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Echocardiography

ORIGINAL INVESTIGATION

Transesophageal Echocardiography during Pulmonary Vein Cryoballoon Ablation for Atrial Fibrillation

Edmund Kenneth Kerut, M.D.,* Curtis Hanawalt, R.D.C.S.,† and James McKinnie, M.D.†

*Heart Clinic of Louisiana, Marrero, Louisiana; and †West Jefferson Medical Center, Marrero, Louisiana

We describe our first 20 cases of cryoablation of atrial fibrillation (AF) using transesophageal echocardiography (TEE). Continuous procedural monitoring with TEE by a cardiologist and senior sonographer assists the electrophysiologist in performance of the cryoballoon procedure of AF. Previously using intracardiac echocardiography (ICE) we have found TEE to have better overall procedural imaging, and monitoring for pericardial effusion or thrombus formation. We have found TEE monitoring to be helpful with positioning for interatrial septal (IAS) puncture, catheter tip avoidance of the left atrial appendage (LAA), and guidance of the balloon catheter into each pulmonary vein (PV), with proper positioning within each PV orifice, and documentation of PV occlusion for the cryoballoon procedure. Procedural equipment and the cryoballoon protocol used are presented in detail. The role of TEE imaging during the procedure and in preventing potential dangers is illustrated. It is the goal of this study to demonstrate how the electrophysiology and echocardiography laboratories work together in this cryoablation procedure. (Echocardiography 2014;00:1–9)

Key words: TEE, cryoablation, ICE, atrial fibrillation, pulmonary veins

Cryoballoon ablation (CBA) of the pulmonary veins (PVs) is approved for symptomatic drug-refractory paroxysmal atrial fibrillation (AF) (Table I). In addition to the established radiofrequency (RF) ablation procedure of the PVs, the Arctic Front and Arctic Front Advance Cardiac CryoAblation balloon catheter (AFC) (Medtronic Inc, Minneapolis, MN, USA) has been approved by the United States Food and Drug Administration (FDA) for catheter therapy of AF.[1,2] A probe with a balloon is introduced across the interatrial septum (IAS) and into the left atrium (LA). The probe and balloon is introduced sequentially into the orifice of each PV, and then inflated (Fig. 1). While within the orifice of each PV, the refrigerant N_2O is introduced into the balloon. Each PV orifice is circumferentially "frozen" with resultant electrical isolation of the PVs from the LA.[3–8]

It is the scope of this review to describe our experience with the first 20 cases with use of continuous monitoring by transesophageal echocardiography (TEE) with a cardiologist (ECHOmd) and senior sonographer to assist the electrophysiologist (EPSmd) in performance of CBA for AF (Table II). TEE has negated the need for intracardiac echocardiography (ICE) (Table III), PV pressure measurements, and reduced the amount of radiopaque contrast agents (ROC) and also fluoroscopy time during the CBA procedure.[8,9]

Address for correspondence and reprint requests: Edmund Kenneth Kerut, M.D., Heart Clinic of Louisiana, 1111 Medical Center Blvd Suite N613, Marrero, Louisiana 70072. Fax: 504-349-6621;
E-mail: kenkerut@gmail.com

Methodology:

Anticoagulants (warfarin or one of the newer oral anticoagulants) are stopped 2 days prior to the procedure. All antiarrhythmic agents are continued. The cryoablation protocol begins with general anesthesia and endotracheal intubation. An arterial line is placed in the radial artery and a thermometry probe placed in the esophagus.[10,11] A TEE probe (Toshiba PET 512MC, Toshiba Aplio 500, Toshiba America, Tustin, CA, USA) is then guided into the mid-esophagus. Initially, the multiple lobes of the left atrial appendage (LAA) are evaluated in at least 2 orthogonal views to rule out the presence of thrombus.

Two short 7 French (Fr) sheaths are placed in the left femoral vein. A 6 Fr decapolar catheter is positioned in the coronary sinus and another 6 Fr decapolar catheter in the superior vena cava (SVC) for phrenic nerve stimulation. Both are placed under fluoroscopic guidance. Intracardiac and surface electrograms are recorded and displayed on an oscilloscope at 100 mm/sec.

An 8 Fr Mullins introducer sheath (Medtronic Inc) is placed in the right femoral vein. Under

TABLE I

Table of Abbreviations

ACT	Activated clotting time
AF	Atrial fibrillation
AFC	Arctic front cardiac cryoablation balloon catheter
ASD	Atrial septal defect
AV	Arteriovenous
CBA	Cryoballoon ablation
CT	Computed tomography
DVT	Deep venous thrombosis
ECHOmd	Echocardiographer
EPSmd	Electrophysiologist
FCAS	FlexCath advance steerable sheath
FDA	Food and Drug Administration
Fr	French
IAS	Interatrial septum
ICE	Intracardiac echocardiography
LA	Left atrium
LAA	Left atrial appendage
LLPV	Left lower pulmonary vein
LPV(s)	Left pulmonary vein(s)
LUPV	Left upper pulmonary vein
LV	Left ventricle
MV	Mitral valve
NavX	EnSite NavX navigation mapping system
PV	Pulmonary vein
RA	Right atrium
RIPV	Right inferior pulmonary vein
RF	Radiofrequency
ROC	Radiopaque contrast
RPV(s)	Right pulmonary vein(s)
RSPV	Right superior pulmonary vein
RSV	Right subclavian vein
SJRS	St. Jude Reflexion Spiral catheter
SVC	Superior vena cava
TEE	Transesophageal echocardiography

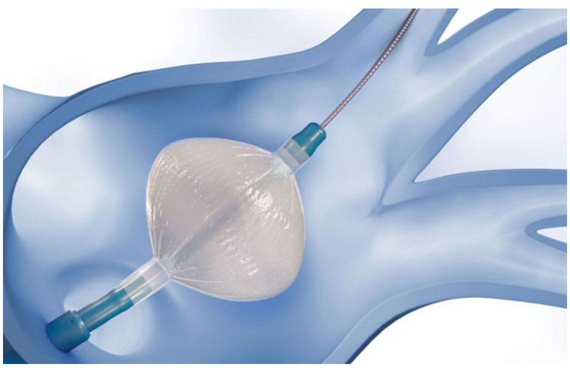

Figure 1. ArcticFront balloon introduced across the IAS within the LA. The balloon is inflated and directed toward the LUPV. (Image courtesy of Medtronic Inc, Minneapolis, MN, USA). IAS = interatrial septal; LUPV = left upper pulmonary vein.

fluoroscopy it is advanced past the right atrium (RA) into the SVC and further up into right subclavian vein (RSV). After the three venous sheaths have been placed a bolus of 100 units/kg intravenous heparin is administered. Throughout the procedure the activated clotting time (ACT) is monitored every 30 minutes and boluses of heparin given to maintain an ACT level between 350 and 400 seconds.

Using both fluoroscopy and TEE guidance the Mullins introducer sheath is pulled back from the RSV to the level of the IAS within the RA. A Baylis needle (Baylis Medical, Montreal, Quebec, Canada) is introduced through the Mullins sheath and abuts the IAS (Fig. 2, movie clip S1). If a patent foramen ovale (PFO) is found by TEE, the

TABLE II

Steps in Which TEE Used during CBA

1	Positioning IAS for puncture or PFO identification
2	Document position catheter/balloon tip in LA
3	Catheter tip avoidance LAA
4	Guidance of AFC into PVs
5	Proper positioning AFC orifice PVs
6	PV occlusion–color Doppler
	Some incomplete occlusions will occlude within 30 seconds CBA
7	Guidance Spiral catheter (electrode) into each PV postablation procedure
	Document electrical isolation of PVs from LA
8	Assess catheter prior to removal
Continuous monitoring:	
Pericardial effusion	
Soft thrombus formation	

IAS = interatrial septal; PV = pulmonary veins; CBA = Cryoballoon ablation; LAA = left atrial appendage; PFO = patent foramen ovale; TEE = transesophageal echocardiography.

TABLE III

TEE Versus ICE during CBA

EPSmd focus on CBA
ECHOmd follow TEE imaging
Probe away from vascular field
ICE
  located in RA –
    thrombus formation
    dislodge position with FCAS manipulation
  Large bore venous introducer –
    risk femoral injury – AV fistula, hematoma, femoral venous thrombosis

FCAS = FlexCath advance steerable sheath; ICE = intracardiac echocardiography; AV = arteriovenous; CBA = cryoballoon ablation; RA = right atrium; TEE = transesophageal echocardiography.

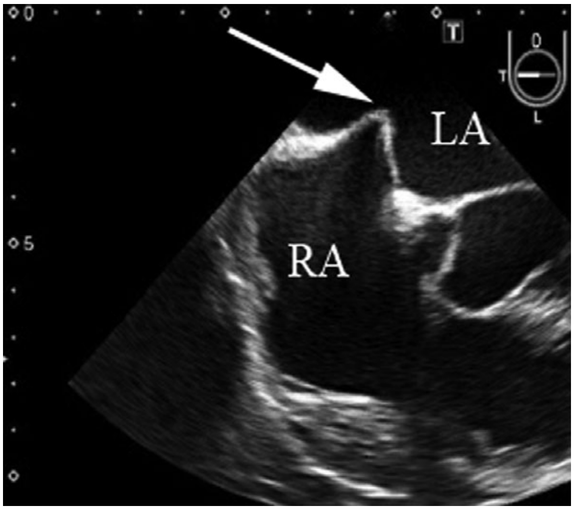

Figure 2. The Baylis needle through the Mullins introducer sheath is pointed toward the IAS (arrow). IAS = interatrial septal.

needle is guided across and into the LA. Otherwise, a small hole is burned through the IAS using a RF source directed to the tip of the Baylis needle (Fig. 3, movie clip S2). The needle is then pushed through this hole into the LA[12] (Fig. 4, movie clip S3). Care is taken not to excessively advance the needle as the Baylis tip tends to enter into the LAA as noted by TEE. Once the Baylis needle has been introduced into the LA, continuous TEE is performed for the remainder of the procedure to monitor for accumulation of pericardial fluid.

The Baylis needle is withdrawn from the Mullins introducer sheath. To verify continued proper position of the Mullins dilator sheath tip within the body of the LA, imaging of the sheath (Fig. 5, movie clip S4) and saline contrast is injected (Fig. 6, movie clip S5), documenting by TEE the presence of saline contrast bubbles within the LA.

A 0.32 Fr J tip guidewire is introduced over the Mullins introducer sheath and then the sheath is withdrawn. Over the guidewire the FlexCath Advance steerable sheath (FCAS) (Medtronic Inc) is introduced, and its tip guided into the body of the LA. Again, TEE is used to document proper tip position within the body of the LA and not the LAA. The guidewire is removed and continuous saline is infused through the lumen.

A St. Jude Reflexion Spiral catheter (SJRS) (St. Jude Medical, St. Paul, MN, USA) is introduced through the FCAS into the LA. Electrical-spatial information is acquired through the EnSite NavX Navigation mapping system (NavX) (St. Jude Medical). This information is merged with a

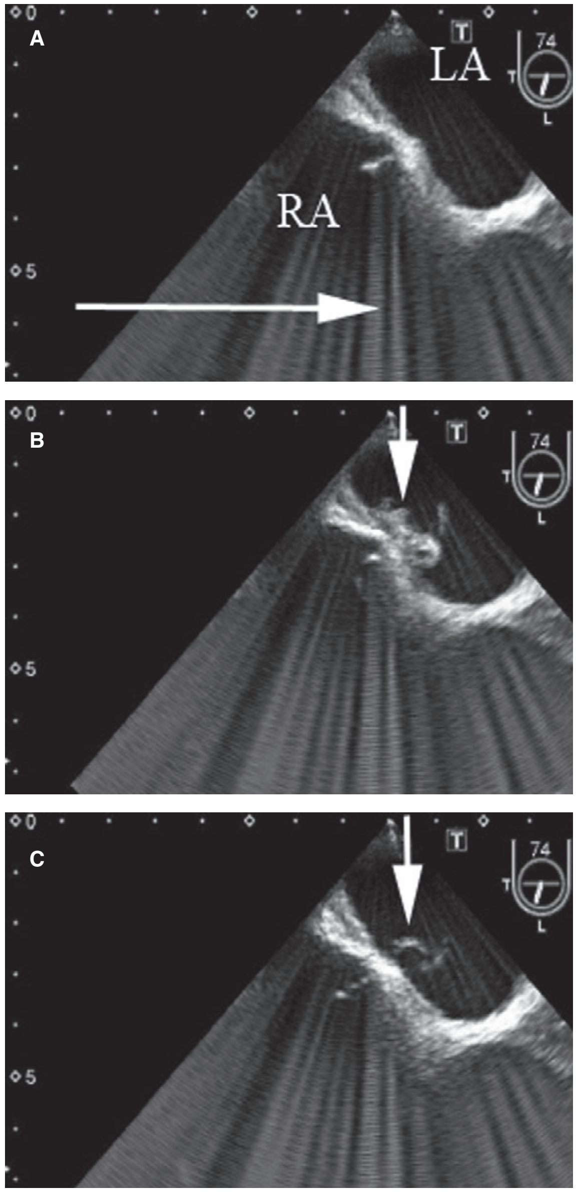

Figure 3. A–C. A hole is burned through the IAS using a RF energy source directed to the tip of the Baylis needle. RF interference is noted (horizontal arrow) during the burn procedure. The image sequence demonstrates a "puff" within the LA as the burn proceeds across the IAS (vertical arrow). IAS = interatrial septal; RF = radiofrequency.

three-dimensional CT (computed tomography) image (previously obtained). Based on this information PV number and anatomy, along with PV sizing is performed. Either a 23 mm or 28 mm AFC is chosen based on this generated image. The SJRS is removed through the sheath and the AFC passed through the sheath over a 0.32 Fr J tip guidewire, into the LA.

Using TEE for guidance the AFC is maneuvered over the guidewire sequentially first into

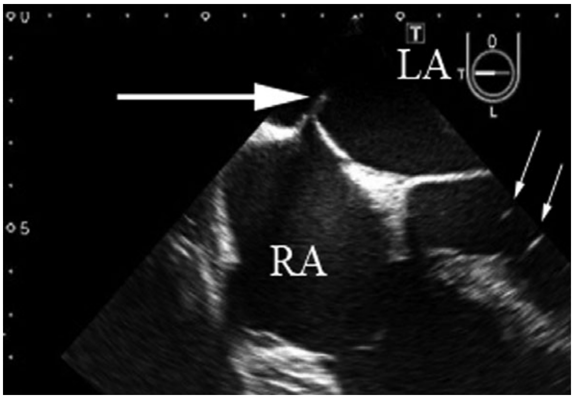

Figure 4. Puncture of the IAS with the Baylis needle (horizontal arrow). Bubbles are noted within the left heart upon puncture (small arrows–seen in left ventricular outflow tract). IAS = interatrial septal.

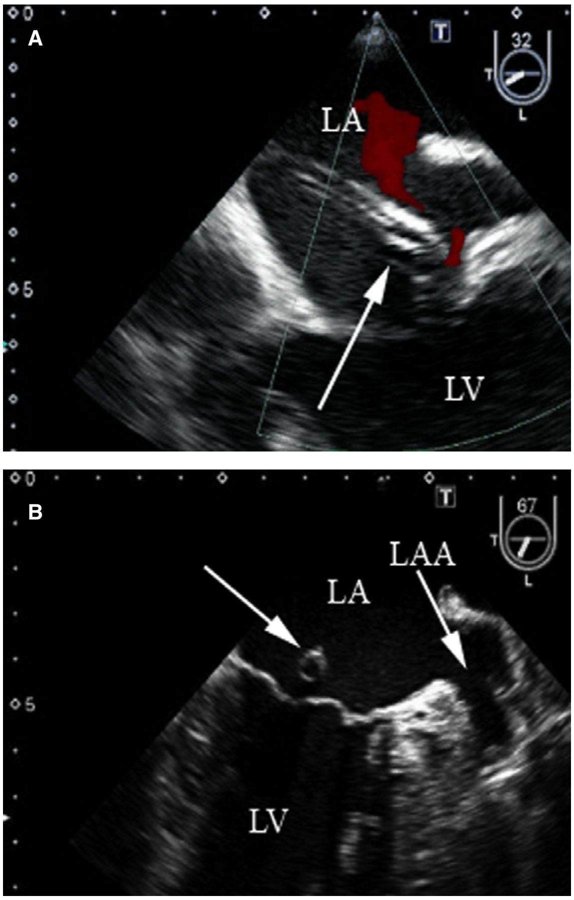

Figure 5. **A**, **B.** Catheter position visualized within the cavity of the LA (arrows).

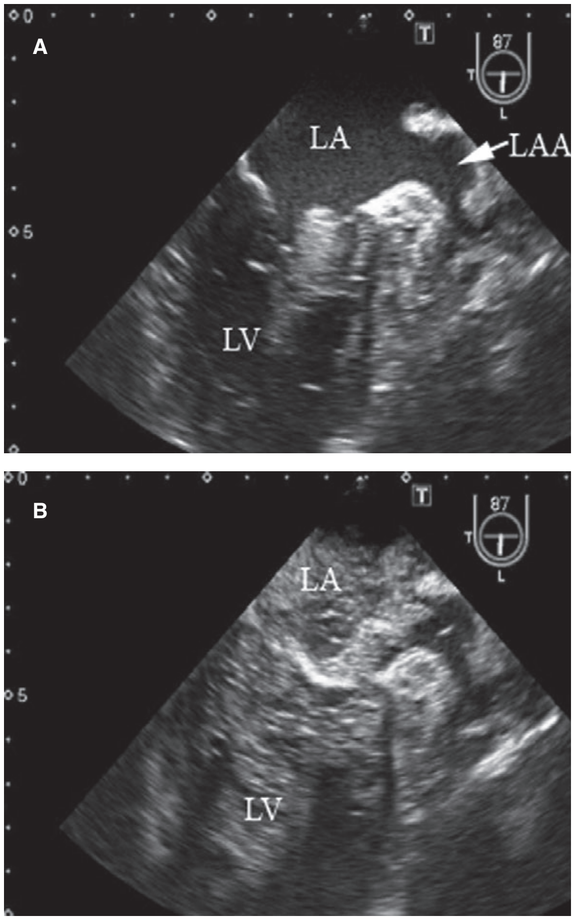

Figure 6. **A**, **B**. Injection of saline to document catheter tip positioning within the body of the LA.

the left superior PV. TEE helps avoid the LAA, as it is often not possible to differentiate positioning of the guidewire within the LAA or left upper pulmonary vein (LUPV) (Fig. 7A,B, movie clip S6). After the LUPV, the guidewire is directed toward the left inferior PV, and then the right superior pulmonary vein (RSPV), and lastly right inferior pulmonary vein (RIPV). Generally, the L PVs are best visualized in the mid-esophagus from about 110°–140° with counterclockwise probe rotation, and the RPVs from about 45°–90° with clockwise probe rotation (Fig. 8A–C, movie clip S7A,B). The left upper and left lower pulmonary veins on occasion will join and enter the LA as a single PV. TEE helps identify previously noted anatomical variations by NavX (location and number of PVs) for the AFC procedure.[13–16] When applying CBA to right-sided PVs, pacing the right phrenic nerve is performed via the SVC pacing catheter.

With direct TEE guidance the AFC is properly positioned as to not enter each PV, but remain just proximal to its orifice. The AFC is inflated and PV occlusion documented when flow by color Doppler no longer is seen around the inflated balloon. ROC is injected through the tip of the

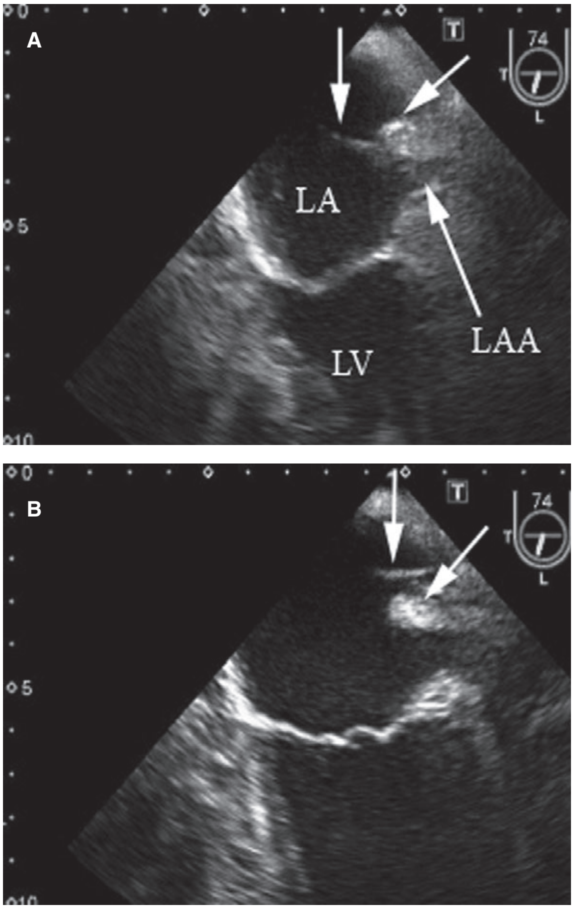

Figure 7. A, B. Transesophageal echocardiography (TEE) documentation of guidewire/catheter tip positioning (vertical arrow). Radiopaque contrast is given to observe position by fluoroscopy, but often differentiation of position within the left atrial appendage (LAA) or LUPV with fluoroscopy is not possible. The guidewire/catheter tip is in (A) the LAA, and (B) LUPV. It is paramount to not confuse the LAA as the LUPV, as perforation of the LAA may occur. (Oblique arrow points toward bulbous ridge between the LAA and LUPV). LUPV = left upper pulmonary vein.

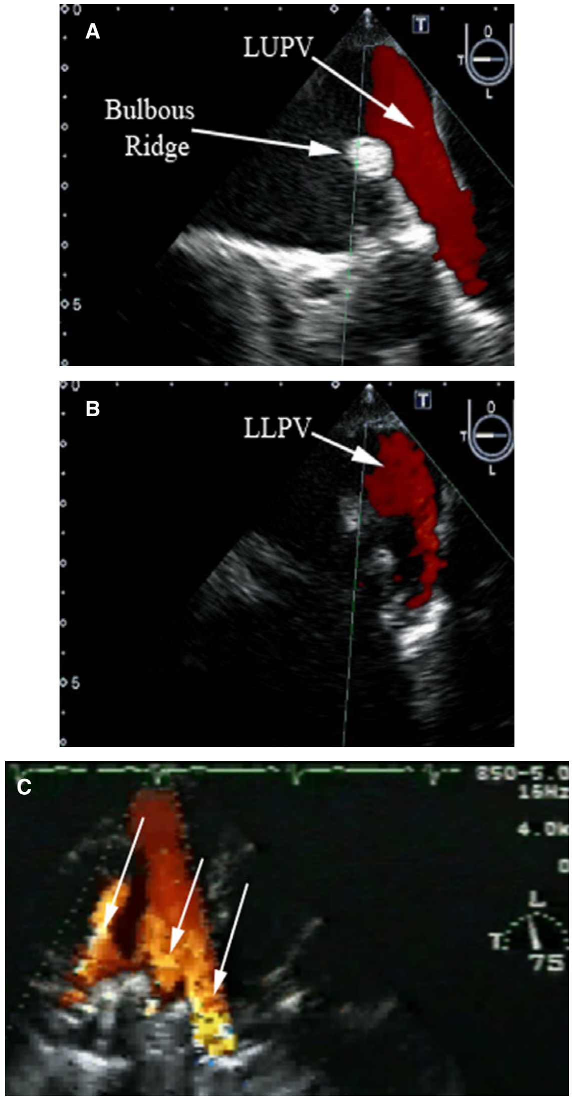

Figure 8. A–C. Transesophageal echocardiography (TEE) with color Doppler for visualization of (A) the LUPV and (B) LLPV. Left PVs generally are best visualized in the mid-esophagus from about 110°–140° with counterclockwise probe rotation. The LUPV is first visualized with the left atrial appendage (LAA) and bulbous infolding serving as landmarks. Advancing the probe will help bring the LLPV into view. The RPVs are visualized from about 45°–90° with clockwise probe rotation. With this image (C) there are three separate RPV-LA ostia. LUPV = left upper pulmonary vein.

AFC. If there is complete PV occlusion noted by TEE, then ROC injection has always been noted to suggest PV occlusion also. However, on occasion, it appears that the PV is occluded using ROC, but TEE documents incomplete occlusion of the PV. On occasion we will "accept" less than complete occlusion as noted by TEE. Often complete occlusion will then occur within the first 30 seconds of the CBA procedure. One should note a drop in the temperature curve to -30°C within these 30 seconds with proper AFC positioning at the PV orifice. If occlusion does not occur within 30 seconds, the CBA procedure is stopped and the AFC is readjusted. Based on the temperature curve, CBA will be performed for 3–4 minutes. CBA is performed twice within each PV. Also, during the CBA procedure we routinely visualize what appears to be ice formation within the blood surrounding the AFC. As of this date, for the first 20 patients, we have had 100% (80/80) success in localizing all PVs and 98.75% (79/80) success in CBA of each PV (Figs. 9A–D and 10A–F, movie clip S8 A–D and S9 A–E). In this initial cohort, the single PV not successful with CBA was a LUPV. RF ablation was successful in this PV with the SJRS.

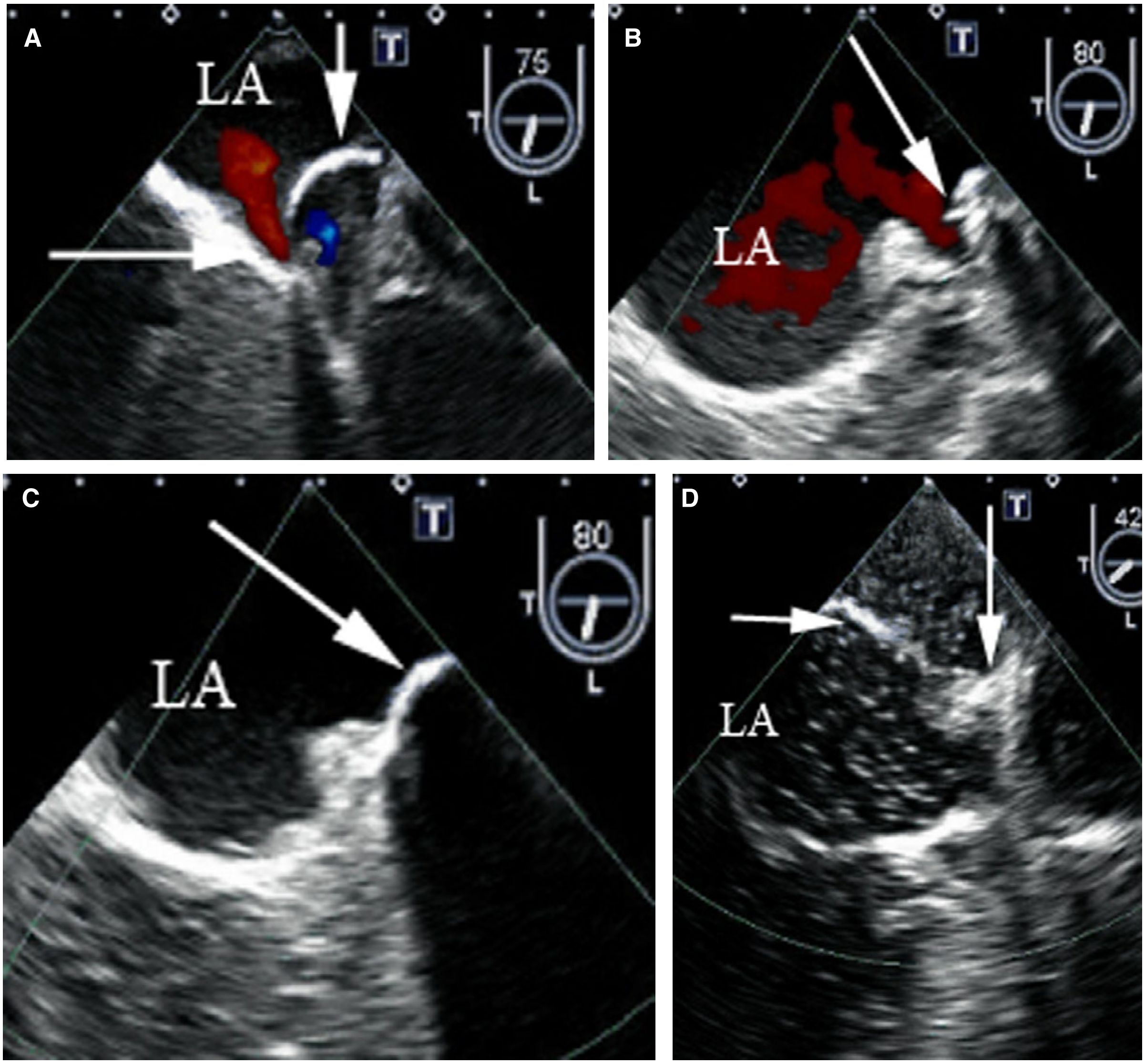

Figure 9. A–D. Example of the sequence of cryoballoon ablation (CBA) demonstrated within the LUPV. The AFC (vertical arrow) is (A) inflated within the LUPV. A small leak appearing as a small red "flame" is noted between the AFC and RUPV wall (horizontal arrow). The AFC is (B) deflated (arrow) and then its position readjusted and (C) reinflated (arrow), demonstrating a complete seal between the AFC and wall of the PV. With deflation (D) of the AFC (vertical arrow) what appears to be ice streaming from around the AFC is noted within the LA. The catheter shaft within the LA (horizontal arrow) is noted. LUPV = left upper pulmonary vein.

When CBA has been completed in the PVs the AFC is removed through the FCAS, and the SJRS reinserted to obtain PV electrograms. TEE helps find the ostium of each PV to evaluate for PV electrical potential disappearance (entrance block). Each PV is also paced to make sure no electrical conductance to the LA occurs (exit block) (Fig. 11, movie clip S10). The SJRS catheter is then removed followed by the FCAS. A residual small restrictive iatrogenic atrial septal defect (ASD) is invariably visualized upon removal of the AFC and FCAS from the LA (Fig. 12, movie clip S11).

Discussion:

Our electrophysiology and echocardiography laboratories have worked in unison for CBA of AF. We have found TEE monitoring to be advantageous to that of ICE monitoring for several reasons (Table III). A ECHOmd and senior sonographer perform TEE monitoring to assist the EPSmd during the entire procedure. Previously, use of ICE for manipulation and imaging/monitoring required the attention of the EPSmd while performing the CBA procedure. As the ICE catheter is located within the RA, it would often become dislodged from its imaging position as

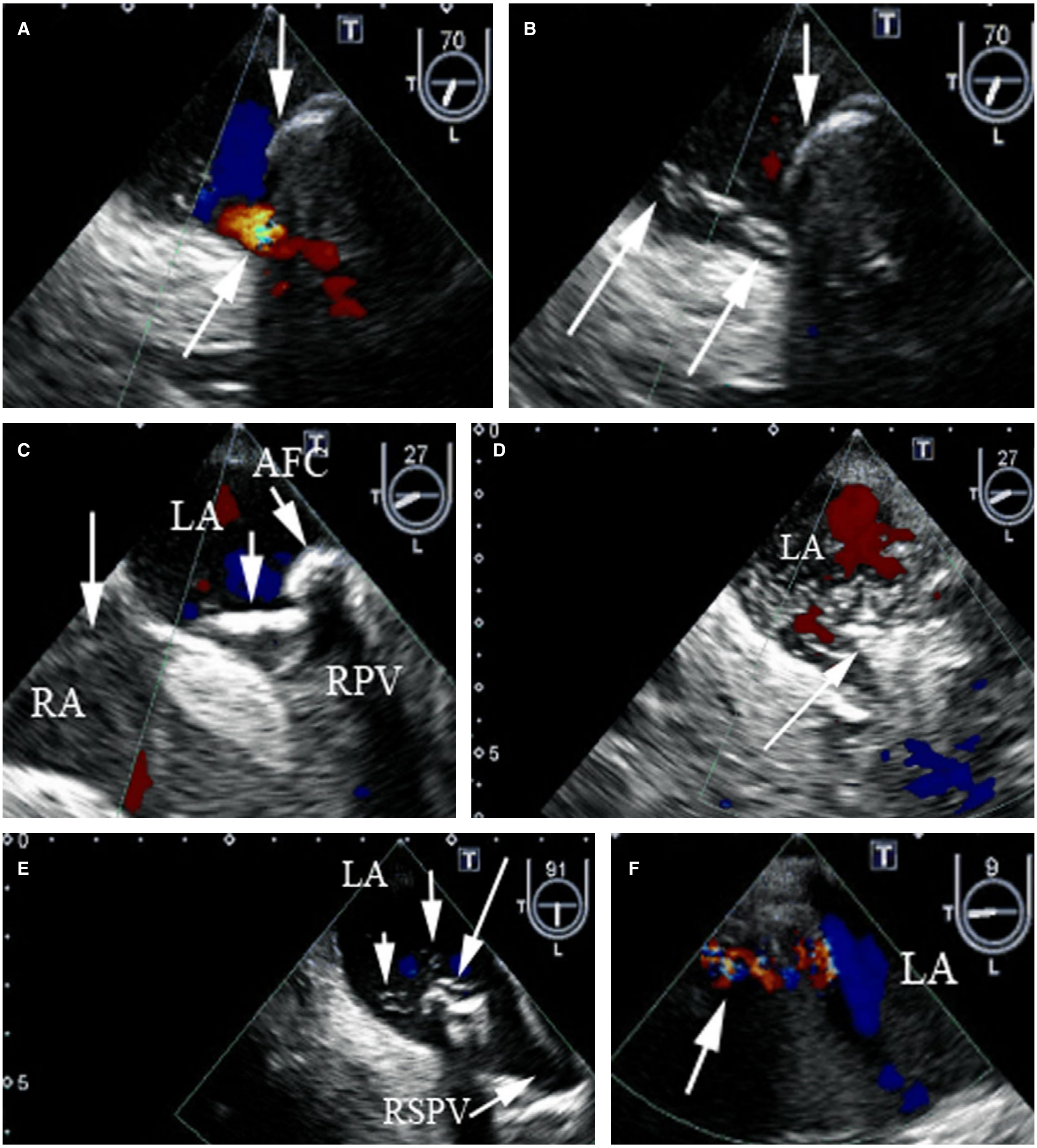

Figure 10. A–F. Sequence of cryoballoon ablation (CBA) within the RPVs. The (A) RUPV is incompletely sealed (oblique arrow) by the AFC (vertical arrow), but the CBA procedure performed. What appears to be (B) ice (oblique arrows) is noted to stream from the area of incomplete AFC-PV closure. Within 30 seconds of initiating CBA (C) the AFC-PV seal is complete. At this TEE angle (27°) the catheter (vertical arrows) is visualized across the IAS and the inflated AFC (oblique arrow) well visualized. As the (D) AFC is deflated (arrow) there is initially a large amount of presumptive ice noted within the LA. Upon (E) slight pullback of the AFC (oblique arrow) presumptive ice is noted (vertical arrows) emanating from the surface of the AFC. During the CBA procedure, when the AFC balloon is (F) inflated the refrigerant N_2O is noted by TEE as a color mosaic pattern (arrow) within the balloon. IAS = interatrial septal; TEE = transesophageal echocardiography.

the Mullins sheath with Baylis catheter were positioned to cross the IAS. Also, imaging of the LA was not optimal, particularly to assess for inadvertent catheter positioning in the LAA, and for guiding catheters into the PVs. Continuous monitoring for development of a pericardial effusion

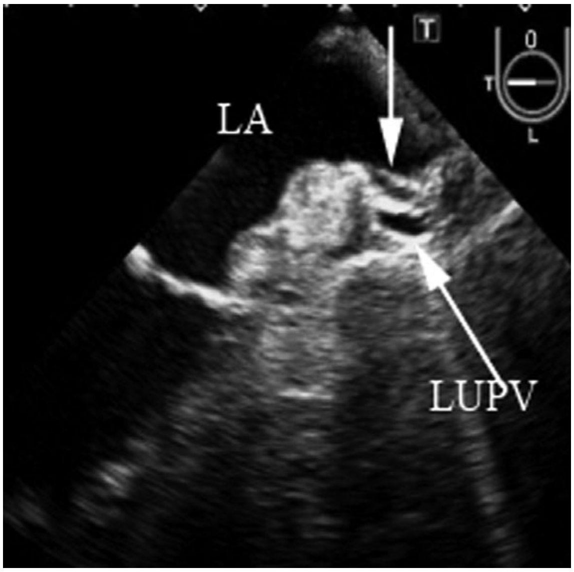

Figure 11. Transesophageal echocardiography (TEE) helps localize each of the PVs for insertion of the St. Jude Reflexion Spiral catheter (SJRS) (arrow) to obtain PV electrograms.

was also difficult. As the ICE catheter is used only once, use of TEE represents a cost savings. Use of ICE requires insertion of a large bore venous sheath, with complications in our laboratory of 2 cases of femoral deep venous thrombosis (DVT) and a femoral arteriovenous (AV) fistula.

With the advent of TEE monitoring we have noted occasional soft thrombus formation on catheters within the RA and also LA (Fig. 13, movie clip S12). When this occurs, often the ACT has dropped below therapeutic range. Thrombus has always "melted" by TEE with an intravenous heparin bolus. During the CBA procedure we continuously monitor for intracardiac thrombus and also development of a pericardial effusion.

Importantly, TEE allows for excellent visualization of catheter tip location and avoidance of the LAA. With fluoroscopy the tip often appears to be in a PV, but by TEE its true location in the LAA is noted. Guidance of the J tip guidewire and AFC is performed under TEE guidance for finding each PV orifice and for proper positioning. Balloon inflation positioning and documentation of PV occlusion with color Doppler is performed with TEE for each PV.

Routinely we visualize what may be either ice formation or dissolved gas coming out of solution (blood temperature locally changes from $-30^{\circ}C$ to body temperature with resultant gas bubble formation–Henry's Law), from around the AFC during and immediately following the CBA procedure. We are unaware what clinical significance, if any, this represents.

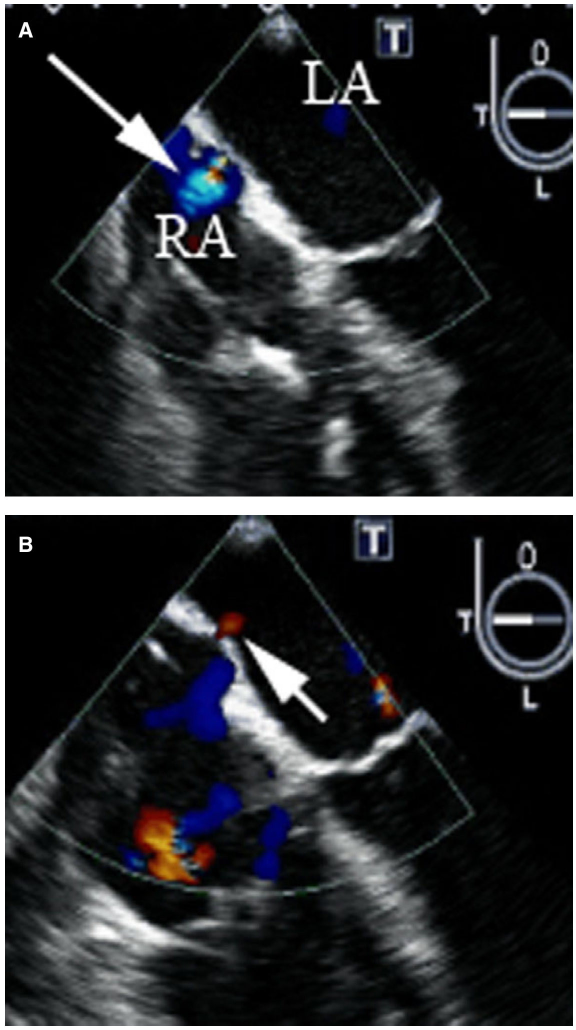

Figure 12. A residual **A.** small iatrogenic restrictive atrial septal defect (ASD) (arrow) is visualized upon removal of the AFC and FCAS from the LA. In this patient a brief **B.** right to left shunt direction is also noted (arrow). FCAS = FlexCath advance steerable sheath.

Conclusion:

Our electrophysiology laboratory has been performing CBA of the PVs for AF using TEE monitoring in conjunction with the echocardiography laboratory. TEE has been instrumental in facilitation of each step in the CBA procedure and in prevention of complications.

In our experience, TEE has had an advantage over that of ICE, in that ICE requires a large bore venous introducer and is located in the RA. With the large bore venous introducer we have had complications including AV fistula formation and femoral DVT. We have noted thrombus formation on the ICE catheter and also dislodgement of ICE imaging position during manipulation of the FCAS. In addition, the use of TEE with the

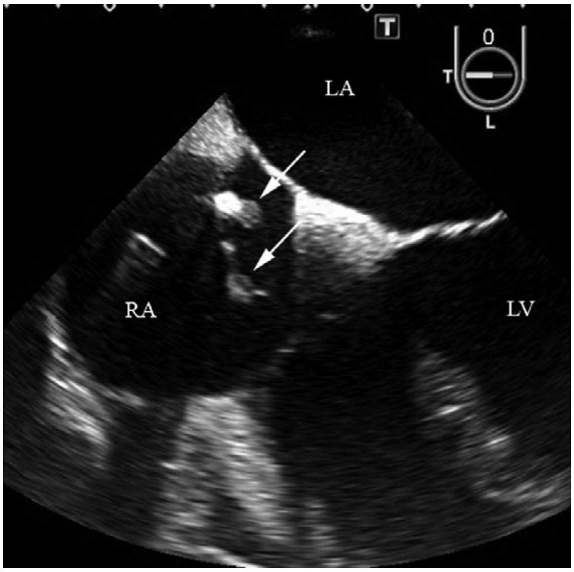

Figure 13. Thrombus formation (arrows) noted on catheters within the right atrium (RA).

ECHOmd has allowed the EPSmd to "focus" on the ablative procedure.

Use of TEE monitoring has resulted in a perceived reduction of ROC and fluoroscopy time. It readily allows for continuous monitoring for development of pericardial effusion and soft thrombus formation.

Particularly, we have found TEE monitoring to be helpful with positioning for IAS puncture, catheter tip avoidance of the LAA, guidance of the AFC into each PV, proper AFC positioning within each PV orifice, and documentation of PV occlusion for the CBA procedure.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Movie clip S1. The Baylis needle through the Mullins introducer sheath is pointed toward the IAS.

Movie clip S2. A hole is burned through the IAS using a RF energy source directed to the tip of the Baylis needle. RF interference is noted during the burn procedure. A "puff" within the LA is noted as the burn proceeds across the IAS.

Movie clip S3. Puncture of the IAS with the Baylis needle. Bubbles are noted within the LA upon puncture.

Movie clip S4. Catheter position visualized within the cavity of the LA with **A.** longitudinal view and **B.** transverse imaging of the catheter. The catheter tip is above the plane of the MV.

Movie clip S5. Injection of saline to document catheter tip positioning within the body of the LA.

Movie clip S6. TEE documentation of guidewire/catheter tip positioning. Radiopaque contrast is given ("puffs" of contrast noted by TEE) to observe position by fluoroscopy, but often differentiation of position within the LAA or LUPV with fluoroscopy is not possible. The guidewire/catheter tip is in **A.** the LAA, and **B.** LUPV.

Movie clip S7. TEE with color Doppler for visualization of **A.** the LUPV and **B.** LLPV. Left PVs generally are best visualized in the mid-esophagus from about 110°–140° with counterclockwise probe rotation. The LUPV is first visualized with the LAA and bulbous infolding serving as landmarks. Advancing the probe will help bring the LLPV into view. The RPVs are visualized from about 45°–90° with clockwise probe rotation. With this image **C.** there are three separate RPV-LA ostia.

Movie clip S8. Example of the sequence of CBA demonstrated within the LUPV. The AFC is **A.** inflated within the LUPV. A small leak appearing as a small red "flame" is noted between the AFC and RUPV wall. The AFC is **B.** deflated and then its position readjusted and **C.** reinflated, demonstrating a complete seal between the AFC and wall of the PV. After the CBA procedure the balloon is **D.** deflated and what appears to be ice is routinely noted.

Movie clip S9. Sequence of CBA within the RPVs. **A.** The RUPV is incompletely sealed by the AFC, as evidenced by the red "flame" between the AFC and PV. The CBA procedure is performed. What appears to be ice is noted to stream from the area of incomplete AFC-PV closure. Within 30 seconds of initiating CBA **B.** the AFC-PV seal is complete. At this TEE angle (27°) the catheter is visualized across the IAS and the inflated AFC well visualized. **C.** As the AFC is deflated (arrow) there is initially a large amount of presumptive ice noted within the LA. **D.** Upon slight pullback of the AFC presumptive ice is noted emanating from the surface of the AFC. During the CBA procedure, when the AFC balloon is **E.** inflated the refrigerant N_2O is noted by TEE as a color mosaic pattern within the balloon.

Movie clip S10. TEE helps localize each of the PVs for insertion of the SJRS in order to obtain PV electrograms.

Movie clip S11. A residual small iatrogenic restrictive ASD (arrow) is visualized upon removal of the AFC and FCAS from the LA. In this patient a brief right to left shunt direction is also noted.

Movie clip S12. TEE helps localize each of the PVs for insertion of the SJRS to obtain PV electrograms.