Observations and Considerations on Patient X-ray Exposure in the Electrophysiology Lab

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Abstract

To assess patient radiation during catheter ablation procedures and operator differences. From 84 patients (51 males, age 63 ± 10 years) undergoing complex catheter ablation by three experienced operators we collected: body mass index (BMI), procedure type and time, fluoroscopy time, dose area product (DAP), air kerma and X-ray system setting (cine, collimation and angiographic imaging angle). A new factor, fluoroscopy DAP–fluoroscopy time ratio, was introduced to compare operator differences. The results show the average procedure time was 179 (± 57) minutes (min), fluoroscopy time was 31 (± 21) min, DAP was 26.4 (± 19.6) Gy.cm² and air kerma was 0.26 (± 0.19) Gy. Procedure types were: pulmonary vein isolation (PVI) (52 %), redo PVI (11 %), pulmonary vein ablation catheter (PVAC) (14 %), ventricular tachycardia (VT) (8 %) and others (15 %). Inter-operator difference was observed in fluoroscopy and cine usage. Fluoroscopy DAP-time ratios showed a similar level of patient radiation dose rate by operator A and B (correlation: 0.89), and a significantly higher dose rate by operator C (correlation: 0.20, $p<0.001$; 0.26, $p<0.01$, to operator A and B). In conclusion, operators should be aware of patient radiation exposure levels and the influencing factors. Inter- and intra-operator differences can be measured and bench marked for improvement in X-ray efficiency and patient radiation reduction.

Keywords

Catheter ablation, electrophysiology, patient radiation dose, operator difference, radiation reduction

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Due to its high success rates and low complication risks, catheter ablation has evolved as a first-line treatment for various cardiac arrhythmias, including more complex arrhythmias such as ventricular tachycardia (VT) and atrial fibrillation (AF).[1–4] Greater understanding of arrhythmia substrates and the development of advanced electroanatomical mapping systems have contributed to a rapid growth in the numbers of complex catheter ablations performed worldwide.[1] Nevertheless, in spite of a growing use of non-fluoroscopic mapping systems to guide these procedures, fluoroscopy still constitutes to be an indispensable tool for image guidance in these procedures.[4]

Exposure to ionising radiation is related to subacute skin injury[5] as well as radiation-induced cancer and genetic abnormalities.[6–10] These risks are of particular concern for young patients and patients undergoing long and complex or repeated procedures. Operators, including technicians and nurses, especially those performing large numbers of procedures, are also exposed to risks from radiation such as malignancy.[11] Radiation exposure to patients in the electrophysiology (EP) lab, as published in many studies, may vary widely,[5,12–14] sometimes even exceeding threshold dose required for the onset of radiation-induced skin injuries.[5–11,15]

Therefore, it is of pivotal importance to understand the radiation dose-related parameters as provided by the X-ray system (i.e. dose area product (DAP), air kerma (AK) and fluoroscopy time) and particularly these parameters in relation to operator's preference in X-ray usage. Better understanding and awareness of these parameters may lead to a reduction of potentially harmful X-ray exposure for both patients and workers in the EP lab. Easy measures such as image collimation, avoidance of steep projection angles, minimising source image distance (SID) as well as using low dose fluoroscopy and avoidance of magnification significantly reduce patient and operator radiation dose exposure.[5] The purpose of this paper is to explain the meaning and determinants of radiation dose parameters, and to share thoughts on how these parameters can be interpreted to reduce X-ray exposure in the EP lab without jeopardising procedural outcome and safety.

Methods

Study Design

We included 84 consecutive patients (51 males and 34 females) undergoing complex catheter ablation procedures by three experienced electrophysiologists in the Catharina Heart Center in Eindhoven, The Netherlands (end-August to mid-November 2011). At each procedure we collected the following data: patient body mass index (BMI), procedure type and time, fluoroscopy time, DAP, AK and the operating physician. In addition, technical parameters including cine usage, SID, X-ray projection angle and image collimation were retrieved from X-ray system logging to recognise the operators' X-ray usage preferences and differences. The ablation procedures were categorised as:

- Pulmonary vein isolation (PVI), during which an electromagnetic mapping system is used, such as CARTO® (Biosense Webster, Diamond Bar, US) or Ensite™ (St Jude Medical, St Paul, US).

- Redo of PVI for paroxysmal AF, which in this centre is performed with a circular diagnostic catheter and a thermo-cool ablation catheter while using X-ray as the sole imaging modality.
- Pulmonary vein ablation catheter (PVAC, Medtronic, Minneapolis, US) procedure for paroxysmal AF, in which EP-navigator and a multi-electrode phased radio-frequency (RF) PVAC are used – in a subgroups of PVAC-procedures three-dimensional (3D) rotational atriography was used.[16]
- VT ablation including procedures for both scar dependent VT and idiopathic VT, for which CARTO or Ensite mapping were always used.
- Supraventricular tachycardia (SVT) ablation, solely dependent on X-ray imaging.
- Atrial tachycardia ablation for which CARTO or Ensite mapping were always used.

All the procedures were done in one catheterisation lab using a monoplane flat panel angiographic system (Allura Xper FD10, Philips Healthcare, Best, The Netherlands). This registry was approved by the hospital's ethics committee.

Understanding of Radiation Dose Parameters in Practice

Angiographic systems report a set of radiation dose parameters. We hereby explain in simple terms what they mean for better understanding in practice.

Typically, radiation is measured and reported in both the concentration and the total amount. Radiation concentration describes the 'strength' or per-unit energy delivered to (or absorbed by) the patient under X-ray exposure. AK is a measure of this kind. It stands for kinetic energy released per unit mass of air. It is a measure of the amount of radiation energy, in the unit of joules (J) per unit mass (kg) of air, i.e. gray (Gy=J/kg). Due to the cone shape of the X-ray beam, the further away from the X-ray source, the less concentrated the radiation is. By regulation, AK is always reported as the measure at the same reference point in the X-ray beam where it is considered as the radiation entry point to the patient's body (i.e. 15 cm from the isocentre toward the X-ray source). AK is regulated by the angiographic system to ensure constant image quality. DAP on the other hand describes the total amount of radiation toward the patient. It is the product of dose concentration and exposed area at the plane of measurement, i.e. DAP (Gy.cm²) = AK x irradiated area. Given a fixed AK, DAP varies according to the change of X-ray beam size (e.g. by image collimation).

The clinical relevance of these two parameters is that:

- AK as a radiation concentration measure is an effective indicator of acute radiation injury (deterministic risk, e.g. skin burn and hair loss); and
- DAP as a measure of the amount of energy irradiated to the patient, could be used to relate to potential stochastic effect (e.g. cancer risk).

A Novel Parameter on the Operator – Fluoroscopy Dose Area Product to Fluoroscopy Time Ratio

Fluoroscopy time indicates the amount of fluoroscopy imaging that is needed to accomplish a clinical procedure. It is dependent on the procedure type, the clinical difficulty and the operator's catheter skills. DAP is correlated to fluoroscopy time[17] and hence influenced by these predetermined factors listed above. However, the correlation is weak due to other influencing factors e.g. patient obesity.[14] Moreover, DAP is also determined by the operator's conscious effort in minimising patient radiation by measures such as image collimation and avoidance of steep projection angles. As a result, in order to evaluate and compare operators' active effort in minimising patient radiation, despite other clinical factors, we derived a novel parameter in which procedural DAP from fluoroscopy is normalised by fluoroscopy time.

Fluoroscopy DAP–Fluoroscopy Time Ratio

Patient body size is a major determinant of the radiation dose level and of this ratio. It should be taken into account when analysing this novel parameter.[14]

Table 1: Patient and Procedure Characteristics

Age, years	63 ± 10
Weight, kg	83 ± 15
Height, cm	175 ± 11
BMI, kg/m²	27 ± 4
BMI <25 kg/m², n (%)	28 (34)
BMI 25 to <30 kg/m², n (%)	37 (44)
BMI ≥30 kg/m², n (%)	18 (22)
Procedure time, minutes	179 ± 57
Fluoroscopy time, minutes	31 ± 21
Number of cine runs	4 ± 3
AK, Gy	0.26 ± 0.18
Dose area product (DAP), Gy.cm²	25.9 ± 18.0
Data are mean ± SD	

AK = air kerma; BMI = body mass index; SD = standard deviation.

Patient Effective Dose Simulation

Commercially available software PCXMC (Radiation and Nuclear Safety Authority, Helsinki, Finland) was used for patient effective dose simulation, using the mean values of the observation results.

Statistical Analysis

Data are presented as mean ± standard deviations, unless stated differently. Inter-operator difference was tested by correlation calculations on the fluoroscopy DAP–fluoroscopy time ratios between the patient subgroups per operator. Operator characteristics in patient radiation dose during catheter ablation procedures were derived by regression tests on the fluoroscopy DAP–fluoroscopy time ratios per patient. For each operator, a polynomial trendline was calculated and plotted against patient body size.

Results

General Observations and Procedure Differences

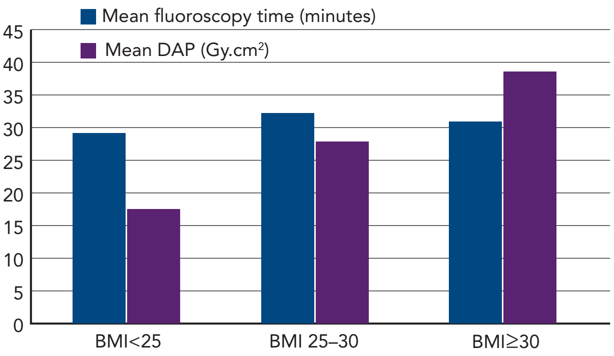
General observations are listed in *Table 1*. The patients had an average age of 63 (± 10) and an average BMI of 27 (± 4) kg/m². Forty-four percent of the patients were overweight (BMI 25–30 kg/m²) and 22 % were obese (BMI ≥30 kg/m²). With all the catheter ablation procedures included, we observed an average DAP of 25.9 (± 18.0, third quartile: 34.1) Gy.cm² and an average AK of 0.26 (± 0.18, third quartile: 0.38) Gy. Mean procedure time was 179 (± 57) minutes (min). Mean fluoroscopy time was 31 (± 21) minutes. On average, 4 (± 3) cine runs were acquired per procedure. Based on the above mean values, effective dose simulation estimated an equivalent dose of 9.3 millisievert (mSv) per procedure.

Table 2: Fluoroscopy Time and Dose Area Product for Each Catheter Ablation Category

	PVI (n=44)	Re-PVI (n=8)	PVAC (n=11)	VT (n=7)	SVT (n=6)	Atrial tachycardia (n=8)	All (n=84)
Fluoroscopy time, minutes	35 ± 18	47 ± 38	20 ± 4	23 ± 18	12 ± 6	35 ± 26	31 ± 21
DAP, Gy.cm^2	30.2 ± 17.6	35.2 ± 21.0	21.5 ± 13.9	18.5 ± 19.5	5.7 ± 2.9	20.5 ± 14.9	25.9 ± 18.0
% in DAP by fluoroscopy	82 %	77 %	61 %	99 %	99 %	91 %	82 %

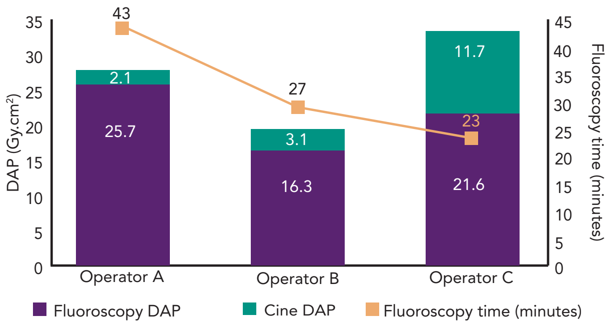
Data are mean ± SD, DAP = dose area product; PVAC = pulmonary vein ablation catheter; PVI = pulmonary vein isolation; SD = standard deviation; SVT = supraventricular tachycardia; VT = ventricular tachycardia.

Figure 1: Fluoroscopy Time and Dose Area Product According to Body Mass Index



BMI = body mass index; DAP = dose area product.

Figure 2: Operator Differences in Fluoroscopy Usage and Efficiency



DAP = dose area product.

The catheter ablation procedures were categorised as PVI (52 %), redo PVI (10 %), PVAC (13 %), VT (8 %), SVT (7 %) and atrial tachycardia (10 %). As shown in *Table 2*, differences in fluoroscopy and DAP time were observed between procedure types. Redo of PVI required the most fluoroscopy (47, ± 38 min) and lead to the highest radiation dose (DAP: 35.2, ± 21.0 Gy.cm^2), whereas SVT required the least fluoroscopy (12, ± 6 min) and the lowest radiation dose (5.7, ± 2.9 Gy.cm^2). Large standard deviation in fluoroscopy time was observed for most of the procedure types except PVAC.

Mean fluoroscopy DAP per procedure was 20.4 (± 14.6, third quartile: 31.2) Gy.cm^2. It accounted for 82 % of the overall procedural DAP, with the remaining of DAP contributed by cine or rotational X-ray acquisition. Fluoroscopy and the resulted DAP were found predominant in VT, SVT and atrial tachycardia procedures (99–91 % of procedure DAP), and least so in PVAC ablations (61 % of procedure DAP).

Patient Size – Impact on Radiation Dose

In three patient groups according to BMI (<25, 25–30, ≥30 kg/m^2, respectively), there was no significant difference in fluoroscopy time ($p>0.48$). However, DAP per group had significant differences ($0.002>p>0.082$). Proportional impact of patient BMI on DAP is shown in *Figure 1*. In catheter ablation procedures, due to direct exposure of X-ray, patient chest size is particularly relevant and a more precise description of the body size compared to BMI. Patient chest size was derived as the average thickness in the chest area per patient during the entire procedure. This was measured and recorded by the X-ray system. In *Figure 3*, patient chest size was plotted against the fluoroscopy DAP–fluoroscopy time ratio in the corresponding procedure. A generic trend of rising radiation dose level (per unit time) with increased chest size was observed, regardless of procedure type and the operator.

Operator Characteristics

Inter-operator differences were observed in fluoroscopy time, fluoroscopy DAP and cine DAP *(see Figure 2)*. Fluoroscopy DAP–fluoroscopy time ratios were calculated per operator to exclude variations in procedure type and procedure difficulty; it therefore serves as an estimate of the operators X-ray awareness. When comparing the fluoroscopy DAP–fluoroscopy time ratios, operator A and B showed similar levels of fluoroscopy usage efficiency (correlation: 0.89), whereas operator C was less efficient and significantly different from the others (correlation: 0.20, $p<0.001$; 0.26, $p<0.01$, to operator A and B).

Operator specific characteristics in the fluoroscopy DAP–fluoroscopy time ratio were analysed using regression tests in the corresponding patient subgroups. Operator influence on patient radiation dose level were modelled by polynomial trendlines based on patient chest size (confidence interval [CI] 95 %, see *Figure 3*). Operator A and B showed great similarity in radiation dose level (per unit time) at all patient chest sizes, whereas operator C had a consistently higher level.

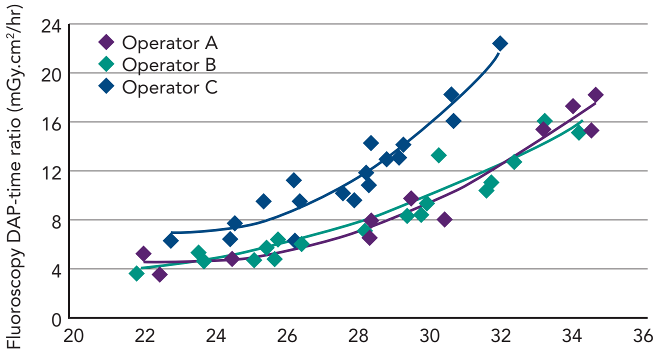
X-ray system usage per operator (see *Table 3*) showed common choice in SID and image projection angles. By X-ray collimation, operator A and B had an average of 28 % smaller exposed image size, hence less radiation to the patient. All three operators mainly used low dose modes in fluoroscopy. Operator C had a large percentage of cine demanding procedures and showed a preference of using a high cine image frame rate, resulting in higher average cine DAP than operator A and B.

Discussion

Our results in DAP, AK, fluoroscopy time and equivalent patient effective dose in catheter ablation procedures are at lower to comparable levels to those reported in the literature.[5,7,8,10,12] Interestingly, compared with a recent multicentre study by Kidouchi et al.,[18] our results showed lower levels of radiation dose on patients with higher BMI values. This could be due to differences in the angiography systems and way of working.

Results reported in the literature and in this study consistently show widespread procedure duration and patient radiation dose in catheter ablation procedures, resulting in large standard deviations in these

Figure 3: Characteristic Patient Radiation Dose Trendlines per Operator



(CI=95 %, excl. outlier). DAP = dose area product

Table 3: Operator Characteristics and Differences

	Operator A	Operator B	Operator C
Patient BMI	28.2±4.4	26.6±4	27.1±3.9
Procedure types that requires minimal cine (VT, SVT, atrial tachycardia), %	40 %	32 %	12 %
X-ray source to image distance (SID), cm	101±6	100±5	101±5
Imaged area (incl. image collimation), cm^2	194±69	198 ±65	274 ±68
X-ray image angulation: cranial-caudal, °	0.8 ±1.5	0.5±1.9	0.0±1.4
X-ray image rotation: LAO-RAO, °	6±28.6	6.8±28.7	3.4±28.4
Percentage of DAP by fluoroscopy	92 %	84 %	65 %
Low dose setting usage in fluoroscopy, %	90 %	97 %	84%
Most frequently used cine image rate[1], per sec	3.75	7.5	15

[1]Exclusive of procedures that require 15 cine images per second by default. LAO = left anterior oblique; RAO = right anterior oblique.

parameters. The reason lies in varying procedural types and complexity, patient size differences, and not to neglect, operator differences in using X-ray and optimising radiation efficiency. *Table 2* shows that, in this study, different procedure types require different amount of fluoroscopic and cine images. VT and SVT require short fluoroscopy time and almost no cine, whereas other types of ablations demand longer fluoroscopy and more cine runs. *Figure 1* and *Figure 3* clearly illustrate the strong correlation between patient size and radiation dose, as has been published previously.[14] In general, the larger the patient, the more radiation is required during the ablation procedure. According to the regression test shown in *Figure 3*, patients with comparable chest size could receive different level of X-ray radiation exposure due to the operator differences. However, the generic trend of increasing radiation exposure with body size is deterministic.

Instead of AK and DAP, fluoroscopy time is often used in clinical practice as an easy estimate for patient radiation level in catheter ablation procedures. With the complexity of procedural difference in X-ray imaging needs, patient chest size variations and operator differences, fluoroscopy time can hardly provide reliable comparison between cases or between operators. *Figure 2* illustrates that between operators, DAP distribution in fluoroscopy and cine varies due to the operator's specialized procedure types and the operator's preference in using X-ray. *Table 3* indicates that indeed operator C had more cine demanding procedure (Re-do PVI, PVAC) than operator A and B and preferred to use higher cine image frame rate. In this study we proposed a new parameter, the fluoroscopy DAP-fluoroscopy time ratio, to further compare the operators' efforts in reducing radiation, independently of procedure time, type and difficulty, as well as catheter skills. Shown in *Figure 3*, patients treated by operator A and B could expect similar levels of fluoroscopy dose rate per unit time, while patients treated by operator C would generally receive higher dose rate at all body sizes. Based on findings in *Table 3*, improvement in X-ray collimation and low dose fluoroscopy usage could potentially help operator C reduce fluoroscopy dose rate and therefore lower the fluoroscopy DAP.

Despite operator differences, in our centre, we emphasize low radiation during interventions by utilising low fluoroscopy setting, low cine frame rate, small SID and avoidance of steep image projection angles. All these elements contribute to minimising X-ray exposure in catheter ablations in EP labs. As X-ray currently remains necessary for all routine EP procedures, it inevitably poses potential risks to the patient and the staff. Lowering X-ray exposure will lower patient and occupational radiation dose. Despite the fact that developments in X-ray techniques and image processing have reduced exposure, dose awareness and simple actions importantly further reduce X-ray exposure.[19] Moreover, in the field of EP practice, comprehensive X-ray usage training on physicians, multicentre radiation dose studies and further optimisation of X-ray imaging techniques, could all contribute to reduce radiation exposure.

Conclusion

Operators in the electrophysiology lab should be aware of patient radiation exposure levels and the influencing factors to patient radiation dose. Inter- and intra-operator differences can be measured and benchmarked for improvement in X-ray efficiency and patient radiation reduction. ■

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