

Patients’ Radiation Exposure during Various Types of Cardiac Arrhythmias Ablation

Somayeh Delavarifar¹, Mohammad Hossein Nikoo^{2,*}, Mohammad Vahid Jorat³, Amir Savardashtaki⁴, Mehrab Sayadi⁵

¹ Student Research Committee, Shiraz University of Medical Sciences, Shiraz, IR Iran
² Non-communicable Disease Research Center, Shiraz University of Medical Sciences, Shiraz, IR Iran
³ Cardiovascular Research Center, Shiraz University of Medical Sciences, Shiraz, IR Iran
⁴ Department of Medical Biotechnology, School of Advanced Medical Sciences and Technology, Shiraz University of Medical Sciences, Shiraz, IR Iran
⁵ Student Research Committee, School of Medicine, Department of Biostatistics, Shiraz University of Medical Sciences, Shiraz, IR Iran

ARTICLE INFO

Article Type:
Research Article

Article History:
Received: 17 Jul 2016
Revised: 04 Feb 2017
Accepted: 07 Feb 2017

Keywords:
Ablation
Radiation
Dosage

ABSTRACT

Background: Cardiac Radiofrequency (RF) ablation is used for treating some types of heart rhythm problems. The number of RF ablation procedures is increasing rapidly due to lower complication risks than surgery and high success rates. Due to higher patient exposure to X-ray radiation in different cardiac ablation procedures, public concerns are increasing regarding the detrimental effects of ionizing radiation, including skin injury, genetic effects, and malignancy.

Objectives: This study aimed to determine patient absorption doses during Electrophysiological Study (EPS) and RF ablation of different cardiac arrhythmias in an electrophysiology laboratory unit with a flat panel detector.

Patients and Methods: This cross-sectional study was performed on 223 patients who underwent cardiac EPS and RF ablation. All procedures were executed on a single panel angiography unit with floor mounted C-arm. Dose Area Product (DAP), Entrance Skin Dose (ESD), and Fluoroscopy Time (FT) were recorded in all different procedures. Also, Total FT (TFT), total DAP, and total ESD were analyzed in the 223 procedures separately. Pearson’s correlation test was used to estimate the relationships between FT and DAP, FT and ESD, and ESD and DAP.

Results: In this study, 56.1% of the patients were female. The mean age of male and female patients was 43.9 and 47.7 years, respectively. Medians of TFT, total ESD, and total DAP were 7.4 min, 165 mGy, and 19.2 Gycm2, respectively. Total ESD was strongly correlated to DAP ($r = 0.945$, $P < 0.001$). Significant correlations were also observed between FT and DAP ($r = 0.843$, $P < 0.001$) and between FT and ESD ($r = 0.747$, $P < 0.001$). AF ablation procedures had the highest medians of DAP, ESD, and FT values during all types of cardiac arrhythmias.

Conclusions: For prevention of deterministic and stochastic effects of radiation exposure, such as skin damage and cancer, operators should attempt to reduce patients’ radiation exposure as low as reasonably achievable. In the current study, none of the patients’ ESDs exceeded the threshold dose. The maximum ESD and DAP values were attributed to AF ablation procedures. Significant correlations between DAP and FT as well as between ESD and FT and the strong correlation between DAP and ESD showed that ESD could be reduced by reducing FT and DAP.

1. Background

Cardiac fluoroscopy is used for diagnostic purposes, catheter positioning, interatrial septal puncture, focal and linear

ablation, pericardiocentesis, and mapping of arrhythmias. Radiofrequency (RF) ablation is a well-proven technique used for treating some types of heart rhythm problems, such as Atrioventricular Nodal Reentrant Tachycardia (AVNRT), Atrial Flutter (AFL), Atrial Fibrillation (AF), Atrial Tachycardia (AT), Ventricular Tachyarrhythmia (VT), Premature Atrial Contractions (PAC), Premature

*Corresponding author: Mohammad Hossein Nikoo, Non-communicable Disease Research Center, Shiraz University of Medical Sciences, Shiraz, Iran, Cellphone: +98-9177115940, E-mail: mhnmp@yahoo.com

Ventricular Contractions (PVC), and Wolff-Parkinson-White Syndrome (WPW). The number of RF ablation procedures is increasing rapidly due to lower complication risks than surgery and high success rates. These procedures have replaced pharmacological therapy and are performed under fluoroscopy guidance (1-6). RF ablation procedures require more prolonged Fluoroscopy Time (FT) compared to conventional angiography. Some ablation procedures need substrate modification that increases the procedure and fluoroscopy time substantially, which can increase the potential risk for both patients and operators. Due to higher patient exposure to X-ray radiation in different cardiac ablations, global concerns are increasing regarding the biological effects of ionizing radiation, including skin injury, genetic effects, and malignancy, especially for young patients (7-10). These biological effects are divided into deterministic and stochastic categories. Skin injury is a deterministic effect of radiation and the severity of the effect increases with increasing the radiation dose exceeding the threshold. According to Food and Drug Administration (FDA), cardiac catheter ablation has the potential to induce serious skin damage (11). Also, multiple diagnostic procedures can occasionally lead to enhancement of cumulative dose and induce skin injury. In addition to deterministic effects, ionizing radiation has stochastic effects. Gene mutation and genomic instability, chromosomal abbreviation, cellular transformation, cell death, and carcinogenesis are some stochastic effects of ionizing radiation in mammalian cells. Carcinogenesis is a somatic and stochastic effect of radiation exposure and is indistinguishable from those occurring due to other reasons. Since DNA is a critical target in mammalian cells, ionizing radiation can induce various types of DNA lesions, such as single-strand breaks and double-strand breaks. Although very low doses of radiation can induce double-strand breaks, they can be repaired by repairing mechanism very effectively. In fact, all primary DNA lesions are exposed to cellular repair processes, but badly-repaired or unrepaired ones may cause chromosomal aberrations and induce cancer and malignancy (12). Thus, for prevention of deterministic and stochastic effects of radiation exposure, such as skin damage and cancer, it is necessary to reduce radiation exposures as low as reasonably achievable. Modern angiography systems have been equipped with transmission ionization chamber to measure the Dose Area Product (DAP). Total DAP and total Entrance Skin Dose (ESD) are good quantities for estimating stochastic effects and dosage absorbed by the skin (13).

2. Objectives

This study aimed to determine patient absorption doses during Electrophysiological Study (EPS) and RF ablation of different cardiac arrhythmias in an electrophysiology laboratory unit with a flat panel detector.

3. Patients and Methods

This cross-sectional study was approved by the Ethics Committee of Shiraz University of Medical Sciences (SUMS), Shiraz, Iran and was performed in accordance with the guidelines of the University. The study was conducted on 223 patients (98 males and 125 females aged

15 - 86 years) who underwent cardiac RF ablation with different types of cardiac arrhythmias. All procedures were performed on a single panel angiography unit (SimensArtis Zee, Erlangen, Germany) with floor mounted C-arm. The data were gathered from the hemodynamic department of the X-ray system from December 2015 to September 2016. The electrophysiology mode was used in all procedures. In addition, a DAP meter, ionization chamber was loaded beyond X-ray collimators for measuring the radiation imparted to the patients. For generating the RF current, a conventional electrosurgical unit (Irvine Biomedical Inc., St. Jude Medical Company, California, USA) was utilized at the frequency of 485 KHz and maximum energy of 150 Watts. A cutaneous dispersive pad was placed on the posterior left thigh or thorax. Once the site of target was determined, the RF energy was delivered between the electrode at the distal side of the ablation catheter and the pad. DAP, ESD, and FT were recorded in different procedures, including EPS, AVNRT, Atrio Ventricular Reentrant Tachycardia (AVRT), WPW, PVC, AT, VT, AF, Right Posteroseptal (Rt-PS) accessory pathway, Left Posteroseptal (Lt-PS) accessory pathway, Left Septal Ventricular Tachycardia (LSVT), Left Ventricular Outflow Tract (LVOT), Right Ventricular Outflow Tract (RVOT), and left lateral and and Rt-anterior-free wall accessory pathway ablation. Also, Total FT (TFT), total DAP, and total ESD were analyzed in the 223 procedures separately. Moreover, the correlations between FT and ESD, FT and DAP, and DAP and ESD were analyzed.

3.1. Statistical Analysis

All statistical analyses were performed using IBM statistics 22 (SPSS Inc., Chicago, Illinois). Descriptive statistics with median, 1st quartile, and 3rd quartile were used to summarize the patients' radiation doses. Besides, Pearson's correlation test was used to estimate the relationships between FT and DAP, FT and ESD, and ESD and DAP. $P < 0.05$ was considered to be statistically significant.

4. Results

In this study, 56.1% of the patients were female. The mean age of male and female patients was 43.9 and 47.7 years, respectively. The details of radiation exposure, such as DAP, FT, and ESD, for EPS and ablation of each type of arrhythmias have been presented in Table 1. Additionally, TFT, total ESD, and total DAP values in the 223 patients with various types of cardiac arrhythmias have been depicted in Table 2. It should be noted that due to non-normal distribution of the data, all values have been represented as median, 1st quartile, and 3rd quartile. The correlations between ESD and FT, DAP and FT, and ESD and DAP have been shown in Figures 1, 2, and 3, respectively. Accordingly, total ESD was strongly correlated to DAP ($r = 0.945$, $P < 0.001$). Significant correlations were also observed between FT and DAP ($r = 0.843$, $P < 0.001$) as well as between FT and ESD ($r = 0.747$, $P < 0.001$). AF ablation procedures had the highest medians of DAP, ESD, and FT values.

5. Discussion

The values reported in the present study were considerably

Table 1. Median and 1st and 3rd Quartiles of Radiation Exposure Data during Cardiac EPS and Ablation Procedures

Tachyarrhythmias	n	Time (minute)			DAP (Gycm2)			ESD (mGy)		
		1st quartile	Median	3rd quartile	1st quartile	Median	3rd quartile	1st quartile	Median	3rd quartile
EPS	17	0.7	1.3	2.4	1.6	2.2	5.3	14.3	24	53
AVNRT	31	1.5	2.7	5	3.1	4.2	14.9	28	40.3	130
AVRT	21	5.5	7.8	9.8	8.2	14.07	28.6	67	109.4	251.6
WPW	18	8	9.8	14.3	16	24.1	48.4	151.1	241.5	415.5
PVC	17	14	16.4	23.7	31.8	38.04	49.3	280.6	328.3	484.5
AT	11	4.7	5.8	11.7	13.8	18.7	28.1	110.6	158	219.5
VT	10	5.2	9.5	18.1	19.9	27.8	39.7	164	268.6	366
AF	26	13.9	18	27.9	31.4	45.9	86.6	278.5	406.3	684.1
Rt-Ps	11	3.1	6.7	15.8	10.9	19.2	55.2	94.1	156	443
Lt-Ps	10	3.2	4.4	11.4	7.2	19.2	27.6	63.7	160.6	256.9
LSVT	10	5.7	6.4	8.1	17.1	19.7	25.7	144.9	178.4	237.8
LVOT	10	5	6.2	9.5	10.5	21.9	28.1	85.3	178.8	260.5
RVOT	10	5.2	11.4	15.3	12.1	28.7	55.3	122.2	237.5	493.2
Left lateral	12	6.1	11.2	19.7	12.8	36.4	66.2	150.7	374.9	810
Rt-Ant-free wall	9	3.3	4.3	5.4	4.08	10.5	14.7	33.5	92	130.8

Abbreviations: EPS, electrophysiology; AVNRT, atrioventricular nodal reentrant tachycardia (AVNRT); AVRT, atrioventricular reentrant tachycardia (AVRT); WPW, Wolff-Parkinson-White syndrome; PVC, premature ventricular contraction; AT, atrial tachycardia; VT, ventricular tachycardia; AF, atrial fibrillation; Rt-PS, right posteroseptal; Lt-PS, left posteroseptal; LSVT, left septal ventricular tachycardia; LVOT, left ventricular outflow tract; RVOT, right ventricular outflow tract; DAP, dose area product; ESD, entrance skin dose

Table 2. Median and 1st and 3rd Quartiles of TFT, Total DAP, and Total ESD in the 223 Patients with EPS and Ablation Procedures

N = 223	1st Quartile	Median	3rd Quartile
TFT, (min)	3.8	7.4	13.6
Total DAP, (Gycm2)	8.2	19.2	37
Total ESD, (mGy)	68.5	165	332

Abbreviations: TFT, total fluoroscopy time; DAP, dose area product; ESD, entrance skin dose

lower compared to those reported in most previous studies. Medians of TFT, total ESD, and total DAP were 7.4 min, 165 mGy, and 19.2 Gycm2, respectively. The maximum ESD and DAP values were attributed to AF ablation procedures. In this study, all ablation procedures were carried out by two experienced electrophysiologists at the same time as the operator and co-operator with a flat panel angiography unit. Therefore, variations in ranges of FT, ESD, and DAP are associated with various types of arrhythmias and RF ablation procedures.

Several researchers have investigated radiation exposure parameters during cardiac RF ablation procedures. Tsapaki et al. (14) collected data from three digital angiography units, two of which being with image intensifier and one with a flat panel detector. They investigated 134 patients with different electrophysiological studies as well as 203 cases of Percutaneous Transluminal Coronary Angioplasty (PTCA). They used slow radiotherapy films for measuring Kerma Area Product (KAP), total KAP, maximum ESD, and FT in these procedures. They observed the highest KAP value in RF ablation procedures in comparison to Percutaneous Coronary Intervention (PCI) despite the fact that RF ablation procedures did not involve cine imaging. Their results showed that patient skin dose could reach the threshold; i.e., 2 Gy, and induce skin damage. In addition, the medians of FT and KAP values for evaluation of patient and staff doses in cardiac ablation procedures were 110 min (range: 44 - 420 min) and 83.5 Gycm2 (range: 3 - 259 Gycm2), respectively. Their results also indicated a rather

significant correlation between KAP and ESD ($r = 0.80$).

Manolis et al. carried out RF catheter ablation for 327 patients, including 280 adults and 47 pediatric patients. All types of cardiac arrhythmias were assessed. The patients' ages ranged from 19 to 82 years in the adults group and 7 to 18 years in the pediatrics group. The safety and efficacy of cardiac RF ablation was also evaluated and compared between the two groups (15). Accordingly, the mean FT was 39 ± 27 and 43 ± 40 min for children and adults, respectively.

Pavodani et al. (16), too, assessed patient doses in interventional cardiac procedures and showed that the medians of FT and KAP for AF ablation were 45 min and 35 Gycm2, respectively. Similarly, Kidouchi et al. (8) investigated 99 patients, including 75 males and 24 females. Catheter ablations for cardiac arrhythmias were performed with six different types of angiographic units in three institutions. The angiographic systems were monoplane and biplane with image intensifier and digital flat panel detector. Different kinds of cardiac arrhythmia were studied. They put special jackets on patients' backs, which had 100 radiosensitive indicators arranged in 10 columns and 10 rows 5 cm apart. After the procedure, they calculated ESD. FT, maximum ESD, DAP of each institution, and the relationships between them were evaluated, as well. Based on the results, only three patients exceeded the 2 Gy threshold dose, but no sign of skin damage was seen after the procedures. Additionally, TFT was about 30 min in the non-AF group in comparison to

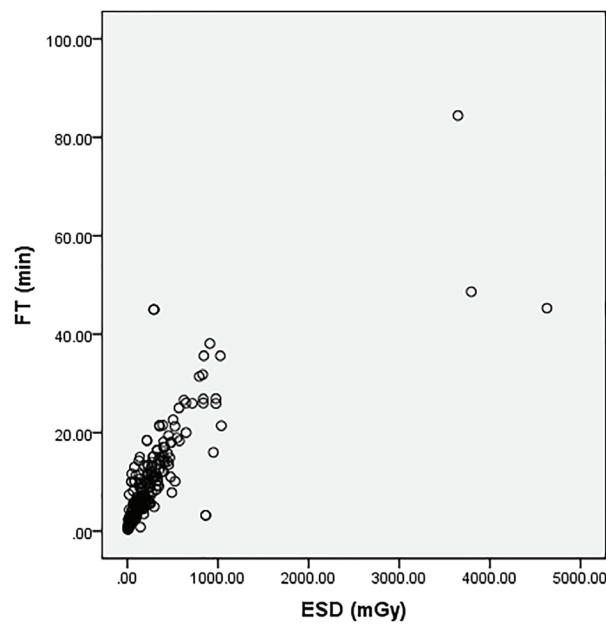


Figure 1. The Correlation between FT and ESD ($r = 0.747$, $P < 0.001$). FT, Fluoroscopy Time; ESD, Entrance Skin Dose

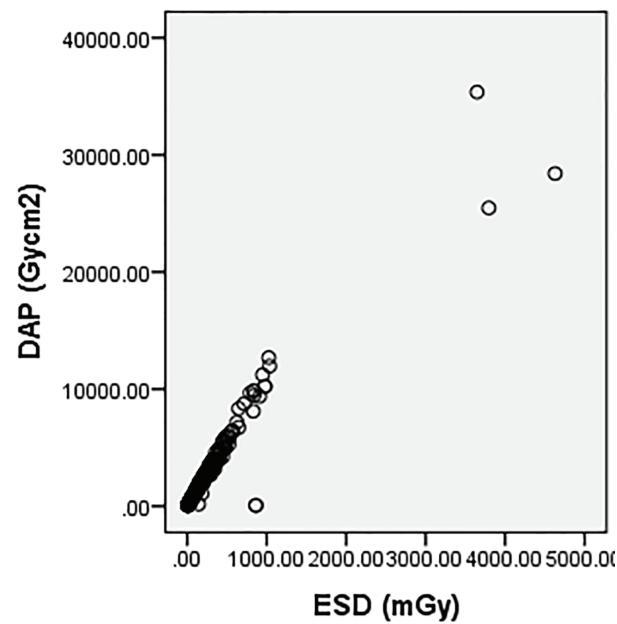


Figure 3. The Correlation between DAP and ESD ($r = 0.945$, $P < 0.001$). DAP, Dose Area Product; ESD, Entrance Skin Dose

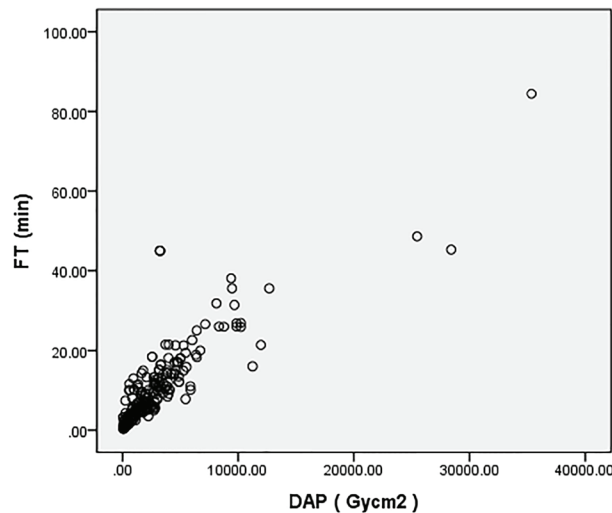


Figure 2. The Correlation between FT and DAP ($r = 0.843$, $P < 0.001$). FT, Fluoroscopy Time; DAP, Dose Area Product

70 min in the AF group. Besides, the means of max ESD and DAP were respectively 0.57 ± 0.51 Gy and 71.2 ± 73.7 Gy·cm² in the AF group. Furthermore, the results revealed strong correlations between DAP and max ESD in all three angiographic units ($r = 0.937$, $r = 0.927$, and $r = 0.905$, respectively).

Chida et al. (17) also determined ESD and DAP values in RF ablation procedures. The results showed that the mean \pm SD of DAP, ESD, and TFT was 109.7 ± 74.7 Gy·cm², 635 ± 551.6 mGy, and 120.8 ± 62.6 min, respectively. In addition, a strong correlation was found between ESD and DAP ($r = 0.942$, $P < 0.001$). A significant correlation was also observed between ESD and TFT ($r = 0.801$, $P < 0.001$).

Overall, the radiation exposure parameters were higher in all above-mentioned researches compared to the present study. On the other hand, the findings of the current study were higher than those obtained by Reents et al. They

indicated a significant reduction in FT (10.57 ± 7.93 vs. 18.52 ± 11.24 min) and DAP (611 vs. 1650 cGy·cm²) in patients who underwent VT ablation. This reduction might have resulted from utilization of 3D mapping system, which was not used in our investigation (5). 3D mapping system, a non-fluoroscopic one, requires special catheters that are more expensive than conventional ones. Although these systems are helpful for reduction of FT, they are not cost-effective for ablation of simple arrhythmias, especially in developing countries, and should be used in complex arrhythmias, such as VT and complex AF (18).

Reduction of patients' radiation exposure is a good approach to reduce the biological effects of ionizing radiation. These biological effects are divided into stochastic and deterministic categories. The "Linear Non Threshold" (LNT) model is accepted for stochastic effects, such as genetic effects and cancer. In this model, with increase in the radiation dose, the risk of cancer increases linearly. Since DNA is a critical target in mammalian cells, ionizing radiation can induce various types of DNA lesions, such as single-strand breaks and double-strand breaks. If primary DNA lesions are badly repaired or unrepaired, they may cause chromosomal aberrations and induce cancer and malignancy (12). For deterministic effects, such as cataract and skin injury, radiation can induce cell and tissue injury. These main effects do not occur below the threshold of radiation dose and the severity increases with the dose (11, 13, 19, 20). According to the International Commission on Radiological Protection 85 (ICRP 85), patients' skin reactions will occur by different amounts of X-ray radiation. For instance, early transient erythema occurs at the threshold dose of 2 Gy, temporary epilation at 3 Gy, and major erythema at 4 Gy (21). Moreover, since the number of cardiac ablation procedures has increased rapidly, public concerns are rising regarding biological effects and enhancement of genetic significant dose. Genetic significant dose is defined as individual gonad

doses received by examined patients, which has the same genetic effect on the upcoming offspring. Therefore, operators should attempt to reduce patient radiation exposure as low as possible. In the current study, DAP values were well less than the European RF ablation reference level; i.e., 46 Gycm² (21, 22). Overall, using high technology angiography and 3D mapping systems would reduce patients' absorbed doses without inducing acute skin injuries.

5.1. Conclusion

In the current study, none of the patients' ESDs exceeded the threshold dose. The max ESD and DAP values were attributed to AF ablation procedures. The results revealed significant correlations between DAP and FT as well as between ESD and FT. A strong correlation was also observed between DAP and ESD, which implies that ESD can be reduced by reducing FT and DAP.

Acknowledgements

The authors would like to thank Shiraz University of Medical Sciences, Shiraz, Iran. Thanks also go to Center for Development of Clinical Research of Nemazee Hospital and Dr. Nasrin Shokrpour for editorial assistance.

Authors' Contribution

Somayah Delavarifar: study concept and design, drafting of the manuscript; Mohammad Hossein Nikoo, Mohammad Vahid Jorat: Providing the cases, do the clinical operation, scientific writing of the manuscript, study supervision; Amir Savardashtak: data gathering; Mehrab Sayadi: statistical analysis and designing the manuscript.

Funding/Support

There is no funding/support.

Financial Disclosure

There is no financial disclosure.

References

1. Calkins H, Yong P, Miller JM, Olshansky B, Carlson M, Saul JP, et al. Catheter ablation of accessory pathways, atrioventricular nodal reentrant tachycardia, and the atrioventricular junction: final results of a prospective, multicenter clinical trial. The Atakr Multicenter Investigators Group. *Circulation*. 1999;**99**(2):262-70.
2. 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. *Circulation Arrhythmia and electrophysiology*. 2010;**3**(1):32-8.
3. Cappato R, Kuck KH. Catheter ablation in the year 2000. *Current opinion in cardiology*. 2000;**15**(1):29-40.
4. Morady F. Radio-frequency ablation as treatment for cardiac arrhythmias. *The New England journal of medicine*. 1999;**340**(7):534-44.
5. Reents T, Buiatti A, Ammar S, Dillier R, Semmler V, Telishevska M, et al. Catheter Ablation of Ventricular Arrhythmias using a Fluoroscopy Image Integration Module. *Pacing and clinical electrophysiology : PACE*. 2015;**38**(6):700-5.
6. Zipes DP, DiMarco JP, Gillette PC, Jackman WM, Myerburg RJ, Rahimtoola SH, et al. Guidelines for clinical intracardiac electrophysiological and catheter ablation procedures. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Clinical Intracardiac Electrophysiology and Catheter Ablation Procedures), developed in collaboration with the North American Society of Pacing and Electrophysiology. *Journal of the American College of Cardiology*. 1995;**26**(2):555-73.
7. Ector J, Dragusin O, Adriaenssens B, Huybrechts W, Willems R, Ector H, et al. Obesity is a major determinant of radiation dose in patients undergoing pulmonary vein isolation for atrial fibrillation. *Journal of the American College of Cardiology*. 2007;**50**(3):234-42.
8. Kidouchi T, Suzuki S, Furui S, Mitani H, Nitta J, Matsumoto K, et al. Entrance skin dose during radiofrequency catheter ablation for tachyarrhythmia: a multicenter study. *Pacing and clinical electrophysiology : PACE*. 2011;**34**(5):563-70.
9. Perisinakis K, Damilakis J, Theocharopoulos N, Manios E, Vardas P, Gourtsoyiannis N. Accurate assessment of patient effective radiation dose and associated detriment risk from radiofrequency catheter ablation procedures. *Circulation*. 2001;**104**(1):58-62.
10. Seguchi S, Aoyama T, Koyama S, Kawaura C, Fujii K. Evaluation of exposure dose to patients undergoing catheter ablation procedures--a phantom study. *European radiology*. 2008;**18**(11):2559-67.
11. Valentin J. Avoidance of radiation injuries from medical interventional procedures, ICRP Publication 85. *Annals of the ICRP*. 2000;**30**(2):7.
12. Hall EJ, Giaccia AJ. *Radiobiology for the Radiologist*. Lippincott Williams & Wilkins; 2006.
13. National Research Council. Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, Health Risks from Exposure to Low Levels of Ionizing Radiation (BEIR VII Phase 2). *Washington, DC: National Academies Press, Date*. 2006;**16**:406.
14. Tsapaki V, Patsilinos S, Voudris V, Magginas A, Pavlidis S, Maounis T, et al. Level of patient and operator dose in the largest cardiac centre in Greece. *Radiation protection dosimetry*. 2008;**129**(1-3):71-3.
15. Manolis AS, Vassilikos V, Maounis TN, Chiladakis J, Cokkinos DV. Radiofrequency ablation in pediatric and adult patients: comparative results. *Journal of interventional cardiac electrophysiology : an international journal of arrhythmias and pacing*. 2001;**5**(4):443-53.
16. Padovani R, Vano E, Trianni A, Bokou C, Bosmans H, Bor D, et al. Reference levels at European level for cardiac interventional procedures. *Radiation protection dosimetry*. 2008;**129**(1-3):104-7.
17. Chida K, Saito H, Otani H, Kohzaki M, Takahashi S, Yamada S, et al. Relationship between fluoroscopic time, dose-area product, body weight, and maximum radiation skin dose in cardiac interventional procedures. *AJR American journal of roentgenology*. 2006;**186**(3):774-8.
18. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Annals of the ICRP*. 2007;**37**(2-4):1-332.
19. Authors on behalf of I, Stewart FA, Akleyev AV, Hauer-Jensen M, Hendry JH, Kleiman NJ, et al. ICRP publication 118: ICRP statement on tissue reactions and early and late effects of radiation in normal tissues and organs--threshold doses for tissue reactions in a radiation protection context. *Annals of the ICRP*. 2012;**41**(1-2):1-322.
20. Stewart FA. Mechanisms and dose-response relationships for radiation-induced cardiovascular disease. *Annals of the ICRP*. 2012;**41**(3-4):72-9.
21. Pantos I, Koukorava C, Nirgianaki E, Carinou E, Tzanalaridou E, Efsthopoulos EP, et al. Radiation exposure of the operator during cardiac catheter ablation procedures. *Radiation protection dosimetry*. 2012;**150**(3):306-11.
22. Hering ER, Kotze TJ, Maree GJ. An estimation of the genetically significant dose from diagnostic radiology for the South African population, 1990-1991. *Health physics*. 1998;**74**(4):419-28.