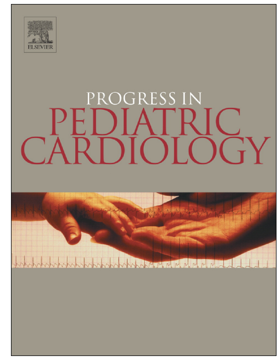
Journal Pre-proof



Transesophageal echocardiography in the pediatric interventional cardiac catheterization laboratory

Katie Hunter, John Cibiras, Michael Bingler

PII: S1058-9813(20)30135-1

DOI: https://doi.org/10.1016/j.ppedcard.2020.101266

Reference: PPC 101266

To appear in: *Progress in Pediatric Cardiology*

Received date: 14 May 2020

Revised date: 18 June 2020

Accepted date: 22 June 2020

Please cite this article as: K. Hunter, J. Cibiras and M. Bingler, Transesophageal echocardiography in the pediatric interventional cardiac catheterization laboratory, *Progress in Pediatric Cardiology* (2020), https://doi.org/10.1016/j.ppedcard.2020.101266

Progress in Pediatric Cardiology

(Nemours ECHO Supplement)

Title: Transesophageal Echocardiography in the Pediatric Interventional Cardiac Catheterization Laboratory

Authors:

Katie Hunter CPNP[1], John Cibiras RCCS [1], Michael Bingler MD, FACC, FACAI [1,2]

[1]Nemours Cardiac Center, Nemours Children's Hospital, Orlando, FL

[2] Department of Pediatrics, University of Central Florida College of Medicine, Orlando FL

Corresponding Author:

Michael Bingler

Nemours Cardiac Center

6535 Nemours Parkway

Orlando FL 32827

Office: 407-650-7470

Email: michael.bingler@nemours.org

Abstract:

As the scope and complexity of transcatheter interventions for congenital heart disease has expanded over the past several decades, so too has the role of transesophageal echocardiography (TEE) in planning, guiding and assessing the results of these procedures. While fluoroscopy and angiography continue to be the primary imaging tools for diagnostic and interventional procedures, TEE provides complimentary and often times superior imaging for a growing number of procedures. These include but are not limited to interventions on the atrial and ventricular septum, balloon dilation or transcatheter repair of mitral and tricuspid valves, occlusion of paravalvar leaks and other interventions following repair of complex congenital heart disease. The purpose of this review is to describe the growing use of echocardiography to guide interventional procedures in the pediatric cardiac catheterization laboratory, with a focus on transesophageal echocardiography.

Keywords: Transesophageal Echocardiography; Pediatric; Interventional; Catheterization

Introduction:

There has been a great expansion over the past 20-30 years in terms of the variety and complexity of transcatheter therapies available for treating congenital heart disease. This includes not only modification and improvement of existing equipment and an ever expanding number of balloon catheters, stents and closure devices, but also more recently transcatheter valves. Along with these advances has come a concomitant increase in the utilization of echocardiography to prepare for and guide percutaneous catheterization procedures. This includes both two-dimensional (2D) and three-dimensional (3D) echocardiography, both transthoracic (TTE) and transesophageal (TEE), and more recently intracardiac echocardiography (ICE). Some have dubbed this new field interventional echocardiography.[1]

While cardiac catheterization procedures have traditionally been guided by fluoroscopy and angiography, both have limitations including: poor tissue differentiation, 2D visualization of 3D structures, the need for radiographic contrast and exposure to ionizing radiation. Echocardiography on the other hand provides excellent tissue differentiation and both 2D and 3D rendering of important cardiac structures. It is portable and imaging can be done in real time to demonstrate how cardiac structures respond to wires, catheters and devices as they are being used and manipulated. In addition it can provide intra-procedural information on efficacy of interventions and/or complications.[2]

Current transcatheter interventions facilitated by echocardiography commonly performed in the pediatric catheterization lab include.[3,4]

1. Closure of atrial septal defects (ASD) and patent foramen ovale (PFO).
2. Closure of ventricular septal defects (VSD).
3. Transseptal puncture.
4. Balloon septostomy/septoplasty and stenting of atrial septum.
5. Balloon dilation or stenting of interatrial baffles.
6. Transcatheter tricuspid or mitral valvuloplasty.
7. Closure of paravalvar leaks.
8. Transcatheter pulmonary valve placement (primarily ICE).

Echocardiography is also being used in an increasing number of transcatheter procedures and interventions for adult structural heart disease and electrophysiology procedures that will not be covered by this review including:

1. Transcatheter aortic valve replacement
2. Mitral and tricuspid valve repair.
3. Device occlusion of left atrial appendage.
4. Alcohol septal ablation.
5. Pulmonary vein ablation/isolation.
6. Laser lead extraction.
7. Placement of percutaneous left ventricular assist devices.
8. Pericardiocentesis.
9. Endomyocardial biopsy.

The purpose of this review is to describe the growing use of echocardiography to guide interventional procedures in the pediatric cardiac catheterization laboratory, with a focus on transesophageal echocardiography.

Device Closure of Atrial Septal Defects and Patent Foramen Ovale

Transcatheter device closure of secundum ASDs and PFOs has become the procedure of choice for those with appropriate anatomy. Device closure is primarily limited to secundum defects with sufficient rim tissue surrounding the defect to anchor the device in place. Other ASDs including primum, sinus venosus, and coronary sinus defects, are typically repaired surgically, although there have been several reports of using covered stents or stent grafts to close some superior sinus venosus defects.[3,4] TTE is the initial modality used to determine the type of defect as well as its hemodynamic significance in the initial selection of patients suitable for device closure. TEE is the gold standard for assessment of ASDs before, during, and after transcatheter device closure.[6] PFO closure is generally indicated in those following transient ischemic attack, stroke, those with peripheral emboli and migraines.[7]

Information obtained via TEE is essential for determining appropriateness for device closure. Current recommendations limit device closure to those defects with a stop flow or stretched diameter measuring less than 38mm and rim tissue measuring at least 5mm in all planes, except the aortic rim.[5] Pre-procedure TEE provides information about the size of the defect, location of the defect in the septum, morphology and size of the surrounding septal tissue, presence of additional defects and pulmonary venous anatomy. X-plane imaging, which is available on can provide simultaneous aortic (30-60°) and bicaval (90-110°) views (Figure 1), while 3D imaging offers a unique “en face” view that often demonstrates the dynamic nature of a defect and can assist in device selection.[8] (Figure 2) Both X-plane and 3D TEE imaging are helpful in guiding closure of fenestrated or multiple ASD. Recent studies demonstrate the possibility of transcatheter closure under transthoracic echocardiographic guidance but this is limited to those with adequate windows for septal assessment.[9]

During transcatheter closure, TEE and/or ICE along with fluoroscopy play an essential role in allowing the interventionalist to position catheters and wires by providing real time assessment of the defect and surrounding tissues. Device selection is made using measurements obtained by echocardiography with or without balloon sizing. Echocardiography aids in delivery of the device by providing information about positioning of the discs in relation to the septum ensuring rim tissue is captured and the device does not impinge on any of the surrounding structures. [10] Use of TEE to guide device positioning permits immediate assessment of the device prior to release allowing for recapturing and repositioning of the device as needed. In the case of multiple fenestrations, echocardiography allows for placement of the device in the largest or most central defect to ensure adequate coverage of all defects. (Figure 3) Prior to device deployment, echocardiography is used to assess for obstruction to systemic and pulmonary venous flow, as well as mitral, tricuspid and aortic valve function or impingement. Following release of the device, TEE assessment of placement, residual shunts, and possible complications such as pericardial effusion, thrombus formation and erosion of the device should occur both immediately following deployment and at regular follow up with TTE.

Device Closure of Ventricular Septal Defects

Similar to closure of defects in the atrial septum, echocardiography plays a significant role in diagnosis and transcatheter closure of ventricular septal defects. TTE is used to determine the type, size, shape and hemodynamic significance of the defect.

Traditionally reserved for muscular defects, transcatheter closure has expanded to include closure of perimembranous defects particularly in the developing world where surgical repair is often cost-prohibitive and patients may present at an older age with co-morbidities that significantly increase risks involved in surgical closure. Some studies have suggested that closure of perimembranous defect is associated with an increased risk for heart block due to impingement on the conduction system which has largely limited more widespread closure of these VSDs. A myriad of devices is currently available for transcatheter VSD closure including those made specifically for muscular VSD closure and those specific to perimembranous closure. Despite this, some perimembranous defects are often closed utilizing devices designed for other uses such as patent ductus arteriosus closure as they are typically less rigid, more readily available and less expensive.[11]

Closure of perimembranous VSDs can be completed with TEE guidance alone but is more commonly used in combination with fluoroscopy. As with ASD closure, X-plane and “en face” 3D TEE imaging can be beneficial in VSD device closure, particularly when there are multiple defects or with a so called swiss cheese septum. [12] Device delivery can be via femoral or jugular vein, typically following placement of a through-and through wire or by a hybrid perventricular approach.[13] Echocardiographic assessment is again performed before, during, and after deployment of the device. TEE imaging allows for assessment of vessels, the size, location, and surrounding rim tissue, as well as wire, sheath, and device placement. (Figure 4) Real-time imaging is critical in assessment of device placement, valvar function, and effect of the device on surrounding structures and residual shunt and allows for recapturing, repositioning, and/or removal of the device if necessary. Following VSD device closure patients require evaluation with TTE and EKG at regular intervals throughout their lives.[14]

Transseptal Puncture

Crossing the interatrial septum is essential for antegrade assessment and intervention on multiple left heart structures. When an existing atrial communication is not present, one must be created. The technique for transseptal puncture that was first described by Ross and refined by Brockenbrough remains largely unchanged.[15,16] This is traditionally done using fluoroscopy alone, based on anatomical landmarks and hemodynamic assessment, but carries an estimated rate of complications such as perforation of the left atrium or aortic root of between 1-4%.[17] The procedure can be even more challenging in patients with scoliosis, complex cardiac anatomy, septal aneurysm, elevated left atrial pressures or dilated aortic root. TEE provides excellent real time visualization of the atrial tissue and surrounding structures, even in complex anatomies. It can aid in creation a more targeted puncture site either at the fossa ovalis or in other locations that may be of benefit to access specific left atrial locations.[18] Biplane or 3D imaging can also be helpful and have been shown to improve proper location of transseptal puncture and decrease complications. [19]

Balloon Atrial Septostomy/Septoplasty and Atrial Septal Stenting

Balloon atrial septostomy is often needed in patients born with transposition of the great arteries with inadequate atrial level mixing leading to cyanosis. It was traditionally performed in the cardiac catheterization lab under fluoroscopic guidance, but has been shown to be safe and effective when done using TTE guidance and is now often done at the bedside in neonatal and cardiac intensive care units.[20] However, creation of an atrial communication in patients with more complex cardiac anatomies or those with a thick or intact atrial septum is not only more challenging but may also require intervention beyond traditional balloon septostomy. Static balloon septoplasty and/or stent placement is often needed to ensure an adequate opening with long term patency.[21] In these cases, TEE is an excellent adjunct to fluoroscopy and angiography allowing for ideal positioning and sizing of balloons and stents and has been shown to increase safety and decrease complication in this high risk population.[22] Similar techniques have also been used to facilitate ideal stent placement in patients with obstructed pulmonary veins or pulmonary venous confluence obstruction in total anomalous pulmonary venous obstruction, both native and postsurgical.[23] (Figure 5)

Balloon Dilation or Stenting of Interatrial Baffles

Prior to the development of the arterial switch operation, surgical correction of transposition of the great arteries involved the Mustard or Senning operations with creation of an interatrial baffle to reroute the systemic and pulmonary veins to the opposite ventricle. Over time these baffles can develop either stenosis and/or baffle leaks. Both can be treated effectively in the catheterization lab with balloon dilation or stenting of important stenoses or device closure of baffle leaks.[24] More recently, covered stents have been used to simultaneously address both stenoses and baffle leaks when they occur together.[25] Success of each of these procedures is importantly assessed by the combination of angiography and TEE.[26]

Tricuspid and Mitral Balloon Valvuloplasty and Transcatheter Valve Placement.

While balloon valvuloplasty of the tricuspid and mitral valves are done relatively rarely in the pediatric population, both TTE and TEE are frequently used during these procedures, primarily to assess for increase in valve insufficiency between serial dilation.[27] More recently, transcatheter valves initially designed for use in the aortic or pulmonary position have been successfully used to palliate degenerated bioprosthetic tricuspid and mitral valves in both adults and children. [28-30]

Closure of Paravalvar Leaks

Prosthetic valves are also less commonly used in children compared to adults but can similarly be complicated by paravalvar leaks. TEE guidance is essential in determining the number, size and location of defects as well as in device selection. Here again 3D TEE has been shown to play an important role in guiding these procedures. [31] It is also instrumental in guiding wire crossing of the defect and device positioning. Finally, it allows for assessment for residual leak or impact on prosthetic valve function.[32,33]

Intracardiac echocardiography (ICE)

Somewhat newer to the field of interventional catheterization is intracardiac echocardiography. Although initially described in the late 1960s, it would be several decades before the technology advanced to the point that commercial availability and decreased cost allowed for its more widespread use.[34] It is currently used to guide many of the same procedures as TEE including interventions on the interatrial and interventricular septum, device closure of left atrial appendage and paravalvar leaks, EP procedures including pulmonary vein isolation, as well as for mitral valve repair and transcatheter aortic valve replacement [35] Recent studies have also shown it to provide excellent imaging of the right ventricle and outflow tract during transcatheter pulmonary valve placement.[36]

Although a complete review of ICE in the pediatric catheterization lab is beyond the scope of this review, it is worth describing some of the relative advantages and limitations of ICE compared to TEE in guiding transcatheter interventions.[35] Both provide high quality images of intracardiac structures with excellent tissue differentiation and can reduce both contrast use and radiation dose. Advantages of TEE over ICE include: not requiring additional venous access (currently 8-10 French sheath), a wider imaging volume window, capability for 3D imaging and lower cost due to the fact that TEE probes are reusable whereas ICE catheters are single use. ICE on the other hand, can be performed under conscious sedation, thus eliminating additional costs associated with general anesthesia and potentially longer hospital stays. ICE also does not require that an echocardiographer be present, as the ICE catheter is usually operated by a member of the interventional team. There is however, a learning curve involved in becoming comfortable and skilled in its use. ICE also offers an alternative to patients with contraindications to TEE such as esophageal varices and may provide superior imaging of far field structures such as the right and left ventricular outflow tracts. As a result ICE does offer potentially superior imaging for transcatheter pulmonary and aortic valve placement.[35,37] Given this, most large volume pediatric catheterization labs, and particularly those with a large adult congenital heart disease population, would benefit from having both TEE and ICE available.

Future Directions in Interventional Imaging

The last decade has seen the rapid expansion of newer techniques and technology that allow for the combination of 3D imaging and standard fluoroscopy. This complimentary image fusion is possible with computed tomography and magnetic resonance imaging obtained prior to the catheterization procedure or can be done during the procedure with 3D rotational angiography.[38,39] More recently a system has been developed that allows for integration of real time 3D TEE.[40] This fusion of fluoroscopy and 3D TEE has been shown to reduce radiation exposure. of these methods allows for improved and potentially superior imaging that facilitate the understanding of complex anatomies for catheter guidance and interventions, all while improving safety and reducing radiation doses.[41] There is also ongoing research in the use of cardiac magnetic resonance imaging guidance for diagnostic and interventional procedures in both adults and children which offers the possibility of radiation free cardiac catheterization.[42]

Conclusion:

As interventional cardiac procedures continue to expand in scope and complexity, so too does the need for improved imaging associated with these procedures. TEE will almost certainly remain an important tool for planning, guiding, and evaluating the success of transcatheter procedures in congenial heart disease. In addition, it improves procedural success and also reduces procedure time, radiation exposure, and need for contrast injection. Complimentary imaging will certainly continue to evolve as evidenced by the increasing use of ICE and more recently ability to overlay and imaging from TTE, computed tomography and magnetic resonance imaging on the fluoroscopic images during procedures.

References:

1. Pislaru SV, Michelena HI, Mankad SV. Interventional echocardiography. Prog Cardiovasc Dis. 2014;57(1):e32-e46.

2. Rigby ML, Transoesophageal echocardiography during interventional cardiac catheterisation in congenital heart disease. Heart 2001;86:ii23-ii29.

3. Puchalski, MD, Lui, GK, Miller-Hance WC. Guidelines for Performing a Comprehensive Transesophageal Echocardiographic Examination in Children and All Patients with Congenital Heart Disease: Recommendations from the American Society of Echocardiography. J AM Soc Echocardiogr. 2019;32(2):173-215.

4. Garg G, Tyagi H, Radha AS. Transcatheter closure of sinus venosus atrial septal defect with anomalous drainage of right upper pulmonary vein into superior vena cava--an innovative technique. Catheter Cardiovasc Interv. 2014;84(3):473-477.

5. Patrianakos AP, Zacharaki AA, Skalidis EI, et al. The growing role of echocardiography in interventional cardiology: The present and the future. Hellenic Society of Cardiology. 2017;58: e17-e31.

6. Rigby ML. Transesophageal echocardiography during interventional cardiac catheterization in congenital heart disease. Heart. 2001;86(Suppl II):ii23-ii29.

7. Snijder RJ, Renes LE, Jan Suttorp M, et al. Percutaneous patent foramen ovale closure using the Occlutech Figulla device: More than 1,300 patient-years of follow up. Catheter Cardiovasc Interv. 2019;93:1080-1084.

8. Magni G, Hijazi Z, Pandian N, et al. Two- and three-dimensional transesophageal echocardiography in patient selection and assessment of atrial septal defect closure by the new DAS-Angel Wings device. Circulation. 1997. 96:1722–1728.

9. Sharfi M, Al-Ata J, Al-Kouatli A, et al. Safety and efficacy of transcatheter closure of atrial septal defect type II under transthoracic echocardiographic guidance: A case control study. J Saudi Heart Assoc. 2019;31:2-8.

10. Savis A., Simpson J. Echocardiographic approach to catheter closure of atrial septal defects: Patient selection, procedural guidance and post-procedural checks. Echo Research Practice. 2018;5(2):R49-R64.

11. Udink ten Cate F, Sobhy R, Kalantre A, et al. Off-label use of duct occluder devices to close hemodynamically significant perimembranous ventricular septal defects: A multicenter experience Catheter Cardiovasc Interv. 2019;93(1):82-88.

12. Cossor W, Cui VW, Roberson DA. Three-Dimensional Echocardiographic En Face Views of Ventricular Septal Defects: Feasibility, Accuracy, Imaging Protocols and Reference Image Collection. J Am Soc Echocardiogr 2015; 28:1020.

13. Bu H, Yang Y, Wu Q, et al. Echocardiography-guided percutaneous closure of perimembranous ventricular septal defects without arterial access and fluoroscopy. BMC Pediatrics 2019;19:302.

14. Tutar E, Ramoglu M, Ciftci O, et al. Transcatheter ventricular septal defect closure: Should we feel comfortable after many years? Anatol J Cardiol. 2015;15:765-767.

15. Ross J Jr, Braunwald E, Morrow AG. Transseptal left heart catheterization: a new diagnostic method. Prog Cardiovasc Dis. 1960;2:315-318.

16. Brockenbrough EC, Braunwald E, Ross J Jr. Transseptal left heart catheterization: a review of 450 studies and description of an improved technic. Circulation. 1962;25:15-21.

17. Hahn K, Gal R, Sarnoski J, et al. Transesophageal echocardiographically guided atrial transseptal catheterization in patients with normal-sized atria: incidence of complications. Clin Cardiol. 1995;18:217–20.

18. Earley MJ. How to perform a transseptal puncture. Heart.2009;95(1):e85-e92.

19. Bayrak F, Chierchia GB, Namdar M, et al. Added value of transoesophageal echocardiography during transseptal puncture performed by inexperienced operators. Europace. 2012;14:661–665.

20. Martin AC, Rigby ML, Penny DJ, et al. Bedside balloon atrial septostomy on neonatal units. Arch Dis Child Fetal Neonatal Ed. 2003 Jul;88(4):F339-F340.

21. Leonard GT, Justino H, Carlson KM, et al. Atrial septal stent implant: atrial septal defect creation in the management of complex congenital heart defects in infants. Congenit Heart Dis. 2006 May;1(3):129-135.

22. Mainzer G, Gorenczny S, Morgan GJ, et al. Stenting of the inter-atrial septum in infants and small children: Indications, techniques and outcomes Catheter Cardiovasc Interv. 2018 Jun;91(7):1294-1300.

23. Tomita H, Watanabe K, Yazaki S, et al. Stent implantation and subsequent dilatation for pulmonary vein stenosis in pediatric patients: maximizing effectiveness. Circ J. 2003;67:187-190.

24. Schneider DJ, Moore JW. Transcatheter treatment of IVC channel obstruction and baffle leak after mustard procedure for D-transposition of the great arteries using Amplatzer ASD device and multiple stents. J Invasive Cardiol. 2001;13:306–9

25. Dragulescu A, Sidibe N, Aubert F, et al. Successful use of covered stent to treat superior systemic baffle obstruction and leak after atrial switch procedure. Pediatr Cardiol. 2008;29:954–6.

26. Farooqi, K, Lopez, L, Sutton, NJ, et al. Closure of a Superior Vena Cava Baffle Leak in a Patient with D-Transposition After Mustard Palliation: Importance of Both Angiography and Echocardiography for Confirmation of Closure. Pediatr Cardiol 2009; 30, 1046–1047.

27. Van Der Velde ME, Perry SB. Transeophageal Echocardiography During Interventional Cardiac Catheterization in Congenital Heart Disease. Echocardiography 1997;14:513-518.

28. McElhinney DB, Aboulhosn JA, Dvir D, et al. Mid-Term Valve-Related Outcomes After Transcatheter Tricuspid Valve-in-Valve or Valve-in-Ring Replacement. J Am Coll Cardiol. 2019;22;73(2):148-157.

29. Kamioka N, Babaliaros V, Morse MA, et al. Comparison of clinical and echocardiographic outcomes after surgical redo mitral valve replacement and transcatheter mitral valve-in-valve therapy. J Am Coll Cardiol Intv 2018; 11:1131–1138.

30. Momenah TS, Alsahari A, Ahmed E, et al. Transcatheter mitral valve-in-valve implantation in a pediatric patient. Catheter Cardiovasc Interv. 2020;95(5):1062-1065.

31. Hamilton-Craig C, Boga T, Platts D, et al. The Role of 3D Transesophageal Echocardiography During Percutaneous Closure of Paravalvular Mitral Regurgitation. J Am Coll Cardiol Img. 2009; 6:771–773.

32. Kort HW, Sharkey AM, Balzer DT. Novel use of the Amplatzer duct occluder to close perivalvar leak involving a prosthetic mitral valve. Catheter Cardiovasc. Interv. 2004;61(4):548–551

33. Turner ME, Lai WW, Vincent JA. Percutaneous closure of tricuspid paravalvular leak, Catheter Cardiovasc Interv. 2013;82(4):E511-E515.

34. Eggleton RC, Townsend C, Kossoff G. Program and abstracts of the eighth ICBME session 10-3., computerized ultrasonic visualization of dynamic ventricular configuration. Chicago: Palmer House 1969.

35. Basman C, Armar YJ, Kronzon I. Intracardiac Echocardiography for Structural Heart and Electrophysiological Interventions. Curr Cardiol Rep 2017;19-102.

36. Whiteside W, Pasquali SK, Yu S et al. The utility of Intracardiac echocardiography following Melody™ transcatheter pulmonary valve implantation. Peditr Cardiol. 2015; 36(8): 1754-60.

37. Rhodes JF, Qureshi AM, Preminger TJ et al. Intracardiac Echocardiography During Transcatheter Interventions for Congenital Heart Disease.

38. Fagan TE, Truong UT, Jone PN, et al. Multimodality 3-dimensional image integration for congenital cardiac catheterization. Methodist Debakey Cardiovasc J. 2014;10(2):68-76.

39. Thaden JJ, Sanon S, Geske JB, et al. Echocardiographic and Fluoroscopic Fusion Imaging for Procedural Guidance: An Overview and Early Clinical Experience. J Am Soc Echocardiogr. 2016;29(6):503-512.

40. Corti R, Biaggi P, Gaemperli O, et al. Integrated x-ray and echocardiography imaging for structural heart interventions. EuroIntervention. 2013;9(7):e863-e869.

41. Jone P, Ross, MM, Bracken JA, et al. Feasibility and Safety of Using a Fused Echocardiography/Fluoroscopy Imaging System in Patients with Congenital Heart Disease. J Am Soc Echocardiogr. 2016;29(6):513-521.

42. Ratnayaka K, Kanter JP, Faranesh AZ, et al. Radiation-free CMR diagnostic heart catheterization in children. J Cardiovasc Magn Reson. 2017;19(1):65.

Funding:

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Conflicts of Interest: The authors have no conflicts of interest to declare.

Figure Captions:

Figure 1: X-plane imaging with Transesophageal echocardiography (TEE) showing an atrial septal defect (ASD) simultaneously from the aortic and bicaval view at 0 degrees and 90 degrees.

Figure 2: Three-dimensional (3D) TEE full volume rendering showing an "en face" view of an ASD. * Inferior vena cava (IVC)

Figure 3: 3D TEE showing an ASD following closure with a 20 mm Amplatzer Septal Occluder device. (A) Mid-esophageal (ME) right ventricle (RV) inflow-outflow view from 60 degrees. (B) "En face" view of the device from the right atrial side.

Figure 4: TEE images showing a large apical ventricular septal defect (VSD). (A) Before and (B) after perventricular closure with a 25 mm Amplatzer Cribiform device.

Figure 5: TEE images showing stent placement in restrictive pulmonary venous confluence. (A) The initial opening is restrictive measuring roughly 2 mm. (B) Imaging during positioning of the stent demonstrating how TEE allows for centering of the stent across the defect. (C) Following deployment the stent is well centered and widely patent with a diameter of 10 mm.

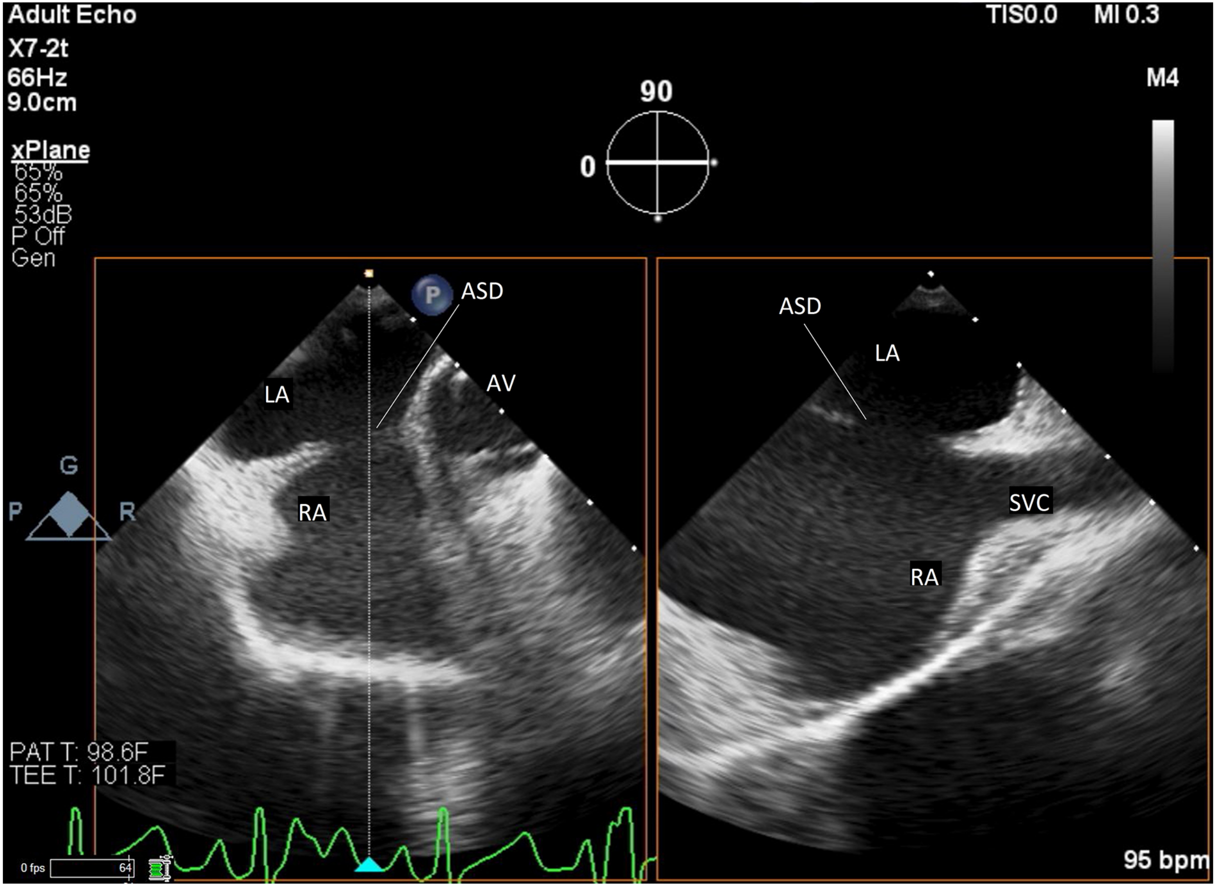
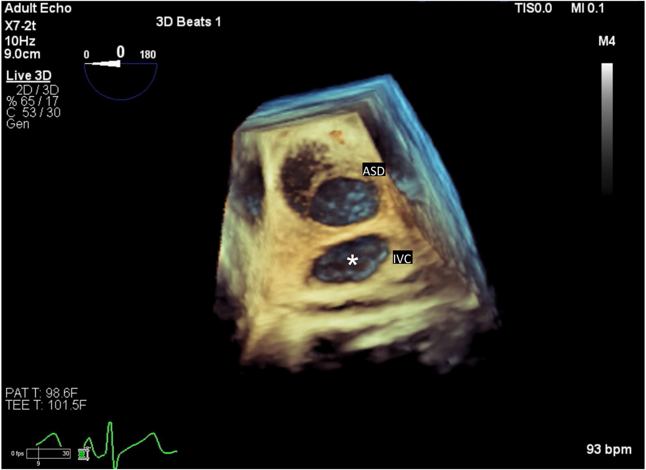

Adult Echo
X7-2t
66Hz
9.0cm
xPlane
65%
65%
53dB
P Off
Gen
TIS0.0
MI 0.3
M4
90
0
G
P
R
ASD
LA
AV
RA
SVC
PAT T: 98.6F
TEE T: 101.8F
0 fps
64
95 bpm

Figure 1



Adult Echo
X7-2t
10Hz
9.0cm
3D Beats 1
0
0
180
TIS0.0
MI 0.1
M4
Live 3D
2D / 3D
% 65 / 17
C 53 / 30
Gen
ASD
*
IVC
PAT T: 98.6F
TEE T: 101.5F
0 fps
30
9
93 bpm

Figure 2

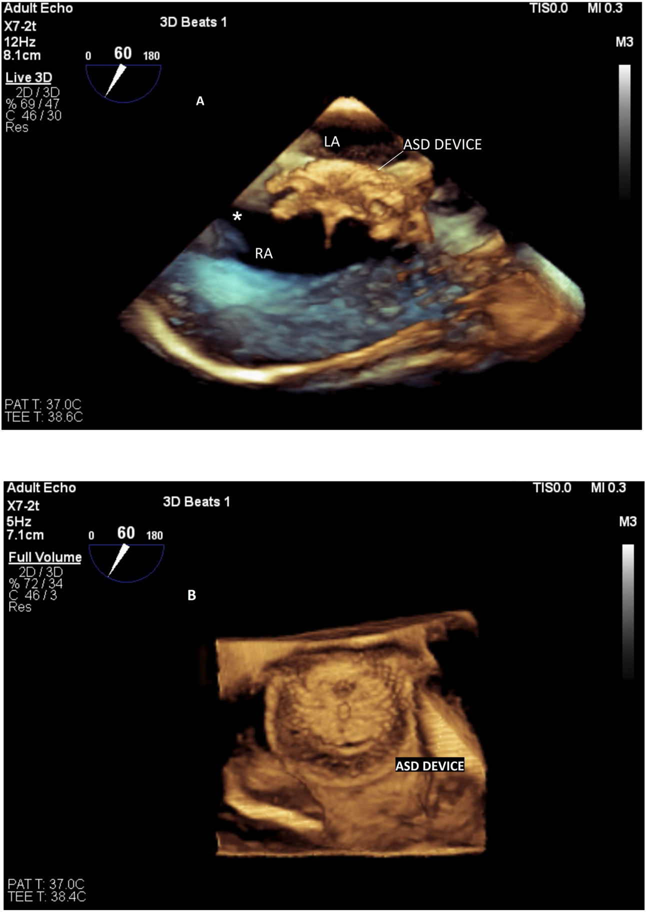

Adult Echo
X7-2t
12Hz
8.1cm
3D Beats 1
0
60
180
TIS0.0
MI 0.3
M3
Live 3D
2D / 3D
% 69 / 47
C 46 / 30
Res
A
LA
ASD DEVICE
*
RA
PAT T: 37.0C
TEE T: 38.6C
Adult Echo
X7-2t
5Hz
7.1cm
3D Beats 1
0
60
180
TIS0.0
MI 0.3
M3
Full Volume
2D / 3D
% 72 / 34
C 46 / 3
Res
B
ASD DEVICE
PAT T: 37.0C
TEE T: 38.4C

Figure 3

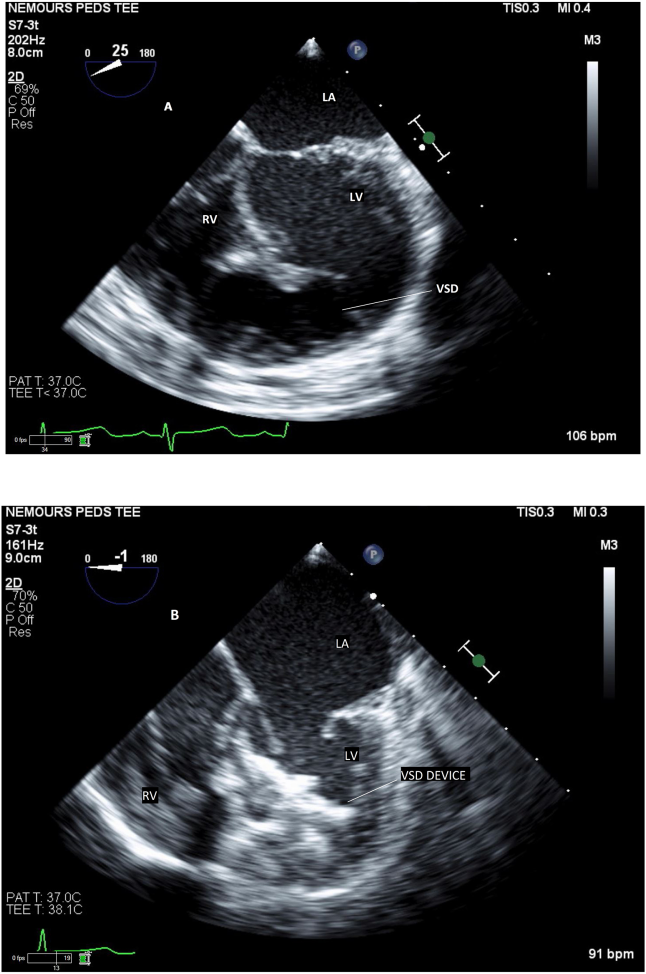

NEMOURS PEDS TEE
S7-3t
202Hz
8.0cm
0
25
180
2D
69%
C 50
P Off
Res
TIS0.3
MI 0.4
M3
A
LA
LV
RV
VSD
PAT T: 37.0C
TEE T< 37.0C
106 bpm
NEMOURS PEDS TEE
S7-3t
161Hz
9.0cm
0
-1
180
2D
70%
C 50
P Off
Res
TIS0.3
MI 0.3
M3
B
LA
LV
VSD DEVICE
RV
PAT T: 37.0C
TEE T: 38.1C
91 bpm

Figure 4

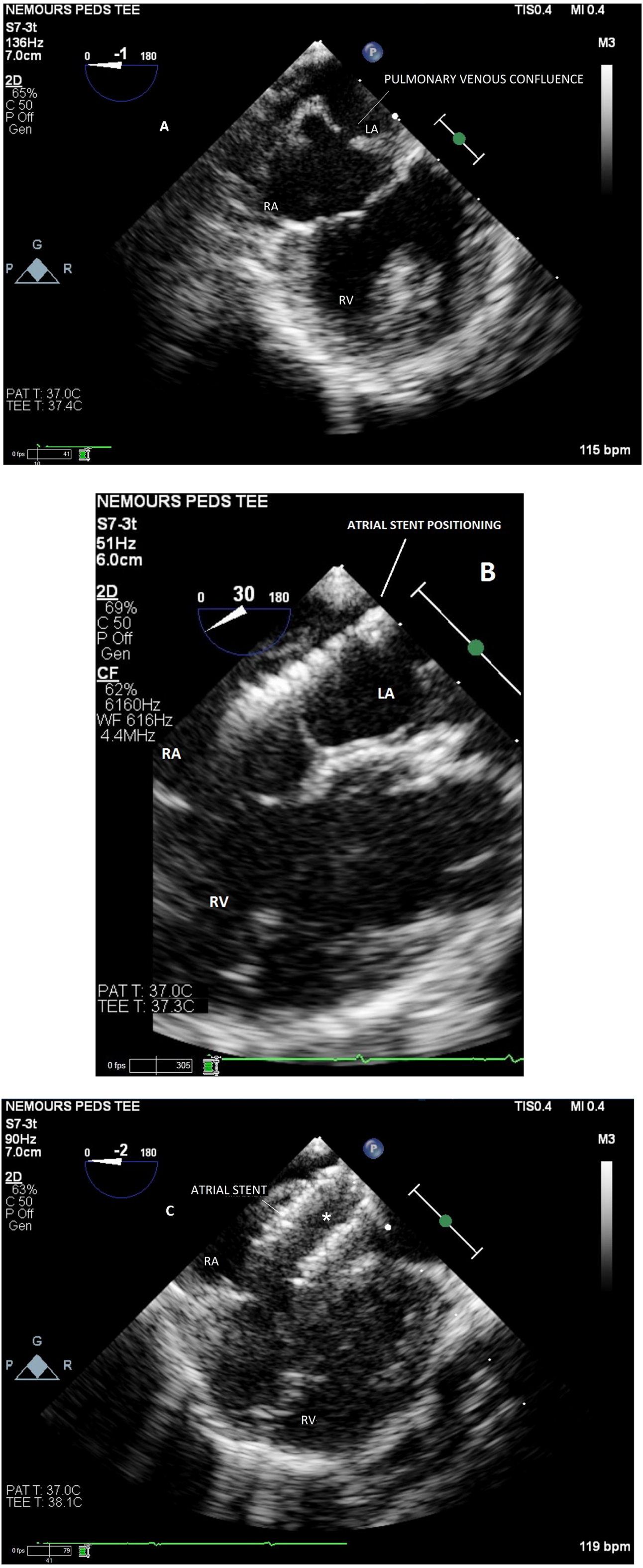

NEMOURS PEDS TEE
S7-3t
136Hz
7.0cm
TIS0.4
MI 0.4
M3
2D
65%
C 50
P Off
Gen
A
PULMONARY VENOUS CONFLUENCE
LA
RA
RV
G
P
R
PAT T: 37.0C
TEE T: 37.4C
115 bpm
NEMOURS PEDS TEE
S7-3t
51Hz
6.0cm
ATRIAL STENT POSITIONING
B
0
30
180
2D
69%
C 50
P Off
Gen
CF
62%
6160Hz
WF 616Hz
4.4MHz
LA
RA
RV
PAT T: 37.0C
TEE T: 37.3C
NEMOURS PEDS TEE
S7-3t
90Hz
7.0cm
TIS0.4
MI 0.4
M3
2D
63%
C 50
P Off
Gen
C
ATRIAL STENT
*
RA
RV
G
P
R
PAT T: 37.0C
TEE T: 38.1C
119 bpm

Figure 5