Predictors of long fluoroscopy time during ablation of atrial fibrillation

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Introduction
Catheter ablation has emerged as effective therapy for AF. Ablation of AF is often a complex and long procedure requiring long fluoroscopy time. An important complication of AF ablation is the delayed effect of the radiation received by the patients and operator.
Objective
We conducted this prospective observational cohort to study factors associated with long fluoroscopy time during catheter ablation of AF.
Patients and Method
This is a prospective observational cohort study, conducted between January 2013 and January 2014 in Critical Care Medicine Department – Cairo University. Patients with symptomatic, drug refractory AF were enrolled. All patients underwent pulmonary vein isolation ± left atrial ablation according to AF type. All operators performed at least 50 previous AF ablation procedures. Clinical (AF type and LA geometry and diameter), and technical (Mapping system and catheters) variables were recorded for each patient. The primary endpoint was to identify variables associated with long fluoroscopy time. Secondary endpoints included identification of complications.
Results
Thirty-one patients with paroxysmal (n=25) and persistent (n=6) AF were enrolled. Pulmonary vein isolation was achieved in all patients. Average fluoroscopy time was 54.2 ± 31.7 mins. We found that the use of CARTO3® system was associated with significantly shorter fluoroscopy time compared to NavX EnSite Velocity® system (48 ± 29.8 vs. 78 ± 27.9 mins, P = 0.02). Using 20-pole circular mapping catheter was also associated with shorter fluoroscopy time as opposed to 10-pole one (47.6 ± 23.2 vs. 98.8 ± 48.4 mins, P = 0.03). Only two patients (6.4%) suffered major complications; major groin bleeding and pericardial tamponade.
Conclusion
The use of CARTO3® navigation system and 20-pole circular mapping catheter seems seems to be associated with shorter fluoroscopy time than EnSite Velocity® navigation system and 10-pole circular mapping catheter.

Keywords:
ablation, atrial fibrillation, complications, fluoroscopy time

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Introduction

Atrial fibrillation (AF) represents an important public health problem. Patients with AF have an increased long-term risk of stroke, heart failure, and all-cause mortality [1–4]. Furthermore, patients with AF describe a considerably impaired quality of life (QOL) that is independent of the severity of the disease [5]. Restoration and maintenance of normal sinus rhythm following treatment directly correlates with improved QOL in these patients [5,6]. Although antiarrhythmic drugs are generally used as first-line therapy to treat patients with AF, effectiveness remains inconsistent. Antiarrhythmic drugs are also associated with cumulative adverse effects over time [1]. Catheter ablation has emerged as an effective therapy for AF, especially when antiarrhythmic drugs (AADs) fail. Several guidelines recommend performing AF ablation after failure of at least one class Ic or class III AAD, in both symptomatic paroxysmal and persistent AF [1,7–10].

Catheter ablation of AF is often a complex and long procedure requiring long fluoroscopy exposure time and often preceded and followed by computed tomography scans. An important, less easily recognized, and rarely considered, potential complication of AF ablation is the delayed effect of the radiation received by the patients.

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Risks can be classified as stochastic (carcinogenic and genetic effects) and deterministic (also called tissue reactions). For stochastic effect, any small amount of radiation involves an increase in cancer risk, whereas for deterministic effect a threshold of 2–3 Gy is required to cause skin injury [11].

Owing to its complexity, catheter ablation of AF requires significantly greater fluoroscopy duration and radiation exposure than simpler catheter ablation procedures. Thus, and especially because AF ablation procedures often need to be repeated, electrophysiologists should make every attempt to minimize radiation exposure.

Accordingly, we conducted this prospective observational cohort to study factors associated with long fluoroscopy time during catheter ablation of AF.

Patients and methods

This prospective observational cohort study was conducted between January 2013 and January 2014 in the Critical Care Medicine Department of Cairo University. Consecutive patients with symptomatic paroxysmal or persistent AF who failed at least one class IC or class III AAD were enrolled. We excluded patients with long-lasting persistent AF, congestive heart failure, left atrium (LA) diameter equal to or more than 5.5 cm, uncontrolled thyrotoxicosis or ischemic heart disease, redo ablation, and those who preferred not to try medical treatment first. The objective was to detect variables associated with long fluoroscopy time. Secondary endpoints included identification of rate of complications.

The study was approved by our local institutional research board. All patients provided informed written consent before the study.

Demographic and clinical data were recorded for all patients. The HATCH score was calculated for paroxysmal or persistent AF patients only (HATCH is an acronym for Hypertension '1 point', Age above 75 years '1 point', Transient ischemic attack or stroke '2 points', Chronic obstructive pulmonary disease '1 point', and Heart failure '2 points'. A score of more than five has a 50% chance of progressing to persistent AF over the following year) [12].

Ablation was done on therapeutic anticoagulation (INR 2–3). However, according to the preference of the operator, warfarin was discontinued before the procedure in some patients and bridging anticoagulation using low molecular weight heparin was used instead. In either case, anticoagulation was started 4–6 h after the procedure, provided there was adequate hemostasis.

The absence of LA thrombus was confirmed by either transesophageal echocardiogram or computed tomography of LA with contrast done in the week before the procedure. The presence of common pulmonary vein (PV) ostia (left or right), middle PV (left or right), roof PV, or any other uncommon PV anatomical variation was considered variant LA anatomy.

The procedure

On the day of the procedure, all patients provided informed written consent. Surface ECG and bipolar endocardial electrograms were stored continuously using multichannel polygraph (LabSystem PRO, Bard Electrophysiology, Lowell, MA, USA or EP WorkMate, St. Jude Medical, Minnesota, USA) for further analysis. Bipolar recordings were filtered from 30 to 500 Hz. Arterial blood pressure and SpO_2 were continuously monitored. Most patients had the procedure done under conscious sedation and local anesthesia. Some patients with persistent AF, in whom extensive ablation was anticipated, received general anesthesia.

In all cases, trans-septal puncture was guided by fluoroscopy and multipolar catheter placed in the coronary sinus. In addition, aortic root was marked by either His catheter or pigtail catheter placed retrogradely at the aortic root. One or two 8-Fr long sheaths were then placed in LA through the puncture.

Following trans-septal puncture, weight-adjusted unfractionated heparin was administered to achieve an ACT of 300–350. It was then repeated every 15–30 min and unfractionated heparin was given accordingly to achieve that target.

Using the 3D navigation system (CARTO3; Biosense Webster, Diamond Bar, California, USA or, EnSite Velocity; St Jude Medical Inc., St Paul, Minnesota, USA), LA shell was reconstructed with special attention to careful delineation of PV ostia. A fully expanded 10-pole (electrode width 1 mm, interelectrode distance 8 mm) or 20-pole (electrode width is 1 mm, interelectrode distance is 2–6–2 mm) circular mapping catheter (Lasso 2515; Biosense Webster, Diamond Bar, CA, USA) was then placed as proximal as possible in PV ostia, and the vein was isolated by either circumferential or segmental ostial ablation. In all cases, demonstration of entrance block into the vein was a mandatory endpoint.

After isolating all veins that demonstrated PV potentials, veins were rechecked at least 20 min later for gaps, and if there had been any, they were closed. According to the operator's discretion, adenosine was sometimes given to unmask dormant conduction into PV, which, when found, was ablated. In those cases, adenosine was given at a dose that produced complete Atrio-Ventricular (AV) block (usually 12–15 mg) [13]. Of note, if the patient remained in AF at the end of procedure, he/she was electrically cardioverted, and all veins were rechecked in sinus rhythm. In patients with persistent AF, further LA ablation for substrate modification was always performed. However, the technique varied among operators. Some operators performed roof and lateral mitral isthmus lines, with demonstration of bidirectional block as a strict endpoint. Others performed ablation of manually identified complex fractionated atrial electrograms (CFAE). In the latter case, areas targeted for ablation were those with low amplitude (<0.15 mV) and fractionated atrial electrograms (composed of two or more deflections) or baseline perturbation with continuous deflections, lasting at least 10 s.

The other CFAE targets were areas with very short AF cycle length (≤120 ms) over a 10-s period [14]. Occasionally, both linear and CFAE ablation techniques were used in the same patient.

Ablation was done using standard 3.5 mm irrigated-tip catheter. The energy delivered was 25 W on the posterior wall of LA and 30–35 W elsewhere. Ablation catheter was continuously irrigated using heparinized saline at a background rate of 2 ml/min that increases to 17 ml/min during Radiofrequency (RF) application. At the end of procedure, protamine was given, at operator's discretion, to reverse the effect of heparin. Procedure time (from skin puncture to removal of sheaths) and fluoroscopy time were recorded. Acute complications related to ablation such as thromboembolism, vascular injury, phrenic nerve injury, and cardiac tamponade were also recorded. Complications were defined according to the 2012 expert consensus statement on catheter and surgical ablation of AF [8].

Statistical analysis

Statistical analysis was done using statistical package for the social sciences (SPSS) software, release 16.0.0 for Windows (SPSS Inc., Chicago, Illinois, USA). Quantitative variables were described using mean ±SD if they were normally distributed, and median and interquartile range if data was skewed. Categorical variables were described using frequencies and percentages. Bivariate analysis of categorical variables was done using χ^2-test with Yates Continuity correction for 2×2 tables. Whenever cell frequency was less than five, Fisher's exact test was used. Comparing two groups of quantitative variable was done using independent samples Student's *t*-test for parametric data, and Mann–Whitney *U*-test for nonparametric one. The correlation between two quantitative variables was explored using Pearson's test for parametric data and Spearman's test for nonparametric one. In all cases, the two-sided significance was always taken as *P* value, and a *P* value less than 0.05 was considered statistically significant.

Results

Our study included 31 consecutive patients who underwent their first radiofrequency ablation for paroxysmal or persistent AF between January 2013 and January 2014, in the Critical Care Medicine Department of Cairo University. In all cases, pulmonary vein isolation (PVI) confirmed by entrance block was a standard target. Additional ablation for persistent AF was left at operator's discretion. Total fluoroscopy and procedure times were recorded for all patients along with several clinical and procedural variables. Our primary endpoint was to identify variables associated with a shorter fluoroscopy time.

Characteristics of the study population are listed in Table 1.

The AAD used were propafenone (*n*=3), flecainide (*n*=17), amiodarone (*n*=10), and sotalol (*n*=1).

We looked at the variables that may be associated with a longer fluoroscopy time (Table 2).

We found that the use of CARTO3 system was associated with significantly shorter fluoroscopy time compared with the NavX EnSite Velocity system (48±29.8 vs. 78±27.9, *P*=0.02). Using a 20-pole circular mapping catheter was similarly associated with shorter fluoroscopy time as opposed to a 10-pole one (47.6±23.2 vs. 98.8±48.4, *P*=0.03) (Fig. 1).

Interestingly, larger LA diameter was not necessarily associated with longer fluoroscopy time. We found no significant statistical correlation between LA diameter and fluoroscopy time (Fig. 2).

Table 1 Characteristics of the study population

	N=31 [*n* (%)]
Age (years)	61.7±13.9
Sex (male)	15 (48.4)
Hypertension	15 (48.4)
DM	2 (6.5)
Prior stroke/TIA	2 (6.5)
LVEF (%)	63.7±7.1
LAD (cm)	3.8±0.6
AF duration (years)	3±2.3
AADs before ablation (count)	1.5±0.6
COPD	3 (9.7)
CAD	1 (3.2)
AF type: PAF	25 (80.6)
Persistent	6 (19.4)
HATCH score (for PAF patients)	1±1.3

AAD, antiarrhythmic drug; AF, atrial fibrillation; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; DM, diabetes mellitus; HATCH, Hypertension, Age, Transient ischemic attack/Stroke, Chronic obstructive pulmonary disease, and Heart failure; LAD, left atrial diameter; LVEF, left ventricular ejection fraction; PAF, paroxysmal atrial fibrillation; TIA, transient ischemic attack.

Table 2 Possible determinants of fluoroscopy time

	Fluoroscopy time (min)	*P* value
AF type		
Paroxysmal (*n*=25)	52±30.1	0.44
Persistent (*n*=6)	63.2±39.5	
LA anatomy		
Normal (*n*=19)	53.9±20.3	0.96
Variant (*n*=12)	54.6±45.5	
Number of PVs with PVP's		
<4 PVs (*n*=12)	52.9±45	0.87
4 PVs (*n*=19)	54.9±20.9	
3D navigation system		
CARTO3 (*n*=25)	48±29.8	0.02
EnSite Velocity (*n*=6)	78±27.9	
Circular mapping catheter used		
20 poles (*n*=27)	47.6±23.2	0.03
10 poles (*n*=4)	98.8±48.4	

AF, atrial fibrillation; LA, left atrium; PV, pulmonary vein; PVP, pulmonary vein potential.

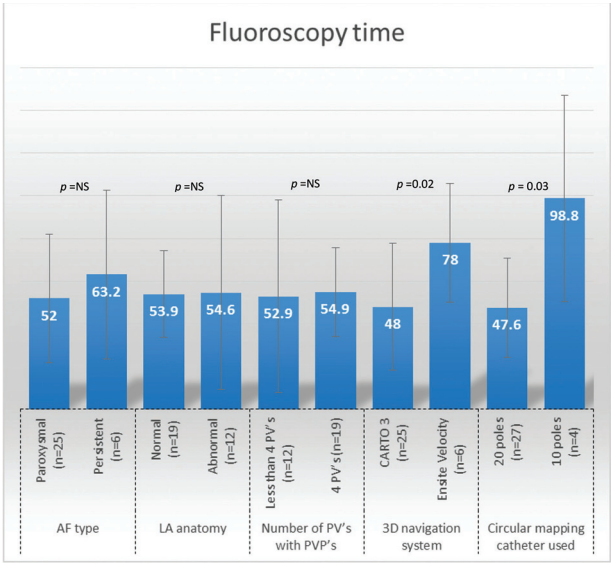
Frequency of acute complications

In our study, two out of 31 (6.4%) patients had major complications (Table 3).

One patient had major groin bleeding that prolonged his hospital stay for 3 days. Bleeding was controlled by manual compression, vascular ultrasound showed no aneurysms, and finally the patient was discharged without blood transfusion.

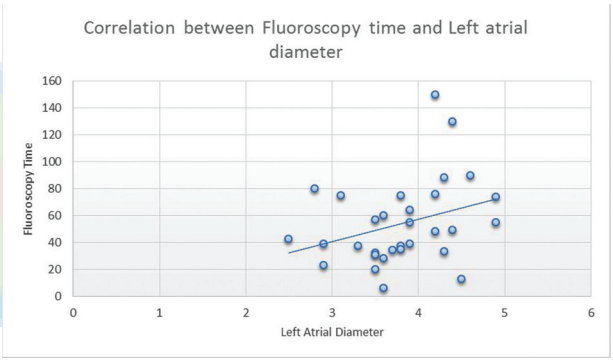
The other patient had pericardial tamponade that was attributed to perforation of LA roof. Pericardial drain was inserted and heparin was reversed with protamine. The patient required repeated pericardiocentesis with retransfusion of the aspirated blood. Eventually bleeding was controlled.

Figure 1



Possible determinants of fluoroscopy time.

Figure 2



Relationship between left atrial diameter and fluoroscopy time.

Table 3 Acute complications associated with RF ablation of atrial fibrillation

Complications	Frequency	Percentage
Major groin bleeding	1	3.2
Pericardial tamponade	1	3.2
Phrenic nerve injury	0	0
Entrapment of circular mapping catheter	0	0
Atrioesophageal fistula	0	0
Stroke	0	0

Discussion

Both patients and doctors are exposed to the hazards of ionizing radiation [11,15]. Risks can be classified as stochastic (carcinogenic and genetic effects) and deterministic (also called tissue reactions). For stochastic effect, any small amount of radiation involves an increase in cancer risk, whereas for deterministic effect a threshold of 2–3 Gy is required to cause skin injury [11]. AF ablation is

notorious for requiring long fluoroscopy time [16]. Accordingly, predictors of long fluoroscopy times and measures to reduce them have been the focus of many studies. In general, the two popular nonfluoroscopic EAMS; CARTO3 (Biosense Webster), or EnSite Velocity (St Jude Medical Inc.) have remarkably reduced fluoroscopy time [16,17]. Whether one of them is superior to the other is another question. Khaykin *et al.* [18] examined the impact of using those two systems on procedural characteristics and clinical outcomes after Pulmonary Vein Antral Isolation (PVAI) for AF. They reported a significantly shorter fluoroscopy time with CARTO3 compared with the Ensite NavX system (52±21 vs. 86±23 min, $P<0.001$). We similarly showed that using the CARTO3 system was associated with significantly shorter fluoroscopy time (48±29.8 min) than the EnSite Velocity system (78±27.9 min, $P=0.02$). This could be explained by not only the higher spatial accuracy of magnetic-based technology of CARTO system in experimental environment [19], but also the stability of its measurements in real-life cases, in contrast to the impedance-based technology of the NavX system which is affected by respiration, periprocedural fluid shifts, and tissue edema.

Interestingly, in our study, the use of 10-pole circular mapping catheter (CMC) to confirm PVI was associated with significantly longer fluoroscopy time than the 20-pole CMC (98.8±48.4 vs. 47.6±23.2 min, $P=0.03$). This has not been specifically reported in the literature before; however, when Hsu *et al.* [20] compared the electrogram quality of 10-pole versus 20-pole CMC during PVI they reported that the higher density 20-pole was significantly superior to the 10-pole one in discriminating local from far-field atrial potentials. We postulate that this higher accuracy of the 20-pole CMC helps accurate identification of PVI and accordingly spares the time of additional unnecessary ablation or diagnostic pacing to differentiate local from far-field signals.

Complications

Catheter ablation of AF is one of the most complex interventional electrophysiological procedures [8]. It is therefore to be expected that the risk associated with AF ablation is higher than for ablation of most other cardiac arrhythmias. The 2010 updated worldwide survey on the methods, efficacy, and safety of catheter ablation for human AF analyzed voluntarily submitted surveys from 182 centers around the world and reported an overall risk of major complications of 4.5% [21]. Cardiac tamponade, vascular complications, and transient ischemic attack accounted for 77.6% of all complications. It must be recognized that the data were from voluntary surveys and likely underestimated the true complication rates. In 2013, Gupta *et al.* [22] published their systematic review on complications of catheter ablation of AF. They pooled the data of 83 236 patients from 192 studies and reported an overall acute complication rate of 2.9%, with vascular complications, pericardial effusion/tamponade, and stroke/transient ischemic attack occupying the first three places on the list. They also observed that between 2007 and 2012 the complications were significantly lower than those during 2000–2006 (2.6 vs. 4.0%; $P=0.03$), which reflects advancements in catheter technology and techniques, as well as an increased experience [22]. The reduction of the overall complication rate between the 2010 worldwide survey and Gupta's systematic review could be explained by, in addition to technological and technical improvements, publication bias in which there is a tendency to publish articles demonstrating low complication rate. Moreover, this systematic review included only studies larger than 100 patients in size and ignored case reports and small series which, according to authors, may underestimate the true incidence of rare adverse events by selectively reporting these events in often very specific patient subgroups, and thus confounding the analysis of the overall complication rate. This is probably why the complication rate in our study (2/31, 6.4%) is perceived to be higher than those reported in those studies, where it could be, in fact, closer to the real-life complication rate. Interestingly, the pilot study of ESC-EUR Observational Research Programme on Atrial Fibrillation Ablation reported an overall complication rate of around 7.3% that is closer to the one reported in our study [23].

Limitations

The technique of PVI, whether segmental ostial isolation or wide-area circumferential pulmonary vein ablation, was left to the operator's discretion. Although circumferential PV ablation is suggested to be superior for minimizing AF recurrences [24,25], it is also more proarrhythmic [26]. Up till now, there is no consensus preference for one technique over the other, as long as PVI has been achieved [8]. A large randomized clinical trial is currently ongoing to test which of those techniques results in better AF control [27].

Owing to the relatively small sample size, predictors of shorter fluoroscopy time were identified using simple bivariate analysis. A larger study would allow for using multivariate analysis.

Conclusion

During AF ablation, reduction of fluoroscopy time should be continuously considered. The use of CARTO3 navigation system and 20-pole circular mapping catheter seems to be associated with shorter fluoroscopy time than EnSite Velocity navigation system and 10-pole circular mapping catheter.

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Conflicts of interest

There are no conflicts of interest.

References

1 Camm AJ, Kirchhof P, Lip GY, Schotten U, Savelieva I, Ernst S, *et al.* Guidelines for the management of atrial fibrillation: the Task Force for the Management of Atrial Fibrillation of the European Society of Cardiology (ESC). Eur Heart J 2010; 31:2369–2429.

2 Wang TJ, Larson MG, Levy D, Vasan RS, Leip EP, Wolf PA, *et al.* Temporal relations of atrial fibrillation and congestive heart failure and their joint influence on mortality: the Framingham Heart Study. Circulation 2003; 107:2920–2925.

3 Benjamin EJ, Wolf PA, D'Agostino RB, Silbershatz H, Kannel WB, Levy D. Impact of atrial fibrillation on the risk of death: The Framingham Heart Study. Circulation 1998; 98:946–952.

4 Krahn AD, Manfreda J, Tate RB, Mathewson FA, Cuddy TE. The natural history of atrial fibrillation: incidence, risk factors, and prognosis in the Manitoba Follow-Up Study. Am J Med 1995; 98:476–484.

5 Singh SN, Tang XC, Singh BN, Dorian P, Reda DJ, Harris CL, *et al.* Quality of life and exercise performance in patients in sinus rhythm versus persistent atrial fibrillation: a Veterans Affairs Cooperative Studies Program Substudy. J Am Coll Cardiol 2006; 48:721–730.

6 Dorian P, Paquette M, Newman D, Green M, Connolly SJ, Talajic M, *et al.* Quality of life improves with treatment in the Canadian Trial of Atrial Fibrillation. Am Heart J 2002; 143:984–990.

7 Camm AJ, Lip GY, De Caterina R, Savelieva I, Atar D, Hohnloser SH, *et al.* 2012 focused update of the ESC Guidelines for the management of atrial fibrillation: an update of the 2010 ESC Guidelines for the management of atrial fibrillation. Developed with the special contribution of the European Heart Rhythm Association. Eur Heart J 2012; 33:2719–2747.

8 Calkins H, Kuck KH, Cappato R, Brugada J, Camm AJ, Chen SA, *et al.* 2012 h/EHRA/ECAS Expert Consensus Statement on Catheter and Surgical Ablation of Atrial Fibrillation: recommendations for patient selection, procedural techniques, patient management and follow-up, definitions, endpoints, and research trial design. Europace 2012; 14:528–606.

9 January CT, Wann LS, Alpert JS, Calkins H, Cigarroa JE, Cleveland JC, *et al.* 2014 AHA/ACC/HRS Guideline for the Management of Patients With Atrial Fibrillation: A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and the Heart Rhythm Society. J Am Coll Cardiol 2014; 64:e1–e76.

10 Verma A, Macle L, Cox J, Skanes AC. Canadian Cardiovascular Society atrial fibrillation guidelines 2010: catheter ablation for atrial fibrillation/atrial flutter. Can J Cardiol 2011; 27:60–66.

11 Heidbuchel H, Wittkampf FH, Vano E, Ernst S, Schilling R, Picano E, *et al.* Practical ways to reduce radiation dose for patients and staff during device implantations and electrophysiological procedures. Europace 2014; 16:946–964.

12 De Vos CB, Pisters R, Nieuwlaat R, Prins MH, Tieleman RG, Coelen RJ, *et al.* Progression from paroxysmal to persistent atrial fibrillation clinical correlates and prognosis. J Am Coll Cardiol 2010; 55:725–731.

13 Gula LJ, Massel D, Leong-Sit P, Gray C, Fox DJ, Segal OR, *et al.* Does adenosine response predict clinical recurrence of atrial fibrillation after pulmonary vein isolation? J Cardiovasc Electrophysiol 2011; 22:982–986.

14 Nademanee K, McKenzie J, Kosar E, Schwab M, Sunsaneewitayakul B, Vasavakul T, *et al.* A new approach for catheter ablation of atrial fibrillation: mapping of the electrophysiologic substrate. J Am Coll Cardiol 2004; 43:2044–2053.

15 Picano E, Vañó E, Rehani MM, Cuocolo A, Mont L, Bodi V, *et al.* The appropriate and justified use of medical radiation in cardiovascular imaging: a position document of the ESC Associations of Cardiovascular Imaging, Percutaneous Cardiovascular Interventions and Electrophysiology. Eur Heart J 2014; 35:665–672.

16 Estner HL, Deisenhofer I, Luik A, Ndrepepa G, von Bary C, Zrenner B, *et al.* Electrical isolation of pulmonary veins in patients with atrial fibrillation: reduction of fluoroscopy exposure and procedure duration by the use of a non-fluoroscopic navigation system (NavX). Europace 2006; 8:583–587.

17 Stabile G, Scaglione M, del Greco M, De Ponti R, Bongiorni MG, Zoppo F, *et al.* Reduced fluoroscopy exposure during ablation of atrial fibrillation using a novel electroanatomical navigation system: a multicentre experience. Europace 2012; 14:60–65.

18 Khaykin Y, Oosthuizen R, Zarnett L, Wulffhart ZA, Whaley B, Hill C, *et al.* CARTO-guided vs. NavX-guided pulmonary vein antrum isolation and pulmonary vein antrum isolation performed without 3-D mapping: effect of the 3-D mapping system on procedure duration and fluoroscopy time. J Interv Card Electrophysiol 2011; 30:233–240.

19 Bourier F, Fahrig R, Wang P, Santangeli P, Kurzidim K, Strobel N, *et al.* Accuracy assessment of catheter guidance technology in electrophysiology procedures: a comparison of a new 3D-based fluoroscopy navigation system to current electroanatomic mapping systems. J Cardiovasc Electrophysiol 2014; 25:74–83.

20 Hsu LF, Jais P, Hocini M, Sanders P, Rotter M, Takahashi Y, *et al.* High-density circumferential pulmonary vein mapping with a 20-pole expandable circular mapping catheter. Pacing Clin Electrophysiol 2005; 28(Suppl 1): S94–S98.

21 Cappato R, Calkins H, Chen SA, Davies W, Iesaka Y, Kalman J, *et al.* Updated worldwide survey on the methods, efficacy, and safety of catheter ablation for human atrial fibrillation. Circ Arrhythmia Electrophysiol 2010; 3:32–38.

22 Gupta A, Perera T, Ganesan A, Sullivan T, Lau DH, Roberts-Thomson KC, *et al.* Complications of catheter ablation of atrial fibrillation: a systematic review. Circ Arrhythm Electrophysiol 2013; 6:1082–1088.

23 Arbelo E, Brugada J, Hindricks G, Maggioni AP, Tavazzi L, Vardas P, *et al.* The Atrial Fibrillation Ablation Pilot Study: An European Survey on Methodology and results of catheter ablation for atrial fibrillation conducted by the European Heart Rhythm Association. Eur Heart J 2014; 35:1466–1478.

24 Arentz T, Weber R, Bürkle G, Herrera C, Blum T, Stockinger J, *et al.* Small or large isolation areas around the pulmonary veins for the treatment of atrial fibrillation? Results from a prospective randomized study. Circulation 2007; 115:3057–3063.

25 Proietti R, Santangeli P, Di Biase L, Joza J, Bernier ML, Wang Y, *et al.* Comparative effectiveness of wide antral versus ostial pulmonary vein isolation: a systematic review and meta-analysis. Circ Arrhythmia Electrophysiol 2014; 7:39–45.

26 Sawhney N, Anousheh R, Chen W, Feld GK. Circumferential pulmonary vein ablation with additional linear ablation results in an increased incidence of left atrial flutter compared with segmental pulmonary vein isolation as an initial approach to ablation of paroxysmal atrial fibrillation. Circ Arrhythmia Electrophysiol 2010; 3:243–248.

27 Feld GK. Effectiveness study of circumferential vs. segmental ablation in paroxysmal atrial fibrillation (PAF). Available at: https://clinicaltrials.gov/show/NCT02106663. 2014. [Accessed 22 March 2015].