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

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

Methods and Results—Twenty-one patients with atrial fibrillation (age, 42 to 73 years; 14 male; 14 paroxysmal, 7 persistent; body mass index, 26 to 38) underwent ablation. A decapolar catheter was advanced through 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 electroanatomic mapping navigation. In 19 cases, no fluoroscopy was used and the staff did not wear protective lead. In 2 cases, 2 to 16 minutes of fluoroscopy was used to assist transseptal puncture. Median procedure time was 208 (188 to 221) minutes; coronary sinus cannulation took 5 (2 to 26) minutes; coronary sinus cannulation took 5 (2 to 26) minutes; double transseptal took 26 (17 to 40) minutes; left atrial ablation time was 103 (90 to 127) minutes. All patients underwent circumferential pulmonary vein ablation and 8 patients underwent additional left atrial ablation. There were no procedure-related complications.

Conclusions—Catheter ablation of atrial fibrillation without 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. (Circ Arrhythm Electrophysiol. 2009;2:611-619.)

Key Words: atrial fibrillation • catheter ablation • fluoroscopy • radiation risk
The distal poles, the catheter was rotated counterclockwise and advanced until atrial and ventricular electrograms were seen, first on the distal electrodes and then on all 5 bipoles (Figure 1). This catheter could be seen moving in real time as a virtual electrode on the screen of the EM system (EnSite NavX, Minn; system reference used) in the left anterior oblique and right anterior oblique projections (Figure 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 before ablating within the left atrium.

Two 9F sheaths (55° Convoy, Boston Scientific, Natick, Mass; Agilis deflectable, St Jude) were then advanced through both femoral veins over a guide wire to the right atrium. Before 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 guide wire were removed and the ICE catheter (9F UltraICE, Boston Scientific) was advanced through the deflectable Agilis sheath while the guide wire was still in place. The sheath could then be seen moving in real time as a virtual electrode on the screen and ensure that it was stable before ablating within the left atrium.

The ICE catheter was then advanced from the right atrium to the superior vena cava and the innominate vein (Figure 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 guide wire 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 plane. The ICE catheter was then advanced until it could be seen with the ICE catheter. The 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 (Figure 4E). The sheath was then advanced over the Brockenborough needle and dilator under ICE guidance. The ICE catheter was then used to position the first catheter in the CS and then on all bipoles (Figure 1). This catheter could be seen moving in real time as a virtual electrode on the screen of the EM system (EnSite NavX, Minn; system reference used) in the left anterior oblique and right anterior oblique projections (Figure 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 before ablating within the left atrium.

**Figure 1.** Top, 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 on the distal pole, then atrial and ventricular electrograms on all bipoles. The catheter could be seen moving in real time as a virtual electrode on the screen of the EM system (EnSite NavX, Minn; system reference used) in the left anterior oblique and right anterior oblique projections (Figure 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 before ablating within the left atrium. Bottom, CS catheter displayed on the mapping system to facilitate its placement. Right and left anterior oblique electrograms on all bipoles (Figure 1) were displayed. The system reference used. The bright yellow catheter (No. 6) shows the final CS position and the other shadows record the path of the catheter as it is advanced through the CS and then on all bipoles (Figure 1). This catheter could be seen moving in real time as a virtual electrode on the screen of the EM system (EnSite NavX, Minn; system reference used) in the left anterior oblique and right anterior oblique projections (Figure 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 before ablating within the left atrium.
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 4 pulmonary veins and the mitral annulus using ICE guidance and EM (Figure 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.2,3 The activated clotting time was maintained between 300 and 350 seconds, using unfractionated heparin while catheters were in the left atrium.

Electroanatomic 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 (Figure 5). We have previously described imaging of the esophagus during AF ablation with rotational ICE.3 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 (Figure 5).

Ablation
A 3.5-mm, irrigated-tip ablation catheter (Celsius ThermoCool, Biosense Webster, Diamond Bar, Calif) with power set at 25 W on the posterior wall, 30 W on the anterior wall, and flow rate of 17 mL/min was used 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 to 10 mm into the vein and swept around the entire circumference of the vein to check that there was no electrogram 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, and 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 in any case. At the end of the electrophysiology study, the ICE catheter was advanced to the left ventricle to image the pericardial space to exclude a pericardial effusion.

Follow-Up

After sheath removal, the patients were observed overnight. Warfarin was restarted, and they were given enoxaparin 1 mg/kg for 2 doses, then 0.5 mg/kg for 4 doses. Patients were seen at 1, 3, 6, and 12 months after ablation. A 12-lead ECG was performed at clinic visits and a continuous 24-hour ECG was performed at 3, 6, and 12 months after ablation. Additional Holter ECGs 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 median (range).

Results

This technique was attempted in 21 patients with AF. Their median age was 63 (42 to 73) years, 14 male, and their body mass index was 29 (26 to 38). Fourteen patients had paroxysmal AF and 7 had persistent AF. Procedural outcomes are summarized in the Table. In 19 cases, no fluoroscopy was used and the staff did not wear protective lead. In 2 cases (cases 2 and 4 in the series), 2 to 16 minutes of fluoroscopy was used to assist transseptal puncture. The median procedure time was 208 (188 to 221) minutes; coronary sinus cannulation took 5 (2 to 26) minutes; double transseptal took 26 (17 to 40) minutes; left atrial catheter manipulation took 103 (90 to 127) minutes; right atrial catheter manipulation took 16 (12 to 22) minutes; and the electrophysiology study took an additional 14 (8 to 23) minutes. All patients underwent circumferential pulmonary vein ablation, 7 had left atrial roof ablation, 4 had mitral isthmus ablation, 8 had cavotricuspid 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 to 11) months follow-up, 16 of 21 (76%) 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% in women and 0.1% in men. Nevertheless, the lifetime 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 dou-
bles for each 3.5 cm of soft tissue, are at particular risk.5 The acute risk of radiation-induced skin ulceration is a well-recognized but rare complication of excessive fluoroscopic exposure during radiofrequency catheter ablation.6,7 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 in adults.5 They are more sensitive to 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 laboratory staff who accumulate significant x-ray exposure with multiple procedures over time may be at even greater risk than are patients.8,9 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.10 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.11 Haisseguerre et al12 have reported a fluoroscopy time of 84±30 minutes for termination of persistent AF targeting multiple sites within the left atrium. Schilling and colleagues13,14 have shown that nonfluoroscopic mapping can significantly shorten fluoroscopy times in persistent AF cases. In general, the savings in total radiation from nonfluoroscopic mapping have only been marginal given the additional radiation of preablation CT scans and registration of these images during the procedure. Robotic catheter navigation has the potential to reduce fluoroscopy. Saliba et al15 reported a mean fluoroscopy time of 64±33 minutes using a steerable sheath system and Pappone et al16 reported 32.3±11 minutes using the remote magnetic system. It is possible that with 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.

Table. Acute Procedural Outcomes of AF Ablation Without Fluoroscopy

| Patients with no fluoroscopy | 19/21 (90) |
| Procedure time, min | 208 (188–221) |
| Coronary sinus cannulation time, min | 5 (2–26) |
| Double transeptal time, min | 26 (17–40) |
| Left atrial catheter manipulation time, min | 103 (90–127) |
| Right atrial catheter manipulation time, min | 16 (12–22) |
| Electrophysiology study time, min | 14 (8–23) |
| Successful pulmonary vein isolation | 76/76 (100) |
| Patients with additional ablation | |
| Left atrial roof | 7 (33) |
| Mitral isthmus | 4 (19) |
| Cavo-tricuspid isthmus | 8 (38) |
| Coronary sinus | 3 (14) |
| Complications | 0 |

Data are presented as n/N (%) or median (range).
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 that also used rotational ICE and 3D mapping. Schwartzman et al completed 200 AF ablation cases with an impressive mean fluoroscopy time of 6 ± 2 minutes.

The variation in fluoroscopy times in the above studies are likely to be even greater in routine clinical practice. These differences probably reflect variations in experience, technique, and technology such as ICE and nonfluoroscopic mapping. Difference in x-ray equipment, radiation protection, and distance from the 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 minutes 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. A conservative estimate of the electrophysiologist’s annual maximum permissible workload based on the annual limit of 20 mSv 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.

Development of Technique

The development of this technique has evolved over several years while accumulating experience in ICE catheter manipulation and electroanatomic mapping. We worked on developing nonfluoroscopic 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 anatomic 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 that 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 superior vena cava 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 puncures 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 cannot 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 anatomic 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 helpful in fully anticoagulated patients undergoing prolonged procedures, especially when there is transient 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 x-ray.

Potential Advantages of a Completely Nonfluoroscopic Technique

A technique that consistently and safely achieves catheter ablation of AF without fluoroscopy potentially offers substantial advantages. In addition to the reduced radiation risk to the patient, laboratory staff, and physician discussed above, there are other possible benefits. Not wearing lead aprons and eye protection would undoubtedly make prolonged proce-
dures 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 using 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 fluoroscopy.

The long-term outcomes of ablation and the safety of this technique must 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, laboratory staff, and physicians and could reduce procedural costs. We hope that this study spurs further research into nonfluoroscopic 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
Drs Ferguson and Mangrum received research grants and consultation fees from St Jude Medical and honoraria from Boston Scientific; Dr Mahapatra is a shareholder for St Jude Medical and received a research grant from BioSense Webster; and Dr DiMarco received honoraria from St Jude Medical and Boston Scientific.

References

**CLINICAL PERSPECTIVE**

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. In addition, patients with AF frequently undergo computed tomography scans, cardiac catheterization, and repeat ablation procedures, thus accumulating even greater radiation exposure with time. Recent advances in electroanatomic mapping systems and intracardiac echocardiography techniques have facilitated catheter manipulation within the left atrium but have reduced and not eliminated fluoroscopy exposure. We report an AF ablation technique using rotational intracardiac echocardiography and electroanatomic mapping without fluoroscopy. Catheter navigation was performed using the “virtual electrodes” on the electroanatomic mapping computer screen, intracardiac echocardiography, and intracardiac electrograms. Twenty-one patients with AF (14 paroxysmal, 7 persistent) underwent ablation using this technique. In 19 cases, no fluoroscopy was used and the staff did not wear protective lead. In 2 cases, 2 to 16 minutes of fluoroscopy was used to assist transseptal puncture. Median procedure time was 208 (188 to 221) minutes. All patients underwent circumferential pulmonary vein ablation, and 8 patients underwent additional linear left atrial ablation. There were no procedure-related complications. In summary, catheter ablation of AF without 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. In addition, it could reduce radiation exposure to physicians and laboratory staff, remove the need for protective lead during prolonged cases, and minimize costs.
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(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.