Catheter Ablation of Atrial Fibrillation Without Fluoroscopy Using Intracardiac Echocardiography and Electroanatomic Mapping

Ferguson: AF Ablation Without Fluoroscopy

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Abstract

**Background**: Catheter ablation of atrial fibrillation (AF) is currently guided by X-ray fluoroscopy. The associated radiation risk to patients and medical staff may be significant. We report an AF ablation technique using intracardiac echocardiography (ICE) and electroanatomical mapping (EM) without fluoroscopy.

**Methods and Results**: Twenty-one patients with AF (age 42-73 years, 14 male, 14 paroxysmal, 7 persistent, BMI 26-38) underwent ablation. A decapolar catheter was advanced via the left subclavian vein until stable coronary sinus electrograms appeared on all electrodes. Two 9F sheaths were advanced transfemorally over a guide wire to the right atrium. A rotational ICE catheter was advanced through a deflectable sheath. Double transseptal puncture was performed with ICE guidance and facilitated by electrocautery. A 3D MRI left atrial image was registered to the ostia of the pulmonary veins using ICE. Catheter ablation was performed using ICE and EM navigation. In 19 cases, no fluoroscopy was used and the staff did not wear protective lead. In 2 cases, 2-16 mins of fluoroscopy was used to assist transseptal puncture. Median procedure time was 208(188-221) mins; CS cannulation took 5(2-26) mins, double transseptal took 26(17-40) mins; left atrial ablation time 103(90-127) mins. All patients underwent circumferential PV ablation and 8 patients underwent additional left atrial ablation. There were no procedure related complications.

**Conclusions**: Catheter ablation of AF without any fluoroscopy is feasible and merits further attention. This technique may be especially helpful in preventing X-ray exposure in children, pregnant women and obese patients undergoing left atrial ablation.

**Key words**: atrial fibrillation, catheter ablation, fluoroscopy, radiation risk
Introduction

Catheter ablation of atrial fibrillation (AF) requires careful, and often difficult, manipulation of electrophysiological catheters within the left atrium (LA). Conventionally, these catheters have been guided by fluoroscopy. Typical cases last from 3-4 hours, and often longer. Patients and medical staff are exposed to significant radiation. In addition, AF patients frequently undergo CT scans, cardiac catheterization and repeat ablation procedures thus accumulating even greater radiation exposure with time. Recent advances in electroanatomical mapping (EM) systems and intracardiac echocardiography (ICE) techniques have facilitated catheter manipulation within the LA but have reduced and not eliminated fluoroscopy exposure.

We have developed a technique to perform catheter ablation of AF using ICE and EM with no fluoroscopy for the entire case. We report the technique and initial procedural results.

Methods

Study design

This was a prospective observational study of 21 consecutive patient referred for catheter ablation of AF at the University of Virginia Atrial Fibrillation Center. All patients underwent cardiac MRI imaging pre procedure and a segmented 3D image was used to
facilitate catheter manipulation. The procedure was performed under conscious sedation with midazolam and fentanyl. Patients were admitted for overnight observation and telemetry post procedure. The protocol was approved by the University of Virginia Institutional Review Board and all patients signed informed consent.

**Procedure**

Venous access was obtained from both femoral and the left subclavian veins using standard Seldinger puncture. Ultrasound was not used for percutaneous venipuncture. A pre curved decapolar catheter (CSL™, St Jude, Minnetonka, MN) was advanced via the left subclavian to the right atrium. Once atrial electrograms were seen on the distal poles, the catheter was rotated counter clockwise and advanced until atrial and ventricular electrograms were seen, first on the distal electrodes and then on all 5 bipoles (Fig. 1). This catheter could be seen moving in real time as a virtual electrode on the screen of the EM system (EnSite NavX™, Endocardial Solutions, Inc., MN; system reference used) in the left anterior oblique and right anterior oblique projections (Fig. 1). A posterior and superior orientation of the virtual catheter helped to confirm placement in the coronary sinus, rather than in the greater cardiac vein or simply curled around the tricuspid annulus. In addition, a shadow was used to mark the location of this coronary sinus electrode on the screen and ensure that it was stable prior to ablating within the left atrium.

Two 9F sheaths (55° Convoy, Boston Scientific, MA; Agilis™ deflectable, St Jude Medical, MN) were then advanced via both femoral veins over a guide wire to the right
atrium. Prior to insertion of these sheaths, the distance from the femoral puncture to the mid sternum was measured to estimate the distance to the right atrium. The long sheath was advanced this length over the guide wire. The dilator and guidewire were removed and the ICE catheter (9 French UltraICE™, Boston Scientific, Natick, MA) was advanced through the deflectable Agilis™ sheath until the catheter tip was protruding just beyond the tip of the sheath. The length of ICE catheter to advance could be measured against the dilator of the sheath. Also, the sudden improvement of the ultrasound image once transducer was free in the blood pool and no longer imaging through the sheath indicated that the catheter had been sufficiently advanced beyond the tip of the sheath. After this the ICE catheter and deflectable sheath were generally manipulated as a single unit. If there was any resistance to the smooth passage of these sheaths towards the right atrium, the dilator and guidewire were removed and replaced with the ICE catheter. The sheath could then be rotated and flexed using ICE guidance to direct the sheath away from small side branches and into the right atrium (Fig. 2).

The ICE catheter was then advanced from the right atrium to the superior vena cava and the innominate vein (Fig. 3). ICE was used to position the tip of the other sheath in the left innominate vein ready for pullback to the fossa ovalis. This was achieved by first visualizing the guidewire and then the characteristic pattern of the sheath in this vein. The precise location of the tip of the second sheath could be confirmed by withdrawing it out of the imaging plane of the ICE and then advancing it back into the image so that it could just be seen. The ICE catheter was then withdrawn to the fossa ovalis. The second sheath with a Brockenborough needle was pulled back from the superior vena cava until
it could be seen tenting the fossa (Fig. 4). Transseptal puncture was performed using ICE guidance and continuous pressure monitoring. The Brockenborough needle was advanced until left atrial pressures were obtained and the tip of the needle was seen in the left atrium. If the needle did not cross to the left atrium with gentle pressure, electrocautery was used to facilitate transseptal puncture and avoid excessive force and potential complications (Fig. 4E). The sheath was advanced over the Brockenborough needle and dilator under ICE guidance. The ICE catheter was then used to position the first sheath, still in the right atrium, in the left innominate vein. The ICE catheter was then switched to the sheath in the left atrium and advanced so that the fossa could be imaged through this sheath to guide the second transseptal puncture. After the second transseptal puncture, an ablation catheter was advanced to the left atrium and could be guided to all four pulmonary veins and the mitral annulus using ICE guidance and EM (Fig 5 and Video Supplement 1). We have previously described the use of ICE to help guide AF ablation although fluoroscopy was also used in those studies. The ACT was maintained between 300 and 350 seconds using unfractionated heparin whilst catheters were in the left atrium.

Electroanatomical Mapping

A 3D image segmented from the cardiac MRI was used to facilitate navigation in all patients. The segmented image was registered to the pulmonary veins using ICE to confirm fiducial markers. Fiducial markers on the mitral annulus were located using ICE and typical mitral annulus electrograms. After registration, ablation was performed and lesions were marked on the 3D image (Fig. 5). We have previously described imaging of
the esophagus during AF ablation with rotational ICE. In summary, the location of the esophagus can be clearly visualized with ICE and its location and the thickness of the left atrium was considered when choosing ablation parameters for the posterior wall. The relationship of the ablation catheter tip to the esophagus could be continuously monitored during energy delivery and power could be interrupted if the ablation tip inadvertently moved too close to the esophagus (Fig. 5).

**Ablation**

A 3.5mm irrigated-tip ablation catheter (Celsius ThermoCool™, Biosense Webster, Diamond Bar, CA) with power set at 25W on the posterior wall, 30W on the anterior wall, flow rate of 17mls per minute for all cases. Ablation was performed using continuous drag lesions until there was complete elimination of the local electrogram. Confirmation of pulmonary vein isolation was performed once sinus rhythm was restored. The ablation catheter was advanced 5-10 millimeters into the vein and swept around the entire circumference of the vein to check there was no electrograms within the vein. We then paced from the tip of the ablation catheter at multiple sites to confirm that there was no atrial capture. A circumferential mapping catheter was not used.

In patients with persistent AF after pulmonary vein isolation, stepwise ablation was performed in the following order: left atrial roof line, ablation of complex fractionated potentials, mitral isthmus ablation, tricuspid isthmus ablation, coronary sinus ablation. Mitral annular block was assessed using differential pacing using the ablation catheter.
and the coronary sinus decapolar catheter. The ablation catheter was manipulated using NavX and ICE guidance.

At the end of ablation a full electrophysiology study was performed. Quadripolar catheters were advanced to the high right atrium, His position and right ventricular apex and their positions were confirmed with electrograms and EM. No additional ablation was required after the study. At the end of the EP study, the ICE catheter was advanced to the left ventricle to image the pericardial space to exclude a pericardial effusion.

**Follow up**

Following sheath removal the patients were observed overnight. Warfarin was restarted and they were given enoxaparin 1mg/kg for 2 doses then 0.5mg/kg for 4 doses. Patients were seen at 1, 3, 6 and 12 months post ablation. A 12 lead ECG was performed at clinic visits and a continuous 24 hour ECG was performed at 3, 6 and 12 months post ablation. Additional holter ECG’s were performed if patients had symptoms between clinic visits.

**End Points**

This was an observational study of the acute procedural outcomes of AF ablation without fluoroscopy. We measured total fluoroscopy time, procedure time from first stick to sheath removal, coronary sinus cannulation time from insertion of catheter into the subclavian sheath to confirmation of electrograms and a posterior position on EM, transseptal time from insertion of the sheaths into the femoral vein to completion of the
second transseptal, left atrial catheter manipulation time, right atrial catheter manipulation time and complications.

Statistics

Continuous variables are expressed as a median (range).

Results

This technique was attempted in 21 patients with AF. Their median age was 63 (42-73) years, 14 male, and their body mass index was 29 (26-38). Fourteen patients had paroxysmal AF and 7 had persistent AF. Procedural outcomes are summarized in Table 1. In 19 cases, no fluoroscopy was used and the staff did not wear protective lead. In 2 cases (case number 2 and 4 in the series) 2-16 mins of fluoroscopy was used to assist transseptal puncture. The median procedure time was 208(188-221) minutes; coronary sinus cannulation took 5(2-26) minutes; double transseptal took 26(17-40) minutes; left atrial catheter manipulation took 103(90-127) minutes; right atrial catheter manipulation took 16(12-22) minutes; the electrophysiology study took an additional 14(8-23) minutes. All patients underwent circumferential pulmonary vein ablation, 7 had left atrial roof ablation, 4 had mitral isthmus ablation, 8 had cavo-tricuspid isthmus ablation and 3 had ablation within the coronary sinus. One of the transseptal sheaths dislodged but was successfully repositioned in 3 cases. There were no procedure related complications. After 7(2-11) months follow-up, 16/21 (76 percent) patients were free of recurrent AF off antiarrhythmic medications.
Discussion

We have shown that catheter ablation of AF can be performed in both paroxysmal and persistent patients with no fluoroscopy. This procedure included double transseptal puncture, ablation around the pulmonary veins and in some patients, ablation of the left atrial roof, mitral isthmus, coronary sinus or tricuspid isthmus. There were no complications.

Radiation Risks of AF Ablation

The radiation exposure to the patients should be considered. The advances in very low frame-rate pulsed fluoroscopy have significantly helped to reduce the risks of radiation even in AF ablations with relatively long fluoroscopy times. The predicted excess risk of fatal malignancies is 0.07 percent in women and 0.1 percent in men. Nevertheless, the life time accumulated exposure to radiation in AF ablation patients may be significant given the radiation from CT scans, nuclear studies, heart catheterizations and repeat ablation procedures. The risk of this accumulated exposure has not been quantified.

Certain patient groups may be more vulnerable to radiation risks. Obese patients whose dose requirement roughly doubles for each 3.5 centimeters of soft tissue are at particular risk. The acute risk of radiation induced skin ulceration is a well recognized although rare complication of excessive fluoroscopic exposure during radiofrequency catheter ablation. This is extremely difficult to treat. A limitation on maximum delivered dose can be set to prevent this complication in prolonged procedures such as AF ablation.
Children and pregnant women may require ablation within the left atrium, usually for indications other than AF. The radiation risk of complex ablation in children is higher than adults. They are more sensitive to the certain cancers, they often undergo repeat procedures and they have a longer life expectancy to manifest radiation induced cancer. The efforts to significantly reduce fluoroscopic times by pediatric electrophysiologists are documented below. Pregnant woman are particularly at risk and ablation procedures are generally avoided during pregnancy.

Physicians and medical lab staff who accumulate significant X-ray exposure with multiple procedures over time may be at even greater risk than patients. Fluoroscopy times for catheter ablation of AF vary widely in published studies. Early reports of pulmonary vein isolation reported a mean total fluoroscopy time of 148±34 minutes. In a subsequent study the same group reported fluoroscopy times of 50±17 minutes for segmental ostial ablation and 39±12 minutes for left atrial circumferential ablation reflecting their increased experience. Haisseguerre has reported a fluoroscopy time of 84±30 minutes for termination of persistent AF targeting multiple sites within the left atrium. In another study of persistent AF, Schilling reported a shorter mean fluoroscopy time of 50±24 minutes using non fluoroscopic mapping. In general, the savings in total radiation from non fluoroscopic mapping have only been marginal given the additional radiation of pre ablation CT scans and registration of these images during the procedure. Robotic catheter navigation has the potential to reduce fluoroscopy. Saliba reported a mean fluoroscopy time of 64±33 min using a steerable sheath system and Pappone 32.3±11 minutes using the remote magnetic system.
automation of robotic navigation, fluoroscopy will be further reduced. With both these robotic systems the major reduction in radiation is for the physician performing the procedure in a shielded console. Nevertheless the physician must obtain venous access and also intermittently manipulate other catheters during the case. Consequently, physician fluoroscopy exposure is minimal, not zero. The patient and medical staff within the room are still exposed to significant radiation. The lowest reported fluoroscopy times for AF ablation are in a study which also used rotational ICE and 3D mapping. Schwartzman completed 200 AF ablation cases with an impressive mean fluoroscopy time of 6±2 minutes 17.

The variation in fluoroscopy times in the above studies, are likely to be even greater in routine clinical practice. These differences likely reflect variations in experience, technique and technology such as ICE and non fluoroscopic mapping. Difference in x-ray equipment, radiation protection and distance from radiation source during cases will result in variation of total dose absorption. Where then should the radiation safety limit be drawn?

A recent study of 182 electrophysiology labs showed that a procedure requiring 40 min of fluoroscopy yields a maximum effective dose of 129 mSv and a maximum value of gonadal dose of 56.8 mSv to staff using a 0.35 mm lead-equivalent apron 8. A conservative estimate of the electrophysiologist’s annual maximum permissible workload based on the annual limit of 20mSv is 155 of such procedures. Staff effective dose values varied by a factor of 40 due to positioning during fluoroscopy and by a factor of 11 due to
radiation protection equipment. As shown above, AF procedures may use more than 40 minutes of fluoroscopy. Together with other x-ray intensive procedures such as cardiac resynchronization therapy, it is likely that many operators perform more than 155 prolonged fluoroscopy cases per year and exceed these recommended radiation limits. These physicians will have a small increased risk of cancer, cataracts and genetic abnormalities conferred on their children. The increased incidence of neck and back pain from wearing lead for prolonged periods is another significant occupational hazard 18.

Previous Studies on Reducing Fluoroscopy

In 2002, Drago and colleagues reported using no fluoroscopy in 9/21 pediatric patients with right sided accessory pathways using a single catheter and the CARTO system 19. Grubb reported using a non fluoroscopic technique in 76 patients with right atrial SVT ablation and, using the NavX system, managed to completely eliminate fluoroscopy in 90 percent of cases 20. The median radiation dose for left sided accessory pathways was 1692 cGy cm². The ability of NavX to display any catheter as a virtual electrode on a 3D mapping system has been used to perform ablation without fluoroscopy by Clark 21 and Smith 22. They have reported right and left atrial ablation without the use of fluoroscopy in children. Their procedures were guided by NavX and transsesophageal echocardiography, not intracardiac echo. They performed a right atrial geometry with the catheter prior to transseptal puncture and used the transsesophageal echo to confirm the location of the transseptal needle first in the left subclavian and then tenting the fossa. Their left atrial procedures involved mapping and ablation of accessory pathways and not
AF. Tuzcu has reported a similar technique using NavX to perform right sided SVT ablations without fluoroscopy in children.23

Development of Technique
The development of this technique has evolved over several years while accumulating experience in ICE catheter manipulation and electroanatomical mapping. We worked on developing non fluoroscopic techniques for individual steps of the procedure over several years until we were confident enough to perform all steps of AF ablation without fluoroscopy. We did not experience an increase in complications during this learning period. Our understanding of the anatomical landmarks as seen on ICE has been helped by incorporating 3D images into the mapping system. These images help to alert the physician to the number, location, size and orientation of the pulmonary veins. Left atrial landmarks which are routinely used to assist in left atrial navigation include the mitral valve, the coronary sinus and the left atrial appendage. The location of the metal tip of the catheter can be clearly and continuously monitored using rotational ICE. The right superior pulmonary veins with adjacent SVC and pulmonary artery and the right inferior pulmonary veins with adjacent esophagus can also be clearly distinguished. The use of electrocautery to assist with difficult transseptal punctures is important to this technique. With electrocautery, very little pressure is required to advance the needle into the left atrium and it has virtually eliminated the potential jump of the Brockenborough needle across into the left atrium by excessive pressure. The tip of the sheaths can not be seen on NavX and an alternative way to ascertain their location is used. The sheath with the ablation catheter can be advanced over the shaft of the catheter until the proximal bipole...
is covered. The resulting increased impedance causes distortion of the virtual electrode on the EM alerting the operator of the location of the sheath. The sheath with the ICE catheter can be advanced over the shaft of the ICE catheter until the tip of the sheath covers the transducer. There is a sudden reduction in the quality of the ultrasound image confirming that the sheath tip is over the transducer. The transducer location can be determined by its adjacent anatomical landmarks. Fluid in the pericardial space can easily be seen while the ICE is in the left atrium and further views can be obtained from the left or right ventricles when ruling out tamponade. This is certainly helpful in fully anticoagulated patients undergoing prolonged procedures, especially when there is transient drops hypotension related to sedation or pacing. With our growing experience outlined above, there has been a gradual reduction in the use of fluoroscopy to the point where we were ready to perform ablation without any X-ray.

**Potential Advantages of a Completely Non Fluoroscopic Technique**

A technique that consistently and safely achieves catheter ablation of AF without any fluoroscopy potentially offers substantial advantages. In addition to the reduced radiation risk to the patient, lab staff and physician discussed above, there are other possible benefits. Not wearing lead aprons and eye protection would undoubtedly make prolonged procedures more comfortable for medical staff and may reduce the risk of neck and back problems associated with their use. Eradicating the need for fluoroscopy could allow these procedures to be performed in a laboratory without digital fluoroscopy. That could substantially reduce capital costs and remove the need (and possibly salary) of a radiology technician.
Limitations

This observational study had no complications but is too small to test the safety of AF ablation without fluoroscopy. With modern X-ray equipment, the fluoroscopic exposure to individual patients is generally low and it is our opinion that patient safety should not be compromised to reduce fluoroscopic exposure to medical staff. However, if the procedure can be performed safely and quickly, there are significant benefits of eliminating radiation to all involved in the procedure. This technique involves rotational ICE which is not as widely used as phased array ICE and adopting this technique would require a change in physician practice.

Conclusions

The American College of Cardiology has highlighted the ALARA principle for cardiac interventions. This emphasizes utilizing techniques and procedures to keep X-ray exposure to a level as low as reasonably achievable. Our study has demonstrated that it is feasible to perform AF ablation without any fluoroscopy.

The long term outcomes of ablation and the safety of this technique need to be addressed in larger cohorts. If this technique proves safe and effective, it has significant implications for complex ablation procedures. It would potentially eliminate radiation exposure to patients, lab staff and physicians and could reduce procedural costs. We hope
that this study spurs further research into non fluoroscopic techniques for AF ablation and, even if cases are not done entirely without fluoroscopy, we have demonstrated that fluoroscopy times can be kept to a safe minimum. This technique is likely to be of particular benefit to obese patients, children and pregnant women who are at the highest risk from fluoroscopically guided ablation in the left atrium.

**Disclosures**

John D Ferguson – research grants from St Jude medical, consultation fees from St Jude medical, honoraria from Boston Scientific

J. Michael Mangrum – research grants from St Jude medical, consultation fees from St Jude medical, honoraria from Boston Scientific

Srijoy Mahapatra – shareholder St Jude Medical, research grant BioSense Webster

John P DiMarco – honoraria from St Jude medical and Boston Scientific
References


### TABLE 1

**Acute Procedural Outcomes of AF Ablation Without Fluoroscopy**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients with no fluoroscopy</td>
<td>19/21 (90%)</td>
</tr>
<tr>
<td>Procedure time</td>
<td>208 (188-221) minutes</td>
</tr>
<tr>
<td>Coronary sinus cannulation time</td>
<td>5 (2-26) minutes</td>
</tr>
<tr>
<td>Double transseptal time</td>
<td>26 (17-40) minutes</td>
</tr>
<tr>
<td>Left atrial catheter manipulation time</td>
<td>103 (90-127) minutes</td>
</tr>
<tr>
<td>Right atrial catheter manipulation time</td>
<td>16 (12-22) minutes</td>
</tr>
<tr>
<td>Electrophysiology study time</td>
<td>14 (8-23) minutes</td>
</tr>
<tr>
<td>Successful pulmonary vein isolation</td>
<td>76/76 (100%)</td>
</tr>
</tbody>
</table>

**Patients with additional ablation**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Count (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left atrial roof</td>
<td>7 (33%)</td>
</tr>
<tr>
<td>Mitral isthmus</td>
<td>4 (19%)</td>
</tr>
<tr>
<td>Cavotricuspid isthmus</td>
<td>8 (38%)</td>
</tr>
<tr>
<td>Coronary sinus</td>
<td>3 (14%)</td>
</tr>
</tbody>
</table>

**Complications**

Continuous variables expressed as median (range).
Figure Legends

**Figure 1:** The top panel shows coronary sinus (CS) electrograms while advancing the CS catheter from subclavian to coronary sinus without using fluoroscopy. Moving from left to right, the panels show first atrial electrograms, then atrial and ventricular electrograms on the distal bipole as the catheter is advanced to the CS os, then atrial and ventricular electrograms on all bipoles confirming CS placement. The electrograms correspond to the positions of the circled numbers below. The lower panel shows the coronary sinus catheter displayed on the mapping system to facilitate its placement. RAO and LAO projection of the virtual catheter were displayed. The system reference was used. The bright yellow catheter (number 6) shows the final CS position and the other shadows record the path of the catheter as it is advanced through the right atrium. The combination of these views and atrial and ventricular electrograms enabled successful CS cannulation in all patients.

**Figure 2:** Panels A-D show serial images as the ICE catheter (within a deflectable sheath) is advanced from the femoral vein to the right atrium. Panel A: The right common iliac vein. Panel B: Junction of the right and left common iliac veins forming the inferior vena cava (IVC). The guidewire from the right side can be seen joining the IVC (red arrow). Panel C: IVC just below the right atrium. Panel D: Right atrium with the ICE catheter located adjacent to the thin walled fossa ovalis. Often a small amount of curve needs to be added to the deflectable catheter to bring the ICE catheter this close to the fossa. The bright acoustic artifact of the coronary sinus catheter traversing the right atrium. Panel E-H also show images during passage of the ICE catheter to the right atrium but in Panel F the dramatic reduction in calibre of the vein (arrow) together with palpable resistance illustrates the inadvertent cannulation of a small side branch. By slowly withdrawing the catheter, gently applying a curve to the deflectable sheath and then rotating the sheath back into the large calibre lumen of the IVC, the catheter can then be easily advanced to the right atrium.

**Figure 3:** This shows serial images as the ICE catheter is advanced from the right atrium to the innominate vein to prepare the sheath for transseptal puncture. Panel A shows the superior vena cava with the coronary sinus (CS) catheter (arrow). Panel B shows inadvertent cannulation of the right innominate vein with the CS catheter (arrow) in the
lumen of the left innominate vein. In panel C the ICE catheter is withdrawn and rotated towards the CS catheter (arrow) to follow it into the lumen of the left innominate vein. Subsequently the guidewire, dilator and tip of the left femoral sheath, all with a characteristic acoustic patterns, can be advanced to this location ready for the transseptal pullback.

**Figure 4:** ICE imaging was used to guide the transseptal puncture from right atrium (RA) to left atrium (LA). The thin membrane of the fossa ovalis (A) and Brockenborough needle tenting the fossa (B) can be used to correctly position the needle tip prior to the puncture. The needle was then advanced while watching the pressure waveform, feeling for the characteristic ‘pop’ and looking to see the needle cross into the left atrium on ICE (C, arrow). The dilator and sheath were advanced over the needle until the sheath could be seen in the left atrium (D, arrow). Electrocautery (‘Cutting’ (not ‘coagulation’) 10 Watts, <2 seconds) was used to facilitate the transseptal puncture if gentle pressure alone was not successful. The Bovi pen was applied to the back of the Brockenborough needle (E) and power turned on as the needle was advanced out of the tip of the dilator.

**Figure 5:** Navigation of the ablation catheter in the left atrium was performed using electroanatomical mapping and intracardiac echo (ICE). Panels A and B show a 3D MRI which has been registered to fiducial points at the ostia of the pulmonary veins using ICE guidance. Panel A shows the PA view of the left atrium with the green tip of the ablation catheter at the lower posterior aspect of a large left common pulmonary vein. The same position of the ablation catheter is shown in an AP projection of the left atrium in panel B and on ICE in panel C. Ablation lesions were marked on the 3D model using red dots. In panel B, the left atrial appendage has been cut away to allow easier viewing of the pulmonary vein behind it. In panel C the ICE catheter is represented by the white circle in the center of the image. This is located in the center of the lumen of the left common vein. The ablation catheter is the bright artifact in contact with the vein wall directly below the ICE catheter. The esophagus (E) can be seen with its characteristic bright lumen. Panel D shows the right superior pulmonary vein with the characteristic pattern of the pulmonary artery (PA) above it and the superior vena cava (SVC), with the coronary sinus catheter (arrow), anterior to this vein. This was a common fiducial point used for registration of the right side of the left atrium.
Fig 2.

Right Atrium

Femoral Vein
Fig 3.
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Supplemental Material:

(Video)

Digital movie of ICE guided ablation around a left common pulmonary vein. The stationary circle in the middle of the image is the ICE catheter which is placed in the center of the lumen of this vein. The metal tip of the irrigated-tip ablation catheter can be seen at 12 o’clock to the ICE catheter. The saline irrigation jets can be seen swirling within the vein around the catheter. The ablation tip then moves to the 11 o’clock position, counter clockwise around the vein. During this movement, contact with the vein wall is temporarily lost and the catheter needed to be rotated clockwise to re-establish contact with the vein wall. The bright straight air filled lumen of the esophagus can be seen traversing posteriorly (to the left) of the pulmonary vein and the distance between the lumen of the vein and the outer muscle layers of the esophagus can be monitored.