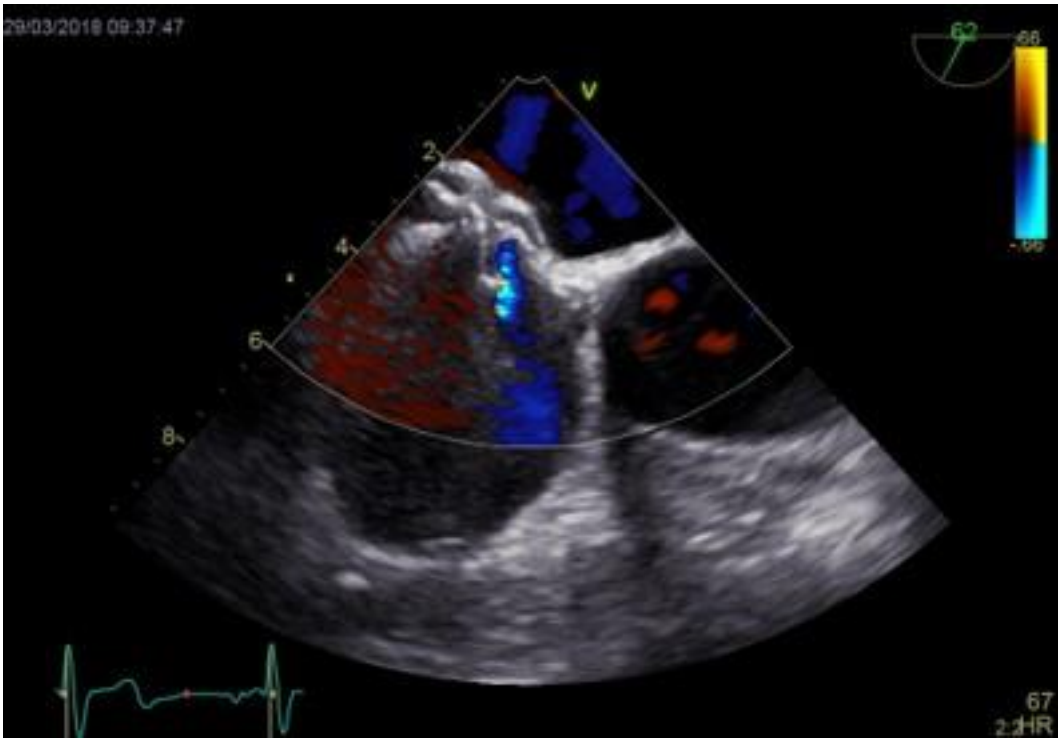
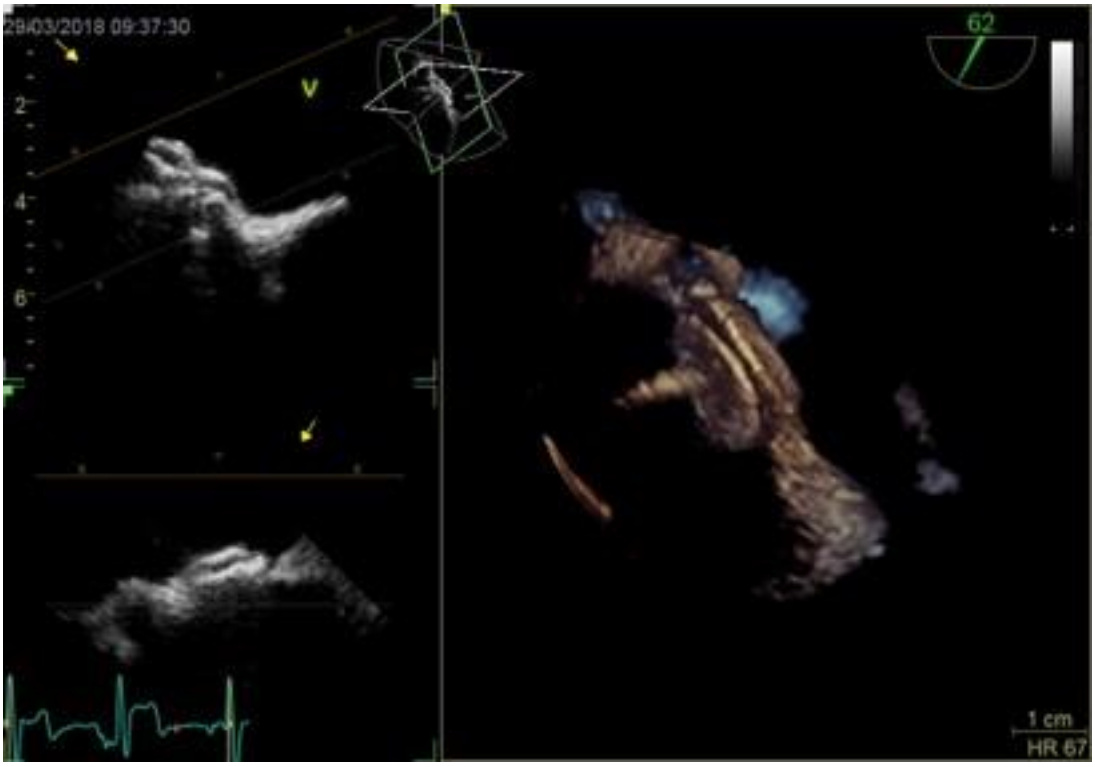


Figure S7F



FIGURES – LEGEND

Fig. S1. TEE Assessment of ASD rims. A, B, C- midesophagus- rotation should be continuous with recording every 15°-30° D- deep position at 0°- coronary sinus ostium is visible E- high position at 0°- aorta and LA roof is visible. Red arrow- ASD II

Fig. S2. 3D TEE A- multi-D (X-plane) modality: two perpendicular simultaneous plane through the hole of the defect; B- color doppler- flow through the single defect; C- dynamic change of ASD size during cardiac cycle; D- measurement of defect: maximal, minimal diameter and area; E- 3D of very oval defect 2F- measurement of oval ASD

Fig. S3 ASD not suitable for percutaneous closure: A,B,C: sinus venosus defect with concomitant ASD II; D- another case: TEE deep position of the probe at 0° , multi-D: large defect very close to sinus venosus ostium; E, F, G another case: huge defect with residual thin and floppy band of septum. Red arrow- ASD II, yellow arrow sinus venosus defect, green arrow- residual band of septum

Fig. S4. Importance of 3D imaging in special cases: A, B, C: two defects: 3D allow to assesse the spatial relations of the hols and surrounding structures and planning the ASD closure procedure; D,E,F: Another patient: large ASD II, close to the mitral valve. 3D allow to plan the procedure and after deployment to verify the contact with mitral valve anterior leaflet. Red arrow- ASD II, yellow arrow- mitral valve anterior leaflet, green arrow- distans between occluder and mitral valve, blue arrow- occluder

Fig. S5. ASD closure procedure. A- wire passes through the defect; B- the optimal position of wire in LUPV; C- catheter passes through the defect; D- 3D helps to verify wire passage through the selected defect especially in the case of a thin septum;
E- classic balloon sizing - measurement performed on the level of waist - yellow arrow; F- balloon sizing with „color flow stop" method- inflation up to stop of flow in color doppler through the defect. Red arrow- ASD II, yellow arrow- wire, blue arrow- catheter, green arrow- balloon

Fig. S6. Step by step implantation of occluder: A- opening of left disc in LA; B- left disc on the left side of the septum; C,D,E,- opening of the right disc; G - final shape of the occluder

Fig. S7. Assessment before final release of the occluder: A, B, C- it is mandatory to verify the presence of septum between two discs of occluder (yellow arrow); D- the same using multi-d imaging; E- verification of residual shunt: the tension of the system can be a reason of small shunts through the occluder (red arrow); F- 3D imaging may helps in assessing position of the device on the septum