First-in-Human Use of a Novel 4D Intracardiac Echocardiography Catheter To Guide Interventional Electrophysiology Procedures

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Abstract

Introduction: Standard two-dimensional (2D), phased-array intracardiac echocardiography (ICE) is routinely used to guide interventional electrophysiology (EP) procedures. A novel four-dimensional (4D) ICE catheter (VeriSight Pro®, Philips, Andover, MA) can obtain 2D and three-dimensional (3D) volumetric images and cine-videos in real time (4D). The purpose of this study was to determine the early feasibility and safety of this 4D ICE catheter during EP procedures. Methods: The 4D ICE catheter was placed from the femoral vein in ten patients into various cardiac chambers to guide EP procedures requiring transseptal catheterization, including ablation for atrial fibrillation and left atrial appendage closure. 2D- and 3D- ICE images were acquired in real time by the electrophysiologist. A dedicated imaging expert performed digital steering to optimize and post-process 4D images. Results: Eight patients underwent pulmonary vein isolation (cryoballoon in 7 patients, pulsed field ablation in 1, additional radiofrequency left atrial ablation in 1). Two patients underwent left atrial appendage closure. High quality images of cardiac structures, transseptal catheterization equipment, guide sheaths, ablation tools, and closure devices were acquired with the ICE catheter tip positioned in the right atrium, left atrium, pulmonary vein, coronary sinus, right ventricle, and pulmonary artery. There were no complications. Conclusion: This is the first-in-human experience of a novel deflectable 4D ICE catheter used to guide EP procedures. 4D ICE imaging in safe and allows for acquisition of high-quality 2D and 3D images in real-time. Further use of 4D ICE will be needed to determine its added value for each EP procedure type.

Introduction

Standard two-dimensional (2D), phased-array intracardiac echocardiography (ICE) is routinely used to guide interventional electrophysiology (EP) procedures. ICE is increasingly used during EP procedures to guide transseptal catheterization, evaluate the position of ablation catheters, assess for occlusion of the pulmonary vein (PV) during cryoballoon ablation (CBA) procedures, and to exclude complications such as a pericardial effusion or thrombus formation[1-3]. Intracardiac echocardiography is also used to guide left atrial appendage closure (LAAC) procedures with the ICE catheter placed in the left atrium (LA) as an alternative to transesophageal echocardiography (TEE) to avoid the need for general anesthesia.[4-5]

Using technology similar to what is currently available on a three-dimensional (3D) transthoracic or TEE probe, a novel ICE catheter has been developed that is capable of additional 3D volumetric ultrasound imaging with color doppler imaging in real-time (4D). The purpose of this study was to determine the early feasibility and safety of this novel 4D ICE catheter during EP procedures.

Methods

A novel 9 French 4D ICE catheter (VeriSight Pro®, Philips, Andover, MA) (Figure 1) was utilized by three different operators, each with extensive experience with the use of 2D ICE during EP procedures. This catheter incorporates the same ultrasound technology as a 4D TEE probe, miniaturized to fit on the tip of a 3.0mm diameter (9 French) catheter. It has a 90 cm working length with a distal 2 cm imaging tip. The imaging matrix consists of 840 elements (15 x 56 element design). This allows for X-plane imaging with live cross-plane 2D imaging. This matrix also enables 90 x 90 degree volume imaging. The 3D imaging can be obtained in real time; color Doppler can also be added to the live 3D imaging. Another feature is digital steering where the catheter is rotated from the console without the operator moving it manually. There are two steering knobs on the handle (Figure 1C), one for anterior-posterior adjustments and the other for right-left adjustments. There is a separate tension control knob. The articulation segment allows for a 120-degree deflection range in each direction. The catheter connects to the Philips EPIQ CVx imaging console, which can also be used for non-invasive cardiac imaging such as transthoracic echocardiography and TEE.[6] Furthermore, the full spectrum of image analysis and post-processing available for TEE is available for ICE imaging including Color Doppler assessment, multiplanar reconstruction and trans-illumination technology.

The catheter was advanced from the left femoral through a 10 French short sheath and positioned in various cardiac chambers during ten interventional EP procedures including catheter ablation and LAAC, during which a standard 2D ICE catheter would ordinarily be used. All procedures were guided with fluoroscopy and performed under general anesthesia. There were no changes to the standard approaches during the EP procedures because of the use of the 4D ICE catheter. A standard TEE probe (Philips) was used as well during the LAAC procedures and images were obtained by the cardiac anesthesiologist. The ICE images were frozen when the procedure was being guided by TEE, and vice versa to prevent artifact during imaging.

The ICE catheter was initially placed in the right atrium (RA). Images were acquired in real time during catheter manipulation by the electrophysiologist, and processed by a dedicated imaging expert at the ultrasound console. Initially views were optimized using a standard 0-degree imaging angle using a combination of manual catheter manipulation and digital steering. In preparation for orthogonal X-plane imaging, views of the same structures were optimized using a -45-degree angle so that orthogonal views would be at +45 and -45 degrees. This approach allowed for better image quality compared to imaging from 0 and +90-degree angles. In a subset of patients, the ICE catheter was placed in the LA and in additional positions to assess its ability to acquire images of the LA and left atrial appendage from other vantage points. The ICE catheter was placed in the LA by advancing it across the same transseptal puncture site as the transseptal sheath using a “shoe-horn” technique without a long sheath.

The VeriSight Pro® 4D ICE catheter is approved for use in humans by the United States Food and Drug Administration (FDA). Procedures were performed after FDA approval, in preparation for a planned registry study that has been approved by the Northwestern Institutional Review Board (IRB) and is sponsored by Philips, the manufacturer of the 4D ICE catheter.

Results

Patients and Procedure Characteristics

Baseline demographics of the ten patients are shown in Table 1; patients had an average age of 65.6 $\pm$ 10.3 years and 60% were female. Single transseptal catheterization was performed in each patient guided by fluoroscopy and ICE. A powered transseptal needle (NRG®, Baylis Medical, Toronto, Canada) was used in nine patients and a powered 8.5 French guidewire (VersaCross®, Baylis Medical, Toronto, Canada) was used in the one patient with an atrial septal defect occluder in place. Pulmonary vein isolation was performed in eight patients who underwent catheter ablation for refractory atrial fibrillation. Cryoballoon ablation was performed in seven patients using the second-generation cryoballoon (Artic Front Pro, Medtronic, Minneapolis, MN), and pulsed-field ablation (PFA) was performed in one patient (PulseSelect PFA System, as part of the Pulsed AF pivotal clinical trial sponsored by Medtronic). In one patient who underwent CBA, additional left atrial posterior wall isolation was performed using radiofrequency ablation (RFA) with an open-irrigation ablation electrode. Left atrial appendage closure was performed in two patients using an FDA-approved plug-type device (Watchman FLX, Boston Scientific, Malborough, MA). The ICE catheter was placed in the LA in two patients who underwent CBA and in two patients who underwent LAAC.

Diagnostic-quality 2D and 4D images of various cardiac structures, transseptal catheterization equipment, long guide sheaths, ablation tools, and closure devices were acquired with the ICE catheter positioned in the RA, LA, PV, coronary sinus, right ventricle, and pulmonary artery. Operators noted that the 4D ICE catheter was easy to advance into the RA and LA and easy to manipulate to acquire images. Compared to other commonly used, commercially available 2D ICE catheters, the 4D ICE catheter was notably more flexible at the segment just proximal to the distal imaging portion. This flexibility enabled the catheter to be placed in alternate positions including the coronary sinus with little risk of cardiac perforation. Fluoroscopy could be used to discern the imaging direction based on the appearance of the tip of the ICE catheter. The standard 2D, X-plane, 3D, and 4D ICE images were of high-quality and were able to guide the EP procedures. A combination of 2D imaging, X-plane imaging, and 3D imaging was used for all cases. There were no complications related to the use of the catheter.

Representative Intraprocedural Images

Figure 2A shows a fluoroscopic image of the ICE catheter in the RA while a pulmonary venogram is performed. The ICE catheter was subsequently advanced and positioned in the LA and the left superior PV (Figure 2B). The appendage was also visualized from lower in the LA (Figure 2C), from the right ventricular outflow tract and pulmonary artery, and from the coronary sinus (Figure 2D).

As with 2D ICE, imaging was initially performed of the tricuspid valve, RA, and right ventricle from the "home view" (Figure 3A). Clockwise rotation of the catheter brought into view the aorta, the left ventricle, mitral valve, and the interatrial septum (Figure 3 – online video). The interatrial septum was clearly visualized in both 2D and 3D (Figure 3B). In Figure 3C, images from the home view in a patient with a prominent moderator band in the right ventricle are shown in 2D and 3D.

As with 3D TEE, volumetric imaging with the novel ICE catheter requires an optimized 2D image. An example of a transseptal catheterization is shown in Figure 4. In panel A, a standard 2D ICE view of the interatrial septum is shown with the needle tenting alongside the 3D reconstruction of the same view. In Figure 4B, a sheath can be seen after it was advanced across the septum. One patient undergoing cryoballoon ablation had a 18 mm atrial septal occluder in place (Amplatzer, Abbott, Plymouth, MN) that had been implanted almost two decades earlier. A 2D ICE image of the interatrial septum demonstrates the sheath inferior to the closure device (Figure 4C). In panel D, a 3D image of the cryoballoon sheath crossing the septum beneath the closure device is shown.

In one patient who underwent radiofrequency ablation, the catheter tip electrode was visualized on the posterior wall. Figure 5 shows the 2D cross sections of the image, where the hyperechoic tissue from ablation is noted as well as the 3D reconstruction. On video recording (Figure 5 online), the saline bubbles from irrigation can be visualized.

Cryoballoon ablation was performed in seven of the patients. In Figure 6A, the cryoballoon is visualized in the left superior PV in 2D. Another unique feature of the 4D ICE system is the ability to digitally steer the volumetric images from the console. In doing so, images such as those shown in Figure 6B can be obtained, showing an en-face view of the cryoballoon in the left superior PV. Color Doppler was added to this image as shown in panel C, demonstrating a leak around the balloon. The ICE catheter was also advanced into the LA and Figure 6D shows the balloon after warming and deflating (online video Figure 6D). The cryoballoon itself could be seen well with 2D and 4D imaging, but it was difficult to image past or through the cryoballoon due to reflections from the balloon.

Pulsed field ablation was performed in one patient using the PulseSelect system (Medtronic), which involves a circular shaped ablation catheter with multiple gold ablation electrodes. Images of this investigational catheter in the left superior PV and LA are shown in Figure 7 (panels A and B, respectively). Irrigation from the catheter in the left superior PV can be seen in the online video.

Because of the ability to place the ICE catheter in various locations closer to the left atrial appendage, visualization during LAAC procedures has improved. Figure 8A demonstrates a 3D image of an implanted

LAAC device, obtained from the LA. From the LA, views can be obtained to measure the mitral shoulder after device deployment. This is shown in Figure 8B using the glass view feature. Lastly, the ICE catheter can be withdrawn from the LA and advanced into the coronary sinus to visualize the closure device in the left atrial appendage (Figure 8C).

Discussion

Main Findings

The main finding of this study is that a novel 9-French deflectable 4D ICE catheter with digital steering and X-plane imaging can be used to safely and effectively image various cardiac structures and devices during interventional EP procedures. The catheter system provides high quality 2D and 4D images with and without color Doppler when the electrophysiologist is assisted by a dedicated imaging specialist.

2D and 4D Image Quality

Ultrasound has been used for many years to guide cardiac interventions. Phased-array ICE has been used to guide transseptal catheterization for over twenty years and is routinely used in many countries, including the United States, in the EP lab during complex ablation procedures. Transesophageal echocardiography can also be used to guide cardiac procedures and is commonly used during structural heart procedures, including LAAC, because it has the advantage of accurate imaging from the esophagus with the ability to generate 3D images. The disadvantage of using TEE to guide procedures in the EP lab is the need for general anesthesia and a dedicated imaging specialist to manipulate the TEE probe to assist the physician performing the procedure. There is already experience using 2D ICE to guide LAAC with the catheter in the LA. A 4D ICE catheter could have even more potential to act as a substitute for a TEE.

There are usually tradeoffs with imaging innovation. Fortunately, this novel 4D ICE catheter also performed well as a basic 2D ICE catheter. The handle is intuitive, the catheter was stable and highly responsive to manipulation, and the catheter tip was flexible enough to provide reassurance to the operator that the risk of cardiac injury during catheter manipulation would be very low. The 2D images from this imaging system were as good or better than the images obtained from the two major commercially available ICE imaging systems. The advantages of the 4D ICE catheter used in this case series are not only the ability to create high quality 3D images in real-time, but the ability to also use digital steering to optimize a view without having to mechanically manipulate the catheter, and the ability to obtain orthogonal X-plane views. For example, with the ICE catheter in one position in the RA, both a short and long axis view of the aortic root could be obtained. This would be very helpful during ablation of ventricular arrhythmias arising from the aortic cusps.

For those accustomed to using 2D ICE, there are certain fluoroscopic positions of the catheter that usually predict views of specific structures. Two-dimensional ICE uses an imaging angle of zero degrees. Because the image quality of the 4D ICE catheter degrades with digital steering as the imaging angle increases beyond approximately +60 degrees, orthogonal views are usually made at -45 and +45 degrees. This requires finding an initial view at -45 degrees rather than at 0 degrees which may not be intuitive for those already comfortable with 2D ICE.

During most EP procedures, the electrophysiologist can use ICE independently and make minor adjustments to the imaging depth, gain, and color Doppler settings. A downside of this 4D system is the need for an additional person to be at the ultrasound console to acquire, process, optimize, crop, and manipulate the images. While electrophysiologists may be accustomed to basic adjustments on the 2D console, few have enough experience with 3D imaging acquisition to take advantage of most of the features of the 4D ICE catheter. Such cases will require either intensive on-site support from manufacturer, or collaboration with cardiologists with advanced imaging expertise.

Transseptal Catheterization

Transseptal catheterization is increasingly performed as the number of atrial fibrillation catheter ablation procedures increases and as new percutaneous valve procedures that require left atrial access are developed. Successful transseptal catheterization does not necessarily require ultrasound guidance, but the use of TEE and ICE can be useful in cases with challenging anatomy, during redo procedures, or to guide site-specific targets for different procedures. It likely also improves the safety of the average procedure. The 4D ICE catheter used in this series provided outstanding 3D views of the fossa ovalis and was useful to provide 3D orientation of the transseptal needle relative to neighboring structures to guide safe passage of the needle. Use of the 4D ICE catheter during a particularly challenging transseptal catheterization in a patent with a preexisting atrial septal defect occluder device illustrates how volumetric imaging and the ability to digitally steer the image can help to ensure safe and successful transseptal catheterization in challenging cases. Whether the digital steering and 4D imaging offer additional value beyond 2D ICE during transseptal catheterization remains to be determined.

Ablation Procedures

Imaging with ICE during ablation procedures can be useful to assess for device-tissue contact and perhaps lesion formation. During PV isolation procedures using the cryoballoon in the present series, standard 2D images with color Doppler were acquired from the RA and proved useful to assess for PV occlusion. In addition, 4D images were used at times to detect a leak around the balloon in a plane that the 2D images might have missed. This may enable operators to use less fluoroscopy and less contrast when checking for balloon occlusion. However, obtaining optimal 4D images requires clear 2D images, which can sometimes be difficult from the RA in patients with a thick atrial septum. The ability to digitally steer the image angle, though, can help optimize these images. Additional imaging from the LA during CBA provided outstanding views of the cryoballoon. Unfortunately, however, it was more difficult than anticipated to view the PVs beyond or through the balloon to assess for occlusion.

Left Atrial Appendage Closure

Intracardiac echo has proven to be a reasonable alternative to TEE as a guide during LAAC. In this case series, useful images were obtained using both 2D and 4D from various vantage points in the LA during LAAC with a plug device to make baseline LAA measurements, to guide deployment, and to measure device compression. Views mimicked those from the 3D TEE imaging that was also performed in the same patients. Given that the use of ICE could obviate the need for a TEE probe and general anesthesia, the threshold to place a 4D ICE catheter in the LA rather than image from the RA will be lower for LAAC procedures than for ablation procedures where a TEE probe is rarely used. In this early experience, good quality 2D and 4D images of the LAAC device and its relationship to the mitral annulus and PV limbus were easily obtained from the proximal coronary sinus suggesting that imaging from this and other sites outside of the LA may be sufficient to guide LAAC procedures with ICE. More experience is needed.

Limitations

A limitation of this initial experience with this specific 4D ICE catheter in the EP laboratory is that it was only evaluated during left atrial EP procedures. Additional experience is needed to determine the feasibility and value of using 4D ICE to guide other complex EP procedures such as catheter ablation for ventricular tachycardia and lead extractions.

Conclusion

This first in human experience suggests that a novel deflectable 4D ICE catheter with digital steering can be used to safely acquire high-quality, useful 2D and 3D images in real-time to guide interventional EP procedures. Further use of 4D ICE will be needed to determine the added value for each EP procedure type.

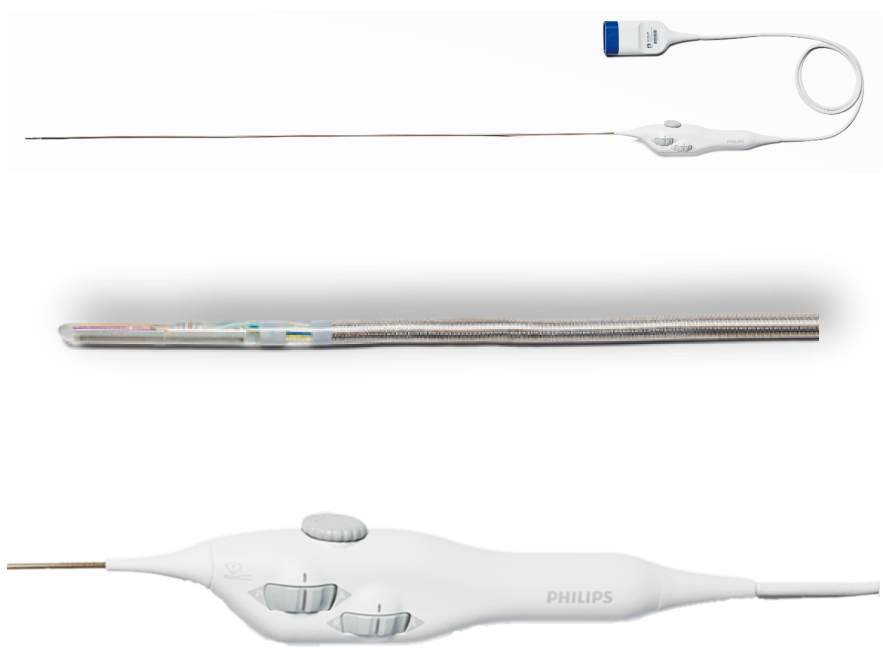
References:

1. Kim SS, Hijazi Z, Lang RL, Knight BP. The Use of Intracardiac Echocardiography and Other Intracardiac Imaging Tools to Guide Interventional Cardiac Procedures. State of the Art Review. J Am Coll Cardiol 2009;53:2117-28.

2. Saksena S, Sra J, Jordaens L, Kusumoto F, Knight BP, Natale A, Kocheril A, Nanda NC, Nagarakanti R, Simon AM, Viggiano MA, Lokhandwala T, Chandler ML. A prospective comparison of cardiac imaging using intracardiac echocardiography with transesophageal echocardiography in patients with atrial fibrillation. The Intracardiac Echocardiography Guided Cardioversion Helps Interventional Procedures Study. Circ Arrhythm Electrophysiol. 2010;3:571-577.
3. Basman C, Parmar Y, Kronzon I. Intracardiac Echocardiography for Structural Heart and Electrophysiology Interventions. Curr Cardiol Rep (2017) 19:102.
4. Alkhouli M, Chaker Z, Alqahtani F, Raslan S, Raybuck B. Outcomes of routine intracardiac echocardiography to guide left atrial appendage occlusion. *JACC Clin Electrophysiol.* 2020;6:393-400.
5. Berti S, Pastormerlo LE, Korsholm K, Saw J, Alkhouli M, Costa MP, Odenstedt J, Packer EJ, Tondo C, Santoro G, Nielsen-Kudsk JE. Intracardiac echocardiography for guidance of transcatheter left atrial appendage occlusion: An expert consensus document. Catheter Cardiovasc Interv. 2021 Jun 4. doi: 10.1002/ccd.29791. Epub ahead of print. PMID: 34086394.
6. Information provided by manufacturer (Philips, Andover, MA).

Figure Legends

Figure 1 . The VeriSight Pro(r) 4D Intracardiac Echocardiography catheter used during interventional electrophysiology procedures in this case series – the entire catheter (A), a focused view of the catheter tip (B), and the handle (C) (images courtesy of Philips).

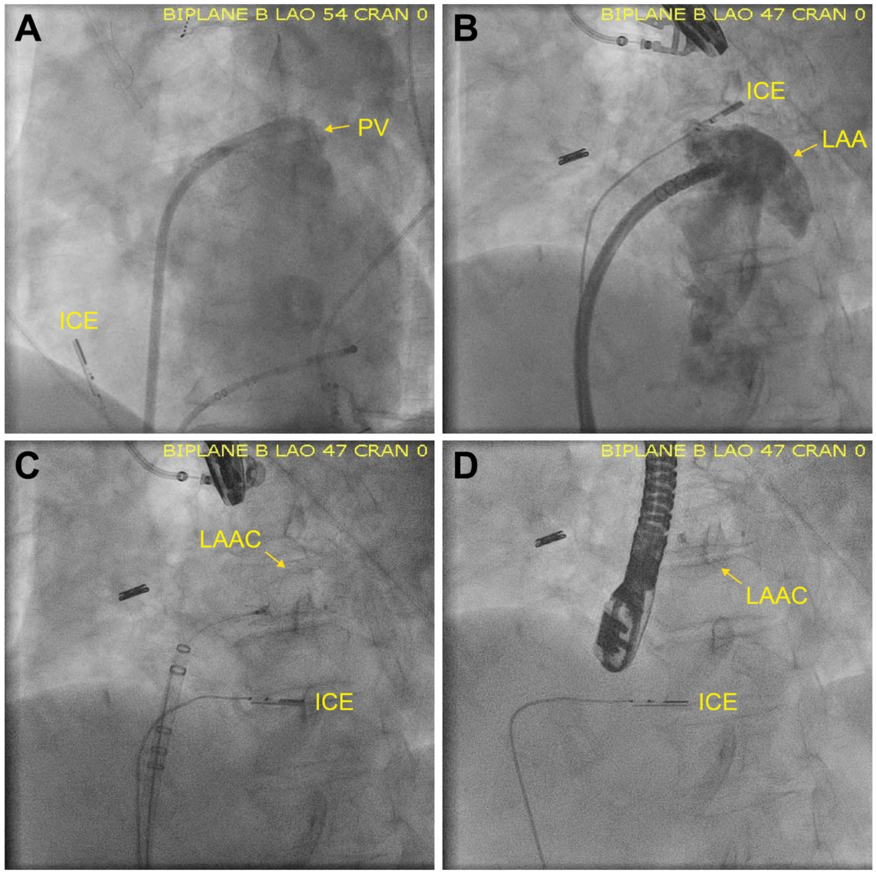


1.

2.

3.

Figure 2 . Fluoroscopic left anterior oblique images of the ICE catheter in the right atrium during a pulmonary venogram (A), left superior pulmonary vein during left atrial appendage angiography (B), inferior left atrium (C) and in the coronary sinus (D)



ICE – Intracardiac echocardiography catheter

LAA – left atrial appendage

PV – pulmonary vein

LAAC – Left atrial appendage closure device

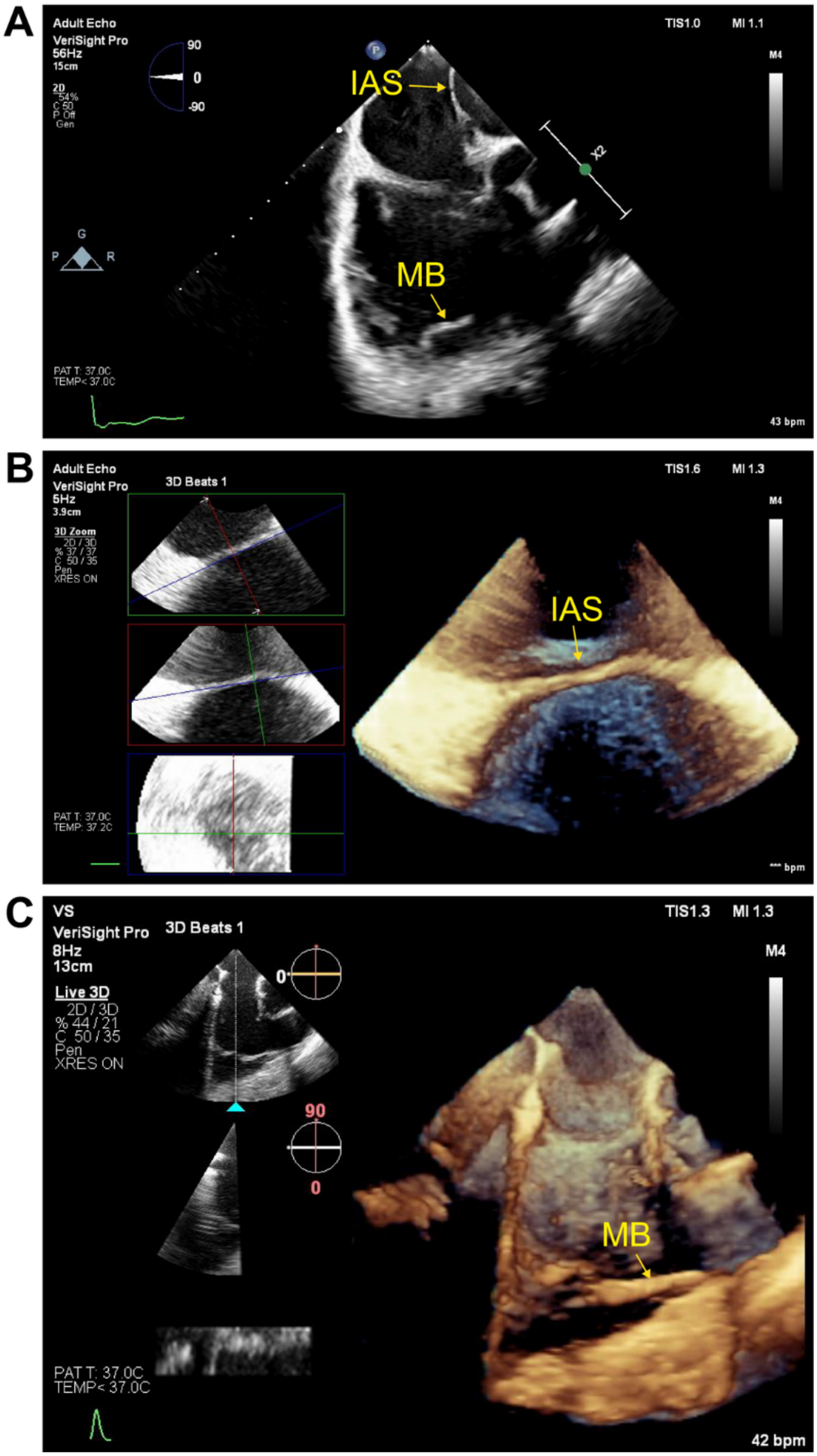


Figure 3 . 2D ICE images from the initial "home view" (A) during clockwise rotation to the interatrial

septum (online video), 2D and 3D images of the interatrial septum focused on the fossa ovalis (B), and 2D and 3D images of a prominent moderator band in the right ventricle (C).

IAS – Interatrial septum

MB – Moderator band

Figure 4 . Images obtained during transseptal catheterization showing the transseptal needle tenting the fossa ovalis in 2D and 3D (A), the sheath across the septum (B), the sheath across the septum inferior to an atrial septal defect occluder device in 2D (C), and the sheath across the septum inferior to an atrial septal defect occluder device in 3D (D).

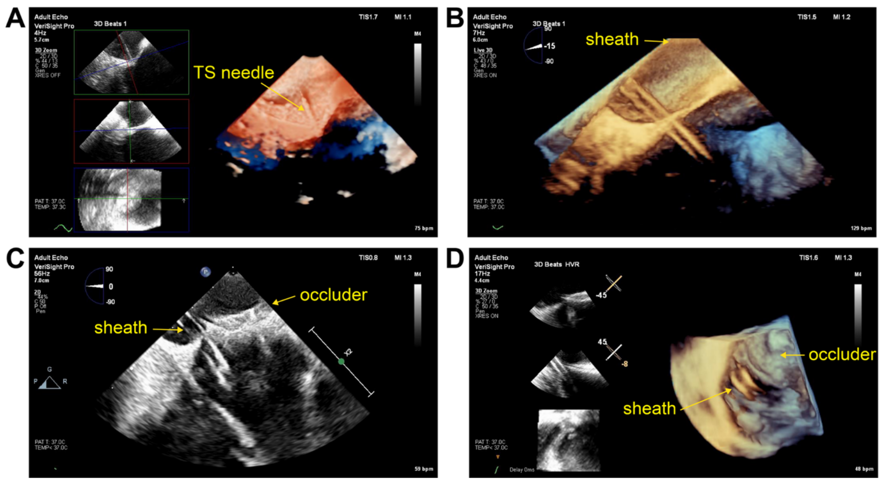


Figure 5 . Images from the right atrium during irrigated radiofrequency ablation with the ablation catheter along the posterior left atrium in 2D and 3D (arrow denoting catheter, online video)

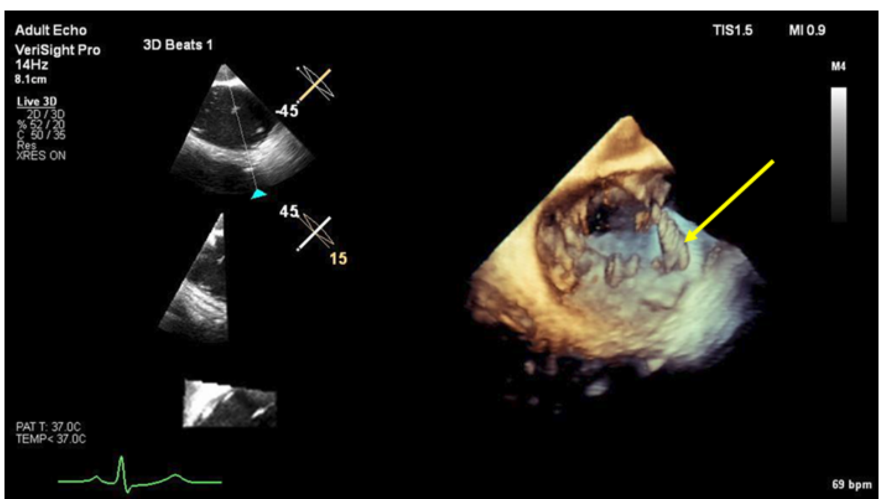
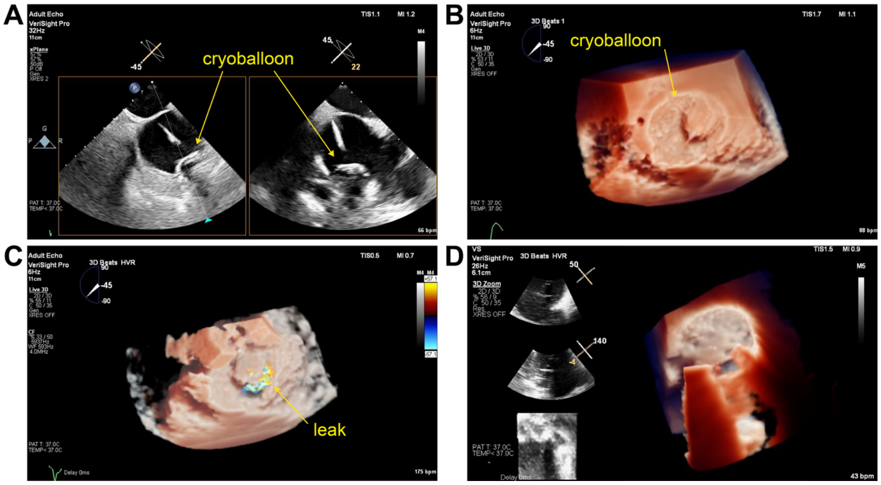


Figure 6 . Images of the cryoballoon in the left superior pulmonary vein in 2D (A), 3D en-face view obtained after digital steering (B), 3D color Doppler demonstrating a peri-balloon leak (C), and the deflated balloon (D – online video)


A
B
C
D
cryoballoon
cryoballoon
leak

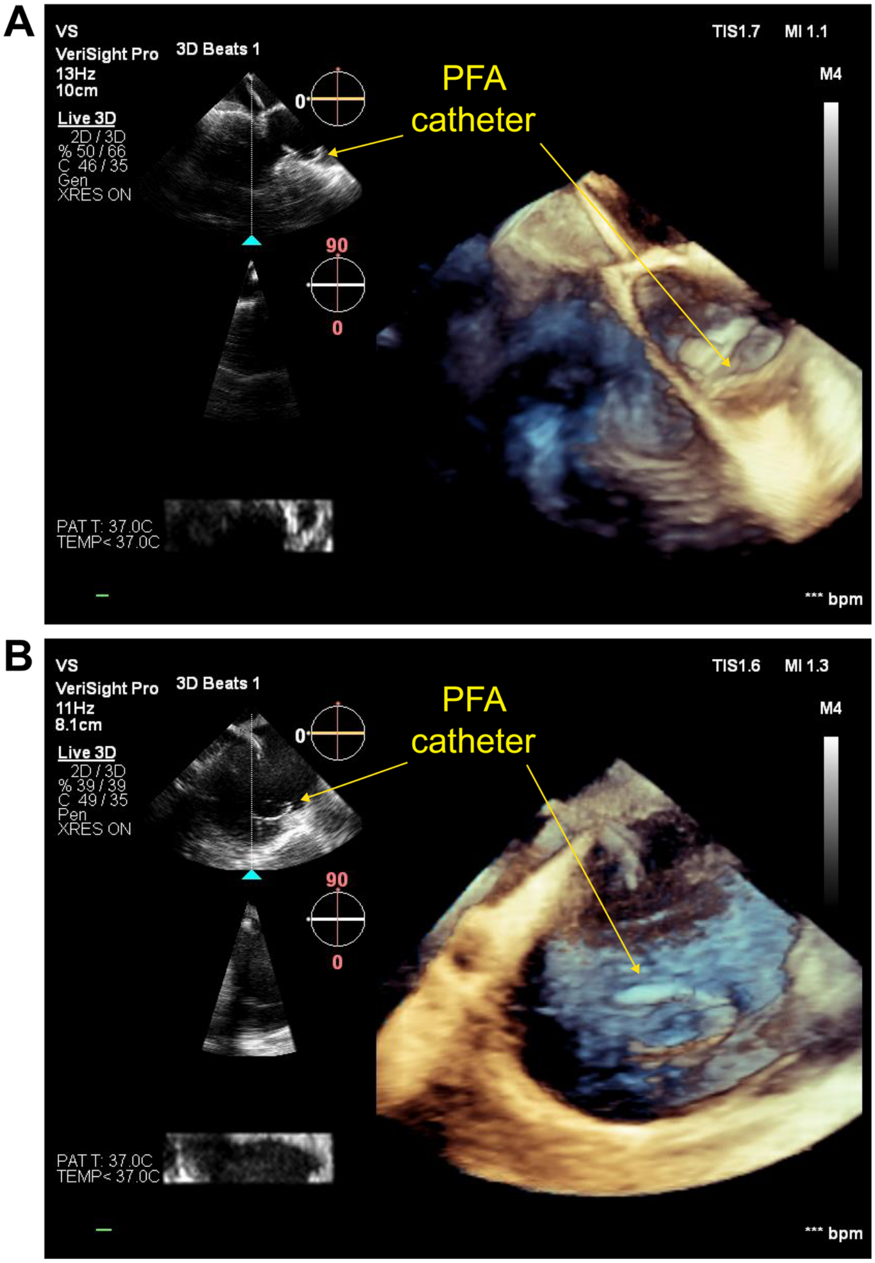


Figure 7. Images of the semi-circular pulsed field ablation electrode catheter in the left superior pulmonary vein (A – online video) and in the left atrium (B)

PFA – Pulsed field ablation

Figure 8. Images from the left atrium of a left atrial appendage closure device (A), a glass view of the closure device mitral shoulder (B), and imaging from the coronary sinus of the device after deployment (C).

Table 1. Patient Demographics.

	Patients (N=10)
Age (years)	65.6 ± 10.3
Female gender (No., %)	6 (60)
Weight (kilograms)	92.1 ± 26.1
CHA_2DS_2-VASc score	2.3 ± 1.4
Hypertension (No., %)	4 (40)
Diabetes (No., %)	3 (30)
Left ventricular ejection fraction (%)	61.2 ± 7.1
Procedure duration (minutes)	132.9 ± 35.8
Complications (No., %)	0 (0)

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