A Nonfluoroscopic Approach for Electrophysiology and Catheter Ablation Procedures Using a Three-Dimensional Navigation System

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Background: *Three-dimensional (3D) electroanatomical navigation systems decrease the fluoroscopy time of electrophysiology and ablation procedures. The aim of this study was to assess the safety and efficacy of a complete nonfluoroscopic approach for electrophysiologic studies and right-sided catheter ablations for supraventricular tachycardia in patients with normal cardiac anatomy using a 3D, surface electrode-based navigation system (NavX^{TM}, St. Jude Medical, St. Paul, MN, USA).*

Methods and Results: *Electrophysiologic studies were performed in 26 consecutive cases (12.7 ± 7.5 years) using NavX^{TM} without fluoroscopy. The procedure time was 98.7 ± 49.7 minutes. Nonfluoroscopic catheter ablations were performed in 24 of 28 consecutive patients. Cryoablation was used in 23 of 24. The procedure time was 193.5 ± 80 minutes. The coronary sinus access was obtained in 32.1 ± 12 (range: 15–60) seconds. No complications occurred. All patients (n = 19) who underwent cryoablation for right-sided arrhythmia substrates with conventional fluoroscopic guidance in addition to NavX^{TM} were used as a control group (10.1 ± 5.2 years). Catheter ablation success rate of the control group (16/19, 84%) was not significantly different compared to the patients who underwent ablation without fluoroscopy (22/24, 92%). The procedure time was also not significantly different between the two groups (P = NS).*

Conclusion: *This study demonstrates that nonfluoroscopic electrophysiologic studies and right-sided catheter ablations for supraventricular tachycardia can be safely and effectively performed in the majority of patients with normal cardiac anatomy using NavX^{TM}. Further studies will be necessary in order to establish the potential utility of NavX^{TM} in eliminating or decreasing radiation exposure for other electrophysiology procedures. (PACE 2007; 30:519–525)*

electrophysiology*, *ablation*, *mapping

Introduction

Electrophysiology and catheter ablation procedures are performed under fluoroscopy guidance. Patients and the staff working at the electrophysiology laboratory can be exposed to a significant amount of fluoroscopy during these procedures. Radiation exposure presents even more risk for individuals with certain conditions such as pregnant women and patients with immune system dysfunction. The main purpose of fluoroscopy during these procedures is to guide in placement and navigation of catheters.

In recent years, nonfluoroscopic three-dimensional (3D) navigation systems are used to help in mapping and ablation.[1–3] These systems reduce x-ray exposure significantly.[1,4]

The aim of this study was to assess the safety and efficacy of a complete nonfluoroscopic approach for electrophysiologic studies and right-sided catheter ablations for supraventricular tachycardia in patients with normal cardiac anatomy using a 3D, surface electrode-based navigation system (EnSite NavX^{TM}, St. Jude Medical Inc., St. Paul, MN, USA).

Methods

Study Population

From December 2004 to September 2005, invasive electrophysiology testing was performed without fluoroscopy in 26 consecutive patients. None of these patients required catheter ablation.

Right-sided catheter ablations for supraventricular tachycardia in patients with normal cardiac anatomy were performed without fluoroscopy in 24 of 28 consecutive patients. Exclusion criteria were the presence of left-sided supraventricular tachycardia, congenital or acquired heart disease other than arrhythmias. Two patients with mild Ebstein's malformation of the tricuspid valve (TV) were included. Cryoablation was the primary catheter ablation choice in 23 of 24 of these patients.

All of the patients who underwent cryoablation (n = 19) for right-sided supraventricular tachycardia substrates under fluoroscopic guid-

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ance prior to the initiation of nonfluoroscopic approach were used as a comparison group. Since cryoablation has been the primary ablation modality in our electrophysiology laboratory, radiofrequency (RF) ablation procedures performed prior to the institution of cryoablation were not selected for comparison. The study protocol was approved by the University of Arkansas for Medical Sciences Institutional Review Board.

Electrophysiology Procedure

NavX^{TM} is used to perform electrophysiologic studies and catheter ablation procedures without fluoroscopy. This system allows visualization of all electrophysiology catheters during the procedures.

Catheter ablation procedures are done under general anesthesia in our Pediatric Electrophysiology Laboratory. Previous electrophysiology procedures performed in our laboratory showed that NavX^{TM} system is very sensitive to motion of the reference catheter. It is not unusual even for catheters placed in the coronary sinus to move during a long-lasting procedure. In that event, one has to reconstruct the right atrial geometry. Therefore, we used an esophageal catheter as a reference catheter and that resulted in having a very stable geometry throughout the procedures. For patients who may not need anesthesia, use of a stable intracardiac catheter would still be a reasonable approach.

The right atrial geometry was constructed using a deflectable quadripolar electrophysiology catheter following the placement of the femoral venous sheaths in both groins. The catheter was inserted blindly into the femoral vein and was advanced into the right atrium gently without fluoroscopy. NavX^{TM} helped in guiding that catheter in the inferior vena cava (IVC) if a resistance is felt before entering the right atrium. Catheters can be viewed with NavX^{TM} when they are in IVC and similar to the fluoroscopy, one can visualize the distal part of the catheter and can therefore appreciate if catheter tip is in undesirable structures such as renal or hepatic veins. For younger patients, 4-Fr deflectable catheters were used in order to have the softest tip catheter available for reconstructing the right atrial geometry. Transvenous intracardiac recordings using the same catheter were used as electrical reference. After the catheter was advanced into the right atrium and when the right atrial electrograms were noted, the catheter was pulled back and when the electrograms were lost, this location was marked as inferior vena cava. The catheter was then advanced back into the right atrium and then into the superior vena cava (SVC) using anteroposterior and lateral views of NavX^{TM}. After marking the SVC, the catheter was pulled back and areas where atrial and ventricular electrograms were close to equal in amplitude were marked as TV annulus. His signals were searched for and marked on the geometry when identified. His signals were identified in all patients. For cases where coronary sinus catheters were used, a deflectable decapolar electrophysiology catheter was then advanced into the right atrium from one of the femoral venous sheaths using the right atrial geometry under NavX^{TM} guidance. The catheter was placed into the coronary sinus. Following that, multielectrode catheters were placed in the right ventricle, His, and high right atrium locations.

For electrophysiologic studies where ablation was not expected, one or two catheters were used with less detailed construction of the right atrial geometry.

Statistical Analysis

Data are expressed as mean values ± SD. Student's *t*-test is used for comparison of two groups with single dependent variable. Chi-square test was used for comparison of categorical variables. Correlations between variables were assessed with Pearson's correlation coefficient. Statistical analysis was done with SPSS (Release 13.0 for Windows SPSS, Inc, Chicago, IL, USA). A value of $P < 0.05$ was considered to be statistically significant.

Results

The mean age of patients who underwent electrophysiologic studies without fluoroscopy was 12.7 ± 7.5 years (range: 6 months to 38 years). The mean procedure time was 98.7 ± 49.7 minutes (Table I). None of these cases required additional fluoroscopic guidance. No complications occurred.

There was no significant difference between the mean age of patients who underwent nonfluoroscopic catheter ablation compared to the patients who underwent catheter ablation with fluoroscopic guidance (11 ± 4.3 years, range: 4–19 years, vs 10.1 ± 5.2 years, range: 2 months to 17.2 years, P = NS).

During the study period, 4 of 28 patients required additional fluoroscopic guidance besides NavX^{TM}. Two of these patients were infants (a 2 month old with incessant junctional ectopic tachycardia, and an 11 month old with incessant atypical atrioventricular nodal reentrant tachycardia (AVNRT), both underwent successful cryoablation). The third patient had both typical and atypical AVNRTs. The fourth patient had Wolff-Parkinson-White Syndrome involving a parahissian accessory pathway (AP) with fast-conduction properties in spontaneous atrial fibrillation. This pathway was able to be ablated at the fourth electrophysiologic study with extensive RF ablation and atrioventricular (AV) conduction remained intact.

The procedure time (skin-to-skin including a 45-minute waiting period) of patients undergoing nonfluoroscopic catheter ablation was not significantly different compared to the cases performed with fluoroscopy (193.5 $\pm$ 80 (range: 90–360) minutes vs 208.2 $\pm$ 64.5 (range: 105–360) minutes, respectively, P = NS). The mean fluoroscopy time for the cryoablation comparison group was 14.3 $\pm$ 10.6 minutes (range: 2.4–40.5). Of note, NavX^{TM} was used in these patients besides fluoroscopy.

The placement and navigation of catheters were performed without any difficulty in patients who underwent nonfluoroscopic electrophysiologic studies. For cases where guidance was needed in advancing catheters into the heart safely, the catheter that was previously inserted was used as a reference catheter by pulling back into the inferior vena cava or iliac vein. The venous channel was marked that way for guiding the rest of the catheters into the heart. The mean time spent to place the catheters (2–4 catheters) inside the heart including the time to construct right atrial geometry was 9.8 $\pm$ 6.4 (range: 2–40) minutes. The mean time to insert the coronary sinus catheter was 32.1 $\pm$ 12 (range: 15–60) seconds.

Among the 24 patients who underwent catheter ablation without fluoroscopy, 15 had AVNRT, 9 had AV reciprocating tachycardia utilizing APs and 1 had both AVNRT and AV reciprocating tachycardia. These patients had a total of 7 APs that manifested preexcitation, 4 APs with unidirectional retrograde conduction, 15 typical AVNRTs, and 1 atypical AVNRT. Figure 1 illustrates the 3D geometry of the right atrium from a patient who underwent successful cryoablation (Freezor Xtra 6-mm tip catheter, CryoCath Technologies, Montreal, Canada) for typical AVNRT. No complications occurred during any of the procedures. Patients were monitored in the recovery unit following the procedure and all of them were discharged home within 6 hours.

No significant correlation was found between the procedure time and the age of patients who underwent ablation with or without fluoroscopic guidance ($r = -0.2$, $r = -0.1$, respectively, P = NS). However, there was a significant negative correlation between the age of the patients undergoing ablation without fluoroscopy and the time to place the catheters in the heart ($r = -0.45$, $P < 0.05$).

Catheter ablation was successful in 22 of 24 (92%) patients who underwent nonfluoroscopic catheter ablation. Acute success rate for AVNRT ablation was 100% (16/16), and acute success rate for AP ablation was 82% (9/11). No complications occurred. Ablation was unsuccessful in 2 patients in that group. One of these was a 10-year-old female who had undergone a previous unsuccessful RF ablation attempt at the age of 7. She had Wolff-Parkinson-White Syndrome involving an epicardial right anterolateral AP. Fast-mapping with a 6-mm tip cryoablation catheter which involved short cryoablation lesions up to a maximum of 63 seconds failed to affect the AP. RF test lesions also failed to have any effect. Deeper and larger lesions were not placed at that location due to the potential proximity of the right coronary artery and also considering that AP did not have fast conduction properties during induced atrial fibrillation. It was decided to reconsider ablation at an older age if supraventricular tachycardia is not controlled with medications, at which time right coronary angiography will be necessary in order to assess proximity of the coronary artery to the AP location before placing deeper lesions. The second one was a 7-year-old patient who had right anteroseptal AP with close proximity to AV node where a safe location could not be identified with cryomapping. We were able to eliminate AP conduction temporarily during cryomapping with reversible adverse effect on the AV node conduction. Since we were able to identify the AP location, we did not see any benefit in using fluoroscopy.

RF was used in 4 patients who underwent nonfluoroscopic catheter ablation. Of these, RF was unsuccessful in a patient with epicardial anterolateral AP and also in a patient with right anterior AP where cryoablation was successful. The third patient had AVNRT that could not be ablated with cryoablation; however, it was ablated successfully with RF. The fourth patient had successful RF ablation of a right lateral AP where cryoablation was not attempted.

Catheter ablation was successful in 16 of 19 (84%) patients who underwent catheter ablation under fluoroscopic guidance. RF was used besides cryoablation in three patients. The acute success rate for AVNRT ablation was 100% (9 typical and 5 atypical AVNRTs, 14/14), and acute success rate for AP ablation was 63% (5/8). In all three patients in whom ablation was unsuccessful, cryomapping demonstrated septal APs with significant risk to the AV node and a safe location could not be identified.

The catheter ablation success rate was not significantly different between the patients who underwent nonfluoroscopic ablation procedures compared to the patients who had fluoroscopy (92% vs 84%, respectively, P = NS). Although the number of cryoablation lesions tended to be less with the nonfluoroscopic technique, the difference was not statistically significant (7 $\pm$ 6 vs 5.2 $\pm$ 4.6 lesions, P = NS).

The follow-up appointments were scheduled for 2 weeks and 6 months following the proce-

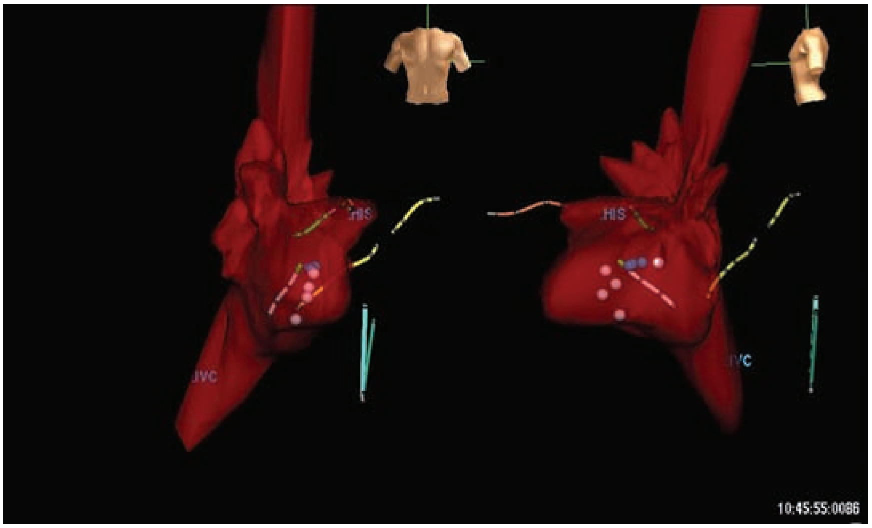

Figure 1. *Anteroposterior (left), and lateral (right) views of the geometric contour of the right atrium. Yellow catheter is located in the coronary sinus, green catheter is at His, red catheter is in the right ventricle, blue catheter is in the esophagus, and the white cryoablation catheter with the green tip is in the midseptal region of the TV annulus. White dots represent cryomapping application points and blue dots represent the cryoablation points for successful AV node slow pathway modification.*

dures. No complications related to the procedures were noted at 2-week follow-up appointments. The mean follow-up time was 275.5 ± 53.8 days for the group who underwent nonfluoroscopic ablation and 401.8 ± 64.5 days for the historical comparison group ($P < 0.001$). Recurrence was noted in 4 of 21 (19%) patients who had acute success with nonfluoroscopic approach and in 2 of 15 (13%) patients in the comparison group (P = NS).

Discussion

This study demonstrated the safety and efficacy of a nonfluoroscopic approach using a 3D navigation system for electrophysiologic studies and right-sided catheter ablations for supraventricular tachydardia in patients with normal cardiac anatomy.

Having a 3D representation of the right atrium allows the operator to view the catheters from many angles. That helped us in achieving a very fast and safe placement and navigation of electrophysiology catheters in the heart. The majority of catheter ablations were performed with cryoablation. The mean procedure time of 193.5 minutes for nonfluoroscopic catheter ablation procedures was comparable to the mean procedure time of cryoablation procedures performed with conventional fluoroscopic approach in recent studies. A recent study assessing the efficacy and safety of cryoablation in children (n = 32) reported a mean procedure time of 249 minutes.[5] The authors used a different intracardiac navigation system LocaLisa® (Medtronic, Inc., Minneapolis, MN, USA) besides conventional fluoroscopy (median fluoroscopy time = 16.2 minutes, range: 6.5–40). Overall success rate for AV reciprocating tachycardia and AVNRT ablation was 88.9% in that study. The International Registry for cryoablation in children (n = 64) reported mean procedure times ranging from 168 to 230 minutes for different AV reciprocating tachycardia substrates and for AVNRT.[6] The fluoroscopy time ranged from 17 to 46 minutes and the acute success rate was 69%. Therefore, the success rate (92%) achieved in the present study did not seem to be adversely affected despite the lack of fluoroscopy.

Although there was not a statistically significant difference, the acute success rate seemed to improve with the nonfluoroscopic technique (92%) compared to the fluoroscopic one (84%). Acute success rate of AVNRT ablation was 100% in both groups; however, AP ablation revealed a higher acute success rate with the nonfluoroscopic approach (82% vs 63%). Therefore the overall difference was due to the change in the AP ablation success rate. Cryoablation was the choice of ablation for the majority of the APs and the control group which consisted of patients before nonfluoroscopic technique was introduced represented our earlier experience with cryoablation. A recent study performed at our center showed that there was a significant institutional learning experience effect with cryoablation of APs in children.[7] The tendency of needing less number of lesions without a compromise in the acute success rate was also accepted as a reflection of improved experience. Therefore the increase in the overall acute success rate with the nonfluoroscopic approach should not be misinterpreted.

A previous case study reported successful AV node ablation and permanent ventricular pacemaker implantation without fluoroscopy using NavX™ in a 47-year-old patient.[8] Authors used NavX™ for catheter and pacemaker lead guidance throughout the procedure. They concluded that nonfluoroscopic electroanatomic navigation of standard catheters, including pacemaker leads, through the femoral or subclavian veins and in the right chambers of the heart is feasible and allows the nonfluoroscopy performance of simple ablation procedures and the implantation of permanent pacemakers. This case report is also supportive of the new concept for performing NavX™-guided electrophysiology procedures in the right chambers of the heart without fluoroscopy.

It is not possible to be certain about the mechanism of supraventricular tachycardia before the procedure in the majority of patients. Some of the left-sided ablations needed transseptal puncture for left atrial access in which case fluoroscopy is used and patients with left-sided arrhythmias were excluded from the study. Except for the transseptal puncture part, mapping around the mitral valve with minimal or no fluoroscopy should be possible. That might also help in decreasing the fluoroscopy time in certain long-lasting electrophysiology procedures such as in catheter ablation of atrial fibrillation.

NavX™ was used as an adjunct to fluoroscopic imaging for approximately 6 months prior to starting to do cases without any fluoroscopy. Therefore, knowledge of catheter manipulation will need to be established prior to performing any cases without fluoroscopy. A learning curve will be anticipated for each operator and that period will have some variability among operators. A shorter learning curve might be expected with adult patients.

Of note, none of the electrophysiology (EP) cases performed without fluoroscopy were repeat cases where fluoroscopy was used previously. Otherwise, previously identified locations would lead to significant bias and shorter procedure duration would be expected.

The utilization of the NavX™ also allowed us to map the coronary sinus and therefore have a coronary sinus reference without the need of keeping a catheter in the coronary sinus throughout the procedure. To be able to do that, after accessing the coronary sinus with a catheter, colored marking points were placed throughout the coronary sinus while pulling back the catheter into the right atrium (Fig. 2). This helped us in decreasing the number of catheters used in some procedures.

Despite the fact that we were able to eliminate fluoroscopy in the majority of our patients who underwent catheter ablation (24/28) and in all patients who underwent electrophysiologic

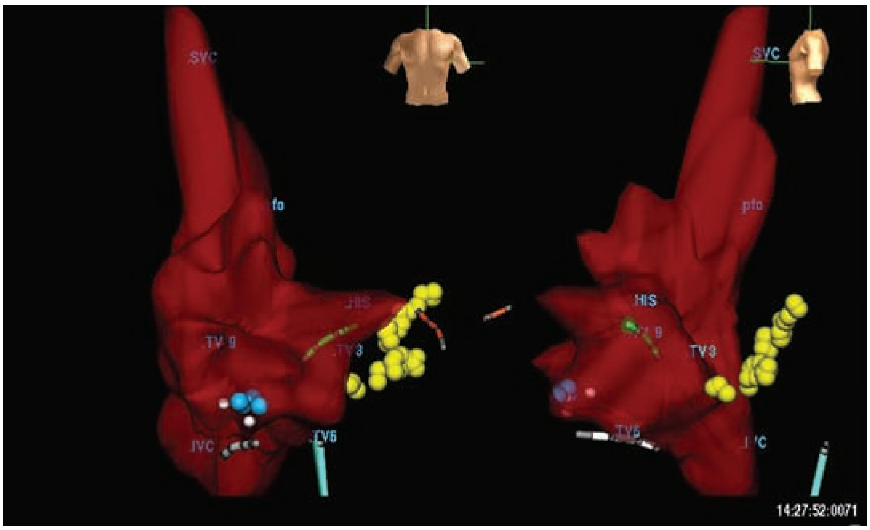

Figure 2. *Anteroposterior (left), and left lateral views (right) of the geometric contour of the right atrium. Yellow dots depict the coronary sinus. Blue dots represent successful cryoablation application points for right lateral AP. TV = tricuspid valve; Pfo = patent foramen ovale; IVC = inferior vena cava; SVC = superior vena cava.*

Table I.

Clinical and Electrophysiological Characteristics of Patients Who Underwent Catheter Ablation with and without Fluoroscopy

Patient	Age (Years)	Diagnosis	Procedure Time (Minutes)	Fluoroscopy Time (Minutes)	Cryoablation Success	RF Ablation Success
1	13.00	Right posteroseptal + right posterolateral	180.00	0	Yes	
2	14.00	WPW-right posteroseptal + AVNRT	330.00	0	Yes	
3	11.00	AVNRT	150.00	0	Yes	
4	16.00	AVNRT	360.00	0	Yes	
5	19.00	AVNRT	90.00	0	Yes	
6	9.00	AVNRT	180.00	0	Yes	
7	7.00	WPW-right anteroseptal	360.00	0	No	
8	14.00	AVNRT	120.00	0	Yes	
9	11.00	AVNRT	210.00	0	Yes	
10	10.00	AVNRT	135.00	0	Yes	
11	16.00	AVNRT	150.00	0	Yes	
12	7.00	WPW-right anterior	270.00	0	Yes	No
13	4.00	AVNRT	180.00	0	Yes	
14	10.00	WPW-right anterolateral	240.00	0	No	No
15	14.00	WPW-right lateral	150.00	0	Yes	
16	11.00	AVNRT	300.00	0	Yes	
17	6.00	Atypical AVNRT	120.00	0	Yes	
18	7.00	AVNRT	240.00	0	No	Yes
19	4.00	Two right posterolateral APs (one preexcited)	120.00	0	Yes	
20	11.00	AVNRT	120.00	0	Yes	
21	16.00	AVNRT	100.00	0	Yes	
22	8.00	Right posterolateral	180.00	0	Yes	
23	18.00	WPW-right lateral	180.00	0		Yes
24	7.00	AVNRT	180.00	0	Yes	
25	6.94	Atypical AVNRT	150.00	40.5	Yes	
26	3.90	AVNRT	260.00	34.7	Yes	
27	15.22	Atypical AVNRT + right posteroseptal	180.00	28.1	Yes	
28	16.74	AVNRT	210.00	18.3	Yes	
29	8.56	Right midseptal	230.00	18.3	Yes	
30	8.67	AVNRT	190.00	17.5	Yes	
31	15.88	AVNRT (typical and atypical)	200.00	17.1	Yes	
32	6.17	Right midsept + Right posteroseptal	180.00	16.6	Yes	
33	13.19	Right anteroseptal	210.00	14.2	No	
34	15.29	Right midseptal	210.00	14.2	No	No
35	0.23	JET	360.00	8.7	Yes	
36	13.64	AVNRT	150.00	8.1	Yes	
37	7.58	Right midseptal	180.00	7.5	Yes	
38	7.96	AVNRT	180.00	7.1	Yes	
39	0.93	AVNRT (atypical)	270.00	5.9	Yes	No
40	17.21	Right anteroseptal	310.00	4.7	No	
41	7.81	AVNRT	105.00	4.4	Yes	
42	14.25	AVNRT (typical and atypical)	270.00	3.7	Yes-typical	Yes-atypical
43	11.13	AVNRT	110.00	2.4	Yes	

WPW = Wolff-Parkinson-White Syndrome; AVNRT = atrioventricular nodal reentrant tachycardia; JET = junctional ectopic tachycardia.

evaluation, it is important to emphasize that all invasive electrophysiology procedures should continue to be performed in the cardiac catheterization laboratories where fluoroscopy is available if deemed necessary. When there is a question about catheter placement or navigation, fluoroscopy should be used in order to ensure patient safety.

There is a concern for long-term x-ray exposure for catheter laboratory personnel, especially more so during the electrophysiology procedures.[9] The utilization of NavX™ should decrease the chance of having potential adverse effects by eliminating or decreasing fluoroscopy time during electrophysiology procedures. Therefore, this new approach is not only beneficial for patients but also for electrophysiology laboratory staff.

For patients who are more vulnerable for deleterious effects of x-ray, such as pregnant women and patients with immune dysfunction, NavX™-guided electrophysiology procedure might be an alternative safe approach.

The majority of the patients in that study were children. Therefore, performing nonfluoroscopic electrophysiology procedures should be even easier in adult patients due to the larger body size compared to children. The youngest child who underwent cryoablation was a 4-year-old patient with typical AVNRT. When extensive mapping is needed in young children, careful and detailed geometry of the right atrium and TV annulus should be obtained in order to ensure patient safety.

Study Limitations

This study involved a small number of patients. Larger patient groups will need to be evaluated prior to the potential application of the proposed technique more widely.

The majority of catheter ablations were performed with cryoablation. Future studies assessing the potential applicability of this nonfluoroscopic approach should also assess the safety and efficacy of performing RF ablation.

Conclusion

This study demonstrates that nonfluoroscopic electrophysiologic studies and right-sided catheter ablations for supraventricular tachycardia can be safely and effectively performed in the majority of patients with normal cardiac anatomy using NavX™. Further studies will be necessary in order to establish the potential utility of NavX™ in eliminating or decreasing radiation exposure for other electrophysiology procedures.

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References

1. Gepstein L, Hayam G, Ben-Haim SA. A novel method for nonfluoroscopic catheter-based electroanatomical mapping of the heart. In vitro and in vivo accuracy results. Circulation 1997; 95:1611–1622.
2. Ventura R, Rostock T, Klemm HU, Lutomsky B, Demir C, Weiss C, Meinertz T, et al. Catheter ablation of common-type atrial flutter guided by three-dimensional right atrial geometry reconstruction and catheter tracking using cutaneous patches: A randomized prospective study. J Cardiovasc Electrophysiol 2004; 15:1157–1161.
3. Wittkampf FH, Wever EF, Derksen R, Wilde AA, Ramanna H, Hauer RN, Robles de Medina EO. LocaLisa: New technique for real-time 3-dimensional localization of regular intracardiac electrodes. Circulation 1999; 99:1312–1317.
4. Cooke PA, Wilber DJ. Radiofrequency catheter ablation of atrioventricular nodal reentry tachycardia utilizing nonfluoroscopic electroanatomical mapping. Pacing Clin Electrophysiol 1998; 21:1802–1809.
5. Kriebel T, Broistedt C, Kroll M, Sigler M, Paul T. Efficacy and safety of cryoenergy in the ablation of atrioventricular reentrant tachycardia substrates in children and adolescents. J Cardiovasc Electrophysiol 2005; 16:960–966.
6. Kirsh JA, Gross GJ, O'Connor S, Hamilton RM. Transcatheter cryoablation of tachyarrhythmias in children: Initial experience from an international registry. J Am Coll Cardiol 2005; 45:133–136.
7. Tuzcu V. Cryoablation of accessory pathways in children. National Turkish Pediatric Cardiology and Cardiovascular Surgery Congress. Istanbul, Turkey, 2006.
8. Ruiz-Granell R, Morell-Cabedo S, Ferrero-De-Loma A, Garcia-Civera R. Atrioventricular node ablation and permanent ventricular pacemaker implantation without fluoroscopy: Use of an electroanatomic navigation system. J Cardiovasc Electrophysiol 2005; 16:793–795.
9. Katz JD. Radiation exposure to anesthesia personnel: The Impact of an electrophysiology laboratory. Anesth Analg 2005; 101:1725–1726.