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Catheter ablation of atrial fibrillation with nonfluoroscopic catheter visualization—a prospective randomized comparison

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Abstract

Purpose The application of a novel platform for nonfluoroscopic catheter sensor tracking within pre-recorded x-ray loops in the context of catheter ablation of atrial fibrillation (AF) demonstrated significant potential for reduction of fluoroscopy. We sought to provide the first prospective randomized comparison of fluoroscopy needs, procedure times, and complications in AF catheter ablation with or without additional use of nonfluoroscopic catheter visualization (NFCV).

Methods Patients with AF were randomized into two groups before scheduled radiofrequency ablation: (1) using established mapping systems and fluoroscopy as needed (CONV group) or (2) with additional NFCV (NFCV group). All procedures were performed in the same lab using the same ablation catheter tip technology and the same mapping and ablation strategies. Primary endpoints were radiation time and dose. Secondary endpoints were procedural parameters, complications, and long-term success.

Results A total of 80 patients (48 male patients, mean age 60 years, 46 patients with paroxysmal AF) were randomized into the two groups. Clinical parameters between both groups were similar. NFCV use reduced mean fluoroscopy time (1.9 vs. 13.2 min, $p < 0.001$) and mean dose (510 vs. 1549 Gycm^2, $p < 0.001$) significantly. Procedural parameters were similar in the two groups. One conservatively treated groin complication occurred (1.3%).

Conclusions Radiation exposure can be significantly reduced by using the novel NFCV technology in addition to standard AF ablation technologies without negative effects on procedure durations, success rates, or complication rates. With the use of the technology, abandonment of lead protection for EP staff is possible following transseptal puncture.

Keywords Catheter ablation · Atrial fibrillation · Nonfluoroscopic · Radiation exposure · MediGuide

Abbreviations

AF	Atrial fibrillation
EAMS	Electro-anatomical mapping system
LA	Left atrium
NFCV	Nonfluoroscopic catheter visualization
PV	Pulmonary vein
RF	Radiofrequency

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1 Introduction

Catheter ablation has become the treatment of choice for a significant proportion of patients with symptomatic atrial fibrillation (AF) [1]. Conventional fluoroscopy is still a substantial imaging technology used for intracardiac catheter maneuvering. Radiation exposure is a relevant side effect for patients and staff [2]. Like optimizations in fluoroscopy [3], nonfluoroscopic imaging technologies aim to minimize exposure to medical ionizing radiation. In this sense, intracardiac echocardiography and especially electroanatomic mapping systems (EAMS) have become indispensable imaging technologies nowadays. The latter is routinely used to support catheter navigation, arrhythmia mapping, substrate description, and strategic lesion creation in complex ablation procedures. However, even with the use of EAMS, it is difficult to completely abandon fluoroscopy, which is often required for catheter introduction, transseptal puncture, and intermittent verification of sheath and catheter position. The latter is

important, because EAMS are still subject to malfunctions like map shifts and geometry inconsistencies during the procedure. Recently, a novel cardiovascular tracking platform has been introduced (MediGuide™ Technology (MGT), St. Jude Medical Inc., St. Paul, MN, USA), enabling navigation of electrophysiology (EP) catheters in the environment of pre-recorded cine loops [4]. Effective and safe nonfluoroscopic catheter visualization (NFCV) application has already been shown resulting in almost zero-radiation and thus lead-free AF procedures [5, 6]. Randomized studies evaluating the effect of additional NFCV on fluoroscopic use, efficacy, and safety for EAMS-supported AF ablation have not been published so far.

2 Methods

Between March 2013 and September 2014, a total of 80 patients were prospectively randomized in a 1:1 fashion to either AF catheter ablation with EAMS alone (EnSite NavX™, St. Jude Medical Inc., St. Paul, MN, USA) or with the addition of the NFCV technology. All included patients were referred to our institution for first catheter ablation of symptomatic AF. Study patients were adults > 18 years of age with documented paroxysmal or persistent AF. Structural heart disease was defined as coronary heart disease, valvular dysfunction, or left ventricular ejection fraction < 45%. Clinical characteristics of the study population are detailed in Table 1. Only two experienced operators performed all procedures. The institutional ethics committee approved the study, and participants provided written and verbal informed consent.

Table 1 Clinical characteristics

Parameter	NFCV group	CONV group	*p* value
Age (years)	59 ± 10	62 ± 10	0.24
Male patients (%)	25 (63%)	23 (58%)	0.82
BMI	28 ± 4	28 ± 4	0.98
Paroxysmal AF (%)	23 (58%)	23 (58%)	1.00
History of AF (months)*	55 ± 73	27 ± 77	0.57
Arterial hypertension (%)	28 (70%)	37 (93%)	0.02
Diabetes (%)	2 (5%)	9 (23%)	0.048
Structural heart disease (%)	3 (8%)	13 (33%)	0.01
LVEF (%)	60 ± 9	59 ± 9	0.38
Left atrial diameter (mm)	42 ± 6	43 ± 6	0.50
LAA flow (m/s)	0.58 ± 0.24	0.45 ± 0.17	0.11

BMI, body mass index; *AF*, atrial fibrillation; *LVEF*, left ventricular ejection fraction; Structural heart disease = coronary heart disease or valvular dysfunction or LVEF < 45%; *LAA*, left atrial appendage. Continuous data given as mean ± standard deviation, or median (interquartile range) in case of non-Gaussian distribution*

2.1 Technology description

All procedures were performed in a dedicated EP lab with a conventional x-ray system (Siemens Artis, Erlangen, Germany). Fluoroscopy mode was set to four frames/s, whereas cine mode was set to 7.5 frames/s. The NFCV (MGT) as well as the technology setup used in our institution has been described extensively in previous publications [4–6]. In brief, the NFCV uses a transmitter to create a 3D electromagnetic field. The transmitter unit is firmly integrated into the flat fluoroscopy detector, resulting in complete alignment of the fluoroscopic as well as the magnetic working space. Submillimeter sensors embedded in the tip of EP catheters are tracked within this 3D field. A reference sensor on the patient's chest works as an anchor for the system and continuously scans patient position within the tracking space. At least two cine or fluoroscopy loops in two different projections (3 s each) taken at the beginning of the procedure serve as the dynamic background imaging. Further on, autoregistered position and orientation of the catheter tips are projected on two screens simultaneously and in real time, giving the impression of a virtual biplane view. Heart beats, patient movement, and patient respiration do not influence the stability of catheter tip visualization because the system uses ECG and a reference sensor for immediate compensation. Utilization of pre-recorded cine loops instead of live fluoroscopy (nonfluoroscopic catheter tracking) is the main driver in reduction of radiation exposure.

2.2 General procedure setup

Randomization did not affect the treatment strategy. Moreover, catheter tip design was the same in both groups (3.5 mm cooled tip, irrigated through proximal and distal pores). The general procedure setup has been described previously [4–7]. Patients were studied under deep propofol sedation supplemented with midazolam and fentanyl. Arterial blood pressure was monitored via a 4F left femoral arterial access. Operator and cath lab staff started the procedure wearing lead aprons. Operators were encouraged to perform the procedure in sinus rhythm. Thus, patients in AF were cardioverted at the beginning of the procedure. In case of cardioversion failure or early recurrence, cardioversion was repeated after pulmonary vein isolation (PVI). We defined certain stages of the intervention in order to evaluate differentiated time consumption and fluoroscopy requirements.

Stage 1: placement of diagnostic catheters

In the CONV group, two diagnostic catheters were positioned in the right ventricular apex and coronary sinus using fluoroscopy as needed. In the NFCV group, native fluoroscopy loops were recorded in the RAO 20–30° and LAO 50–60° projections. Simultaneous display of these two pre-acquired loops in a continuous pseudo-

biplane mode constituted the background for nonfluoroscopic placement of two sensor-equipped diagnostic EP catheters (Livewire™ Catheter, MediGuide-Enabled™, St. Jude Medical) into the right ventricular apex and coronary sinus. At the operator's discretion, the catheters were also used to place markers for the superior caval vein, inferior caval vein, and oval fossa on the MGT screens.

Stage 2: transseptal puncture

In both groups, as a safety standard in our institution, single transseptal puncture was performed conventionally in the cine mode, with contrast dye injection through the needle used in order to prove left atrial access.

Stage 3: reconstruction

In the CONV group, LA geometry in the EAMS was created using the ablation catheter (Therapy™ CoolPath™ Duo, St. Jude Medical) and with fluoroscopic support as needed by the electrophysiologist. This geometry was fused with a pre-procedurally acquired and segmented CT reconstruction of the LA. At this stage, a temperature probe (Sensitherm, Abbott/St. Jude Medical) was inserted in the esophageal lumen at the level of the left atrium with fluoroscopic verification if needed.

In the NFCV group, cine loops with contrast injection into the left superior and right superior PVs via the steerable sheath (Agilis™, St. Jude Medical) were recorded. These angiographic cine loops now replaced the native loops as background movies. In this pre-recorded cine environment, additional fluoroscopy was usually not necessary for catheter navigation and was turned off to allow lab staff to remove lead protection for the remainder of the procedure. A NFCV-enabled ablation catheter (Therapy™ CoolPath™ Duo, MediGuide-Enabled, St. Jude Medical) was then introduced nonfluoroscopically into the LA via the steerable transseptal sheath. At the operator's discretion, anatomical markers were set on the MGT screens at the level of PV ostia. The NFCV-based catheter tracking was used for LA reconstruction in the EAMS (EnSite Velocity™) supported by the MGT field scaling algorithm, and CT image fusion was subsequently performed as described previously [4].

Stage 4: circumferential PVI (first pass)

All patients received antral circumferential radiofrequency (RF) lesions around both ipsilateral PVs. Catheters were navigated using the EAMS in both groups with additional visualization on the MGT screens in the NFCV group. In both groups, operators were encouraged to avoid additional live fluoroscopy. RF energy was delivered with an open-irrigated catheter (Therapy™ CoolPath™ Duo, St. Jude Medical, MediGuide-Enabled in the NFCV group). In our opinion, conformity of catheter tip technology and handling in both groups represents an important strength of the study enhancing the recognition of the true effect of additional NFCV use. Irrigation flow rate was set to 17 ml/min at a maximum tip temperature of 45 °C using 35 W. At the posterior wall, power delivery was reduced to 25 W. RF delivery was halted in case of intraesophageal temperatures > 39 °C. Whenever intraesophageal temperatures exceeded 41 °C, gastroscopy was scheduled for the next day to rule out severe mucosal damage. Bidirectional block was subsequently tested using a decapolar circular catheter (after catheter exchange through the single transseptal sheath).

Stage 5: circumferential PVI (completion)

In case of incomplete block, circumferential PVI was repeated using the "pace-and-ablate" strategy in order to find and close conducting gaps [8]. Bidirectional PVI block was again verified using the circular catheter and ablation repeated until completion of block in all pulmonary veins.

Stage 6 and 7: voltage mapping and additional substrate modification

In all patients, LA voltage maps in sinus rhythm were subsequently created using the ablation catheter as previously described. The decision for or against additional substrate modification followed an individualized concept, which has been published earlier [7]. According to this concept, no further substrate modification was performed in patients without low-voltage areas (< 0.5 mV). Whenever low-voltage areas were identified, these were either ablated by focal homogenization, encircled, or treated with strategic lines such as the septal line (from right superior PV to mitral valve annulus), the roof line (between both superior veins), or the anterior mitral isthmus line (from left superior PV to anterior mitral valve annulus). In case of large septal, anterior, or roof low-voltage areas, all three lines were combined to the so-called trigonal line concept, which also required ablation within this triangle in order to block interatrial connections through the Bachmann bundle. Large posterior low-voltage areas were treated with the box ablation (roof line plus posterior line between the two inferior PVs). Finally, all patients underwent high output (10 V/2 ms) decremental burst pacing in 20 ms steps from a basic drive cycle length until atrial refractoriness. Inducible regular atrial tachycardias were mapped and targeted for ablation. Cavotricuspid isthmus ablation was performed in patients with documented or induced typical atrial flutter.

2.3 Follow-up

Follow-up visits were scheduled after 3, 6, and 12 months. Additional visits were encouraged whenever symptoms occurred. At each visit, 12-lead-ECGs and 3-day or 7-day Holter-ECGs were recorded. Any documented atrial arrhythmia > 30 s was counted as a recurrence. The time period up to the scheduled 3-month visit was defined as a blanking period.

2.4 Data analysis

Continuous variables are expressed as mean ± standard deviation and categorical variables as frequencies (percentage). The Kolmogorov-Smirnoff test was used to check the normal distribution of continuous variables. In case of a non-Gaussian distribution, median (quartiles) is given. Intergroup differences were assessed by using the Student *t* test for independent samples or the nonparametric Mann-Whitney *U* test, as appropriate. The chi-square test or the Fisher exact test was used for discrete variables, as appropriate. A two-tailed p value < 0.05 was considered statistically significant. Analyses were performed using SPSS 20.0 (SPSS Inc., Chicago, IL, USA).

3 Results

3.1 Patients

A total of 80 patients (48 male (60%), mean age 60 ± 10 years, 46 (58%) with paroxysmal AF, and 16 (20%) with structural heart disease) were included in the study. Patient demographics stratified by randomization are shown in Table 1. There were no significant differences between the groups except more patients had arterial hypertension (37 vs. 28), diabetes (9 vs. 2), and structural heart disease (13 vs. 3) in the CONV vs. NFCV group.

3.2 Procedure times and fluoroscopy data

Fluoroscopy time was reduced by 86% (median (interquartile range), 1.9 (2.7) vs. 13.2 (4.6) min, $p < 0.001$), and fluoroscopy dose by 67% (510 (454) vs. 1549 (1973) Gcm^2, $p < 0.001$) using the NFCV system. Total procedure durations did not differ between the two groups (136 ± 43 vs. 141 ± 39 min, p = ns). Table 3 and Fig. 1 give an overview of fluoroscopic durations and doses, as well as time periods required for different stages of the procedure. In the NFCV group, fluoroscopy was mainly used for native loop acquisition for catheter positioning (stage 1), for the transseptal puncture (stage 2), and for the PV angiography loops (at the beginning of stage 3), which were used as the background image for LA reconstruction, voltage mapping, and ablation (stages 3–7). Entirely, non-fluoroscopic catheter placement using the native virtual biplane loops was possible in 38 out of 40 patients in the NFCV group. During the voltage-mapping process,

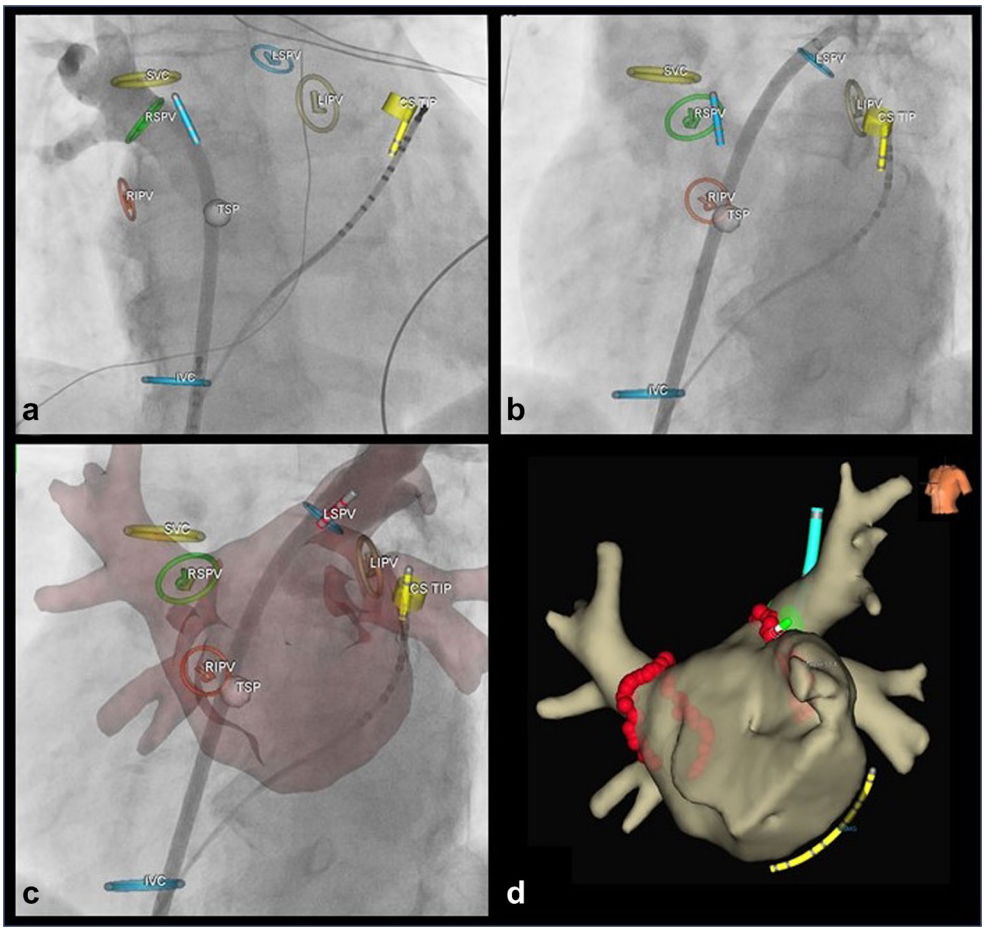

Fig. 1 Representative illustrations of the procedure setting using nonfluoroscopic catheter visualization. Fluoroscopy loops recorded in the RAO 20–30° (**a**) and LAO 50–60° (**b**) projections serve as the dynamic background imaging. The color rings mark the pulmonary vein ostia located by contrast-enhanced pulmonary vein angiography. The tip of the sensor-equipped catheter in the coronary sinus is depicted in yellow, the tip of the ablation catheter in the right superior pulmonary vein is shown in light blue. Additionally, the 3D left atrial shell created in the EAMS can be projected on the MGT screens (**c**). The catheter movement is projected on the two MGT screens simultaneously in real-time as well as in the EAMS (**d**). EAMS, electro-anatomical mapping system; MGT, MediGuide technology

fluoroscopic verification of catheter orientation was occasionally applied. During the entire mapping and ablation process, live fluoroscopy was occasionally used in the NFCV group patients for verification of exact position and orientation of catheter shaft or transseptal sheath. Of note, NFCV-enabled circular mapping catheters were not available at the time of our study. The MGT-based positional reference tool was used to recalibrate minor or major dislocations of the EAMS reference catheter placed in the coronary sinus in most cases.

3.3 Procedural data and outcome

Isolation of all four PVs by circumferential ablation as confirmed by a circular mapping catheter was achieved in all patients. There was no difference in total RF duration (36 (15) vs. 36 (19) min, p = ns) nor in the number of patients in whom additional lesion sets to treat low-voltage areas or induced atrial tachycardias (5 vs. 10 patients, p = ns) or cavotricuspid isthmus ablation (6 vs. 8 patients, p = ns) were necessary (NFCV vs. CONV group, respectively; Table 2). Follow-up duration was > 1 year in all patients of both groups (NFCV group, 566 (545) days vs. CONV group, 503 (407) days, p = ns). There was no difference in AT/AF freedom between the NFCV group and the EAMS group (60% vs. 73%, p = ns, respectively). One femoral arteriovenous fistula occurred in the EAMS group, which did not require surgical treatment. No other complications occurred.

4 Discussion

4.1 Main findings of the study

This is the first randomized study evaluating the effect of a novel catheter tracking technology in addition to a standard EAMS in the context of AF catheter ablation. We have previously demonstrated in an observational study that AF ablations can be done with an 80–90% reduction of radiation exposure compared to our own historical control [5, 6]. These effects were achieved with minor adaptations of established workflows and without increasing procedure duration, arrhythmia recurrence rates, or complications. Allowing the operator and the cath lab staff to perform large parts of the procedure without lead protection ("lead-free") may be feasible following transseptal puncture and acquisition of background angiographies for the NFCV.

Table 2 Procedural and outcome data

Parameter	NFCV group	CONV group	p value
Procedural data			
RF duration (min)*	36 (15)	36 (19)	0.38
CTI	6 (15%)	8 (20%)	0.77
Add. substrate modification	5 (13%)	10 (25%)	0.25
Follow-up data			
Follow-up (days)*	566 (545)	503 (407)	0.99
AT/AF freedom (%)	24 (60%)	29 (73%)	0.34

RF, radiofrequency; *CTI*, cavotricuspid isthmus ablation; *AF*, atrial fibrillation; *AT*, atrial tachycardia. Continuous data given as mean ± standard deviation, or median (interquartile range) in case of non-Gaussian distribution*

4.2 Technological issues responsible for fluoroscopy reduction

The specific feature of the NFCV is the combination of electromagnetic tracking and x-ray imaging on the hardware level. This allows for autoregistered real-time catheter tracking in the environment of two live and pre-recorded fluoroscopy sequences, representing a virtual biplane mode. The opportunity to use contrast-enhanced angiograms as background movies and the compensation for primary and secondary organ movements further increases catheter visualization quality, especially within complex anatomies.

Even though these properties render NFCV valuable as a stand-alone system for rather simple catheter ablations like cavotricuspid isthmus ablation for typical atrial flutter [9], the EAMS benefits from the MGT integration in two ways: (a) adjustment of the EAMS (impedance-based) reconstruction according to the NFCV (electroanatomic) coordinates ("Field Scaling") allowing very precise and realistic LA/PV models (facilitating the subsequent CT integration) and (b) using the sensor-equipped CS catheter as the positional EAMS reference allows for manual or automatic recalibration of map shifts caused by displacement of the reference catheter. Thus, redundant reconstruction and registration processes may be avoided.

Table 3 and Fig. 2 illustrate the amount of time and x-ray utilization at different stages of the procedure. The highest share of fluoroscopy use is caused by the background loop acquisitions in stages 1 and 3, which represent the minimum x-ray requirement. In our institution, transseptal puncture (stage 2) is done with fluoroscopy with a reasonable quality (7.5 frames/s) as internal safety and documentation standard. However, it has already been demonstrated that transseptal puncture can be safely performed with minimal fluoroscopy by using a MGT-enabled guidewire within the transseptal needle. Its distal tip can then be traced on the MGT screens. Successful left atrium access is subsequently confirmed by changes in the pressure curve and by advancing the guidewire into the left pulmonary veins [10, 11]. For the rest of the procedure, fluoroscopy use may be completely abandoned and is still a matter of operator adaption. Due to the fact that the catheter shaft, transseptal sheath, and circular catheter were not visualized on the NFCV screens, additional

Table 3 Procedure times and fluoroscopy data

Parameter	NFCV group	CONV group	*p* value
Overall			
Procedure duration (min)	136 ± 43	141 ± 39	0.45
Fluoro dose (Gycm^2)*	510 (454)	1549 (1973)	< 0.001
Fluoro time (min)*	1.9 (2.7)	13.2 (4.6)	< 0.001
Stage 1: placement of diagnostic catheters			
Duration (min)	22 ± 9	22 ± 10	0.78
Fluoro dose (Gycm^2)*	14 (23)	41 (51)	0.004
Fluoro time (min)	0.2 ± 0.1	1.2 ± 0.5	< 0.001
Stage 2: transseptal puncture			
Duration (min)*	5 (4)	8 (5)	0.21
Fluoro dose (Gycm^2)*	113 (395)	559 (930)	0.004
Fluoro time (min)*	0.2 (0.1)	0.4 (0.5)	0.003
Stage 3: reconstruction			
Duration (min)	19 ± 8	21 ± 9	0.61
Fluoro dose (Gycm^2)	202 ± 90	242 ± 148	0.01
Fluoro time (min)*	0.1 (0.2)	3.5 (2.0)	< 0.001
Stage 4: circumferential PVI (first pass)			
Duration (min)*	50 (31)	40 (51)	0.88
Fluoro dose (Gycm^2)*	11 (36)	115 (206)	0.003
Fluoro time (min)*	0.2 (1.1)	2.3 (2.1)	< 0.001
Stage 5: circumferential PVI (completion)			
Duration (min)	17 ± 14	16 ± 10	0.38
Fluoro dose (Gycm^2)*	5 (40)	101 (54)	< 0.001
Fluoro time (min)*	0 (0.6)	1.3 (1.5)	< 0.001
Stage 6: voltage mapping			
Duration (min)*	8 (7)	8 (12)	0.97
Fluoro dose (Gycm^2)*	2 (10)	93 (107)	0.15
Fluoro time (min)*	0.1 (0.2)	1.3 (0.9)	0.003
Stage 7: additional substrate modification			
Duration (min)*	8 (11)	12 (25)	0.57
Fluoro dose (Gycm^2)*	1 (15)	44 (232)	0.03
Fluoro time (min)*	0.1 (0.4)	1.3 (5.9)	0.10

PVI, pulmonary vein isolation. Continuous data given as mean ± standard, or median (interquartile range) in case of non-Gaussian distribution*

fluoroscopy was mainly used for safety reasons when their orientation was not entirely clear. We still experience an ongoing learning curve, and nowadays, NFCV-guided AF catheter ablations are routinely performed with total fluoroscopy times below 1 min [6].

4.3 Implications of minimal fluoroscopy use

Medical radiation is the largest man-made source of radiation exposure, even higher than natural background radiation [12]. Interventional cardiologists are responsible for most of the exposure, and among these, electrophysiologists play an increasing role. Quantity and complexity of interventional EP studies and AF catheter ablation in particular have been continuously rising over the last two decades [13, 14]. Preprocedural imaging like CT and redo procedures affects each individual patient. All these factors result in high cumulative radiation exposure for both patients and staff, linearly correlating with a higher long-term risk of developing malignancy [2]. For example, an excess risk of (left-sided) brain tumors and breast cancers among interventional cardiologists and radiologic technologists is suspected [15, 16]. Skin injuries and eye cataracts are additional threats caused by excessive medical radiation use [17]. Wearing heavy lead aprons and collars can protect operator and staff from radiation, but may cause orthopedic problems [17]. The best protection against deleterious radiation effects for patients and staff is to apply lowest possible radiation dose needed to complete the procedure successfully (ALARA principle). All possible techniques and procedures must be therefore deployed in order to minimize radiation exposure of both patients and physicians involved in catheter ablation procedures. These measures include appropriate filtration, pulsed fluoroscopy, collimation, and real-time digital fluoroscopy processing in the daily cath lab setup [18]. Moreover, technological tools and developments like 3D navigation and mapping play an important role. Novel technologies using cooperation of x-ray systems and electroanatomic mapping on the hardware level increase the potential to further decrease radiation exposure [6, 19]. Transseptal puncture remains the most significant issue to eliminate radiation use during AF ablation. This is due to the fact that the important anatomic landmarks used to guide safe transseptal passage can be identified on fluoroscopy but not with EAMS systems alone while traceable transseptal needles are not available yet. In this regard, intracardiac echocardiography (ICE) may be valuable, with which the use of which transseptal access can be safely achieved. Application of ICE in addition to the 3D EAMS has been shown to allow left atrial ablation procedures including PVI without fluoroscopy [20–22].

4.4 Future technological developments

Further expansion of the MGT-enabled device spectrum to sheaths, guide-wires, and needles as well as optimizations like catheter shaft visualization will successively make live fluoroscopy for AF catheter ablation dispensable. Acquisition of background loops may then remain the only source of x-ray use. Availability of MGT-enabled catheters with state-of-the-art tip technologies will be necessary for the system to remain competitive with other advanced EAMS.

4.5 Limitations

The study was performed by experienced operators in a single reference EP institution which may limit the generalizability of the results. Outcome interpretation should appreciate that

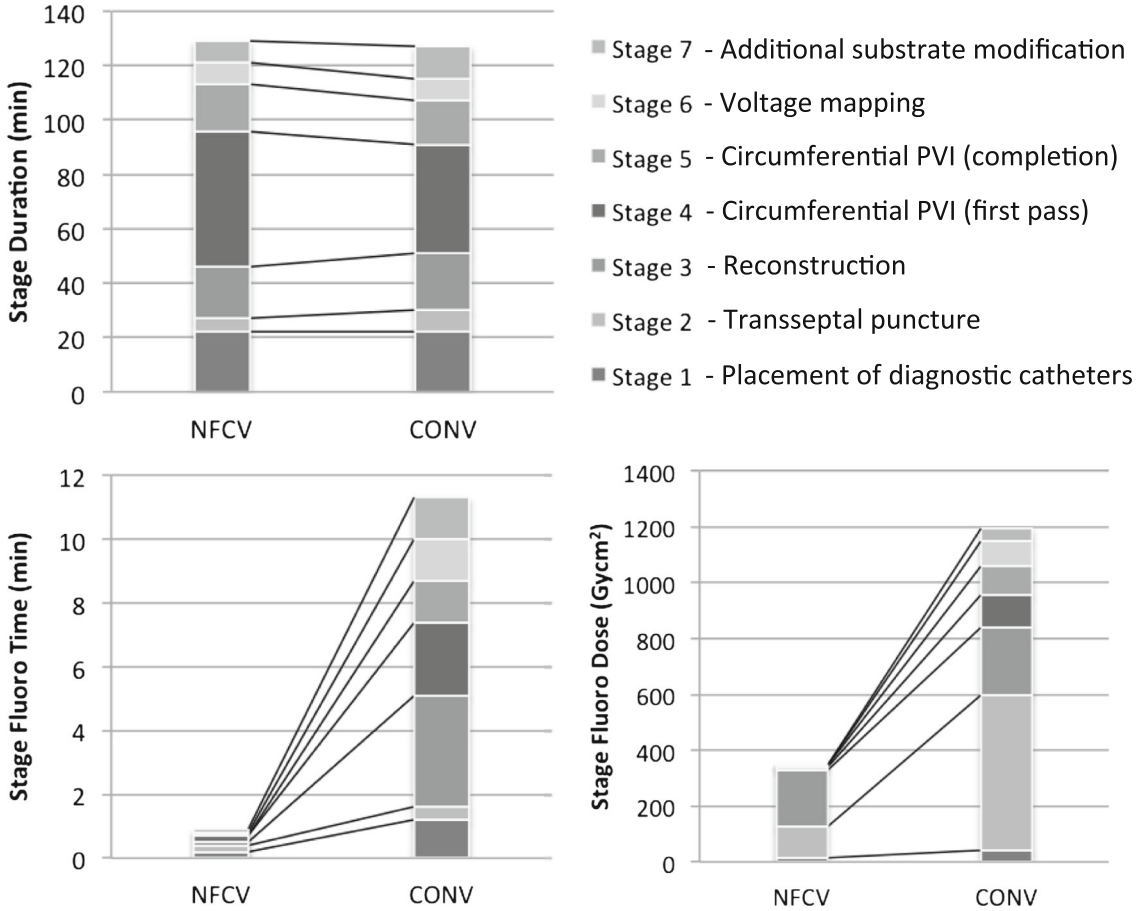

Fig. 2 Graphic visualization of duration, fluoroscopy dose, and time at different stages of the procedure. Stage 1, placement of diagnostic catheters; stage 2, transseptal puncture; stage 3, 3D reconstruction of left atrium; stage 4, circumferential pulmonary vein isolation (first pass); stage 5, completion of pulmonary vein isolation verified by circular catheter; stage 6, voltage mapping; stage 7, additional substrate modification

the examined cohort included patients with quite heterogeneous characteristics including a high proportion of patients with persistent AF and structural diseases. Moreover, contemporary contact force technology was not utilized in this study because such MGT-enabled ablation catheters were not available at the time of study enrollment. Utilization of the currently available sensor-equipped circular mapping catheters would probably have further increased the fluoroscopy savings.

5 Conclusions

Radiation exposure can be significantly reduced to a minimum using the novel NFCV technology in addition to standard EAMS-guided AF ablation technologies without increasing procedure durations, recurrences, or complications. Complete abolition of additional fluoroscopy use, allowing for working without lead protection following transseptal puncture, is possible.

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Compliance with ethical standards

Conflict of interest S. R. and P. S. received modest honoraria for speaking at symposia.

Ethical approval The institutional ethics committee approved the study.

Informed consent All study participants provided written and verbal informed consent.

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