Patient radiation dosimetry during interventional cardiac procedures

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ABSTRACT

Background: Cardiac catheterization plays an essential role in the evaluation of suspected heart failure patients. This work aimed to determine the mean effective dose of patients undergoing catheterization tests and to estimate the associated radiation risk of malignancy. Material and Methods: Measurements were performed during 65 coronary angiographies (CA), 70 coronary angioplasties (PTCA), 27 radio fluoroscopy (RF) ablations and 25 electrophysiology procedures in a dedicated laboratory. The procedures were undertaken with the Siemens and General Electric X-ray equipment. A dose area product (DAP) meter was also used. The DAP values and fluoroscopy times were recorded for each patient. Results: The mean DAP values and patient effective doses were 19.53 Gy.cm$^2$ and 1.71 mSv for CA, 49.74 Gy.cm$^2$ and 4.57 mSv for PTCA, 153.34 Gy.cm$^2$ and 16.38 mSv for ablations and 14.88 Gy.cm$^2$ and 1.65 mSv for electrophysiology, respectively. The patient radiation risk was estimated at 13, 1.3, 1.3, 3.6 fatal cancer per 10000 procedures of ablations, electrophysiology, CA and PTCA cases, respectively. Conclusion: Results showed that the radiation risk due to RF cardiac ablation is higher than the other complication procedures so, efforts should be made to minimize patient radiation risk from RF ablation procedures. Also we found no clear correlation between cardiologist level of experience and reduced level of patient’s dose.

Keywords: patient dosimetry, DAP, cardiac catheterization, effective dose, radiation risk

INTRODUCTION

The clinical use of ionizing radiation in cardiac catheterization (CC) procedures offers a great benefit to modern healthcare (1). In CC procedures fluoroscopy is used to guide the placing of various devices or probes into the circulatory system, to obtain clinical data for diagnostic and treatment purposes (2). Most recently, the associated risk of radiation exposure from CC procedures including coronary angiography (CA); percutaneous transluminal coronary angioplasty (PTCA); electrophysiology procedures and radiofrequency cardiac ablation, raised serious concerns regarding radiation-induced health effects (3-5).

The detrimental effects related to fluoroscopically guided procedures can be classified into deterministic and stochastic risks (6). Deterministic effects such as temporary epilation and erythema can result from high entrance skin doses. Also, extended fluoroscopic exposures, by increasing patient effective dose, are directly related to an elevated risk of radiation-induced carcinogenesis. Nevertheless, deterministic effects can be assessed by air Kerma (kinetic energy released per unit mass), and stochastic risks are evaluated by the dose-area product (DAP) (7). The ultimate goal of radiation protection is to circumventing deterministic damages, and also is diminishing of the stochastic risks by keeping the radiation dose as low as reasonably achievable (ALARA principle) (8).
Based on recommendations from The International Commission on Radiological Protection (ICRP), setting up a local diagnostic reference level (DRL) is required for optimizing radiation exposure \(^9\). DRLs can be used in daily practice to determine whether a delivered dose to a patient undergoing a specific procedure is high or low for that procedure. Therefore, monitoring the irradiation exposure of patients and comparison with DRLs are compulsory tasks in every quality assurance program \(^10, 11\). DAP is one of the approaches to measure the patient’s dose. The DAP meter is the most reliable device to measure DAP values of fluoroscopy examinations \(^12\). However, documented results demonstrated that measured radiation doses of patients are diverse in different CC procedures. The main factors for the reported variation in doses are associated with procedure type, patient size, fluoroscopic equipment, and the expertise of the physicians \(^13, 14\).

Due to minimally invasive characteristics of CC procedures and technological progress in the field which made the possibility of complicated procedures, the number of CC procedures has increased swiftly \(^1\). Although, there are growing concerns about population dose and radiation-induced health effects \(^15\). Accordingly, in this study, we aimed to evaluate the exposure parameters to establish a benchmark for patient dose and their associated cancer risk under different CC procedures at our laboratory.

**MATERIALS AND METHODS**

**Patients**

Radiation dose was obtained for a total number of 187 adult patients of whom 65 underwent coronary angiographies (CA), 70 coronary angioplasties (PTCA), 27 RF ablations, and 25 electrophysiologies. All procedures were performed in one CC laboratory.

Several physicians with the various level of experience participated in this study: two cardiologists (I, II) with more than 20 years of experience, one cardiologist (III) with less than 15 years of experience, and one (IV) cardiologist with 4 years of experience. The study protocol was approved by the ethics committee of Shahid Sadoughi University of Medical Science (The ethics approval number was IR.SSU.MEDICINE.REC.1395.27).

**X-Ray system and acquisition of exposure parameters**

All examinations were performed in two separate rooms. Electrophysiological and ablation procedures performed by a General Electric Fluoroscopic Machine with an image intensifier (Advantx LC model, GE, USA) in a separate room. The tube was placed under the bed and it was not used for image magnification. The device is capable of recording images in both fluoroscopy and cineangiography methods. In a separate room angiography and angioplasty procedures were conducted using a Siemens system (AXIOM Artis model, Germany) equipped with a flat panel. Kilovoltage and tube current were selected by automatic brightness control. Cineangiography mode (25 frames/s) and the input field size (25 cm) were used for all patients. Additional filtration (2 and 3.5 mmAl) was automatically inserted in fluoroscopy mode.

**Radiation dose measurement**

DAP values were measured by DAP meter (VacuDAP OEM, VacuTec, Germany) mounted on the X-ray tube and displayed on the electrometer that was outside of the angiographic room. This meter was equipped with a flat ionization chamber measuring DAP in cGy.cm\(^2\). The DAP meter recorded the total exposure time and the radiation area in a plane perpendicular to the radiological beam. The accuracy of DAP values was checked with the calibrated DAP meter (PTW, Freiburg, Germany). Patient demographic data were collected during all procedures including age, weight, height, body mass index (BMI). The collected technical data were: kV, mA, total filter, fluoroscopy time and corresponding DAP recorded from the DAP meter. The name of the cardiologist who performed the examination was recorded.

**Patient specific dose simulation**

Patient doses were calculated using the
Monte Carlo based computer simulation program PCXMC 2.0 (STUK, Finland)\(^{(16)}\). To evaluate the risk of radiation in CC, an effective dose is required. The simulations take the following registered parameters into account: tube incidence, source to image detector distance, image detector field size, height, weight, kVp, DAP value, position, and angle of the beam.

**Risk estimation**

Lifetime radiation risk caused by the catheterization procedure for the enrolled patients was calculated according to the BEIR VII risk models. The lifetime risk of cancer incidence and mortality was estimated, based on the simulated organ doses, age, and gender of the individual patients. The linear-no-threshold model was adopted according to the ICRP 60 guidelines\(^{(17,18)}\).

**Statistical analysis**

The assumption of normality of data distribution was checked by the visual method (quantile-quantile (QQ) plot) and further supplemented by the Kolmogorov-Smirnov (K-S) test. Correlations in scatter plots were investigated by calculating the linear regression. DAP values and effective doses were presented as mean ± standard deviation (SD) and were compared with reference values using Student’s t-test. Results were considered statistically significant at \(P < 0.05\). The statistical analysis was performed with SPSS Statistics 19 software (SPSS Inc., Chicago, IL).

### RESULTS

**Patient population and exposure data**

Patient’s demographic data and exposure parameters registered during the CA, PTCA, ablation, and electrophysiology procedures are summarized in table 1. A total of 187 CC procedures were performed, including 65 cases of CA (34.7%), 70 cases of PTCA (37.5%), 27 cases of RF ablations (14.5%), and 25 cases of electrophysiologies (13.3%). Among all age groups, patients with an age ranged from 60 to 70 years received the highest number of CC procedures and PTCA was the most frequent one (figure 1). In terms of DAP, ablation with a mean DAP calculated as 153.34 Gy.cm\(^2\) presented statistically significant higher value (\(P < 0.05\)) than CA, PTCA, and electrophysiology. Also, the same result was obtained for difference in fluoroscopy time, where the mean fluoroscopy time for ablation was 14.75 min, while it was 2.24, 8.16, and 3.85 min for CA, PTCA, and electrophysiology, respectively (table 1). The correlation between DAP and fluoroscopy time is demonstrated in figure 2. There was statistically significant correlation between DAP and exposure time of all procedures (\(P < 0.05\)).

| Table 1. Patient demographics and exposure parameters for CA, PTCA, ablation, and electrophysiology procedures. Values are presented as mean ± SD. |
|---|---|---|---|---|
| Demographic patient data | CA | PTCA | Ablation | Electrophysiology |
| Number of patient | 65 | 70 | 27 | 25 |
| Age | 59.9 ± 12.30 | 55.74 ± 12.04 | 47.62 ± 11.92 | 48.75 ± 13.99 |
| BMI (kg/m\(^2\)) | 26.29 | 26.76 | 26.45 | 26.22 |
| DAP (Gy.cm\(^2\)) | 19.53 ± 12.81 | 49.74 ± 29.54 | 153.34 ± 105.32 | 14.88 ± 5.62 |
| Fluoroscopy time (min) | 2.24 ± 1.55 | 8.16 ± 5.10 | 14.75 ± 12.90 | 3.85 ± 1.62 |
| P value | <0.0001 | <0.0001 | >0.276 | >0.568 |
| DAP & BMI | <0.0023 | <0.0018 | <0.006 | <0.0054 |
| DAP & Fluoroscopy time | <0.0001 | <0.0001 | >0.276 | >0.568 |

**Figure 1.** The age distribution of patients whom referred to catheterization laboratory for coronary angiography (CA) and percutaneous transluminal coronary angioplasty (PTCA), ablation and electrophysiology (EPS) procedures is presented.
Figure 3 shows the correlation of DAP with BMI. Regression coefficients of DAP to BMI provided a prediction of increasing radiation exposure by BMI. There was no statistically significant correlation between DAP and BMI of patient in ablation and electrophysiology tests (P=0.276, P=0.568, respectively) and coefficient correlation was $r^2 = 0.0008$ and $r^2 = 0.04$, respectively, which is very weak. On the other hand, there is a positive correlation between BMI and DAP values in CA and PTCA tests (P=0.0001).

In table 2 the summary of the performance of each physician presented based on their level of experience. Level I experienced physician performed CA in a longer time (2.91 min) with a higher number of cinegraphic acquisitions (9.24) than level II (1.9 min and 7.45, respectively) and III experienced physicians (1.38 min and 4.07, respectively). In performing PTCA, level II experienced physician, needed more time (8.96 min) and number of cinegraphic acquisitions (16.26) in comparison to level I (5.47 min and 14.95, respectively) and III (3.06 min and 7.81, respectively) experienced physicians. The number of cinegraphic acquisitions and DAP values were lower for level III experienced physician in both CA (4.07 and 10.10 Gy.cm$^2$, respectively) and PTCA (3.06 and 7.81 Gy.cm$^2$, respectively) procedures.

Based on the simulated organ doses, lifetime radiation risk caused by the CC procedures was estimated according to the BEIR VII report (19). These data are summarized in table 3. The mean effective dose for CA procedures (1.71 mSv) was lower than all other procedures. The rate of
cancer risk for ablation (13 per 10000 cases) was statistically significant higher than CA (1.3 per 10000 cases), PTCA (3.6 per 10000 cases), and electrophysiology (1.3 per 10000 cases) (P<0.05).

**Table 2.** Work experience of the invasive cardiologist and Mean ± SD values of fluoroscopy parameters during CA, PTCA, ablation, and electrophysiology

<table>
<thead>
<tr>
<th>Examinations</th>
<th>Physicians</th>
<th>No. of patients</th>
<th>DAP</th>
<th>Fluoroscopy time</th>
<th>Number of cinegraphy</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA I</td>
<td>28</td>
<td>24.08 ± 14.37</td>
<td>2.91 ± 1.99</td>
<td>9.24 ± 5.00</td>
<td></td>
</tr>
<tr>
<td>CA II</td>
<td>22</td>
<td>19.56 ± 11.12</td>
<td>1.90 ± 0.83</td>
<td>7.45 ± 1.94</td>
<td></td>
</tr>
<tr>
<td>CA III</td>
<td>14</td>
<td>10.10 ± 4.71</td>
<td>1.38 ± 0.37</td>
<td>4.07 ± 0.82</td>
<td></td>
</tr>
<tr>
<td>PTCA I</td>
<td>20</td>
<td>34.51 ± 12.06</td>
<td>5.47 ± 3.09</td>
<td>14.95 ± 4.16</td>
<td></td>
</tr>
<tr>
<td>PTCA II</td>
<td>23</td>
<td>45.14 ± 12.08</td>
<td>8.96 ± 4.37</td>
<td>16.26 ± 3.58</td>
<td></td>
</tr>
<tr>
<td>PTCA III</td>
<td>11</td>
<td>22.13 ± 3.95</td>
<td>3.06 ± 1.70</td>
<td>7.81 ± 1.53</td>
<td></td>
</tr>
<tr>
<td>Ablation IV</td>
<td>26</td>
<td>153.34 ± 20.64</td>
<td>14.75 ± 5.63</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Electrophysiology IV</td>
<td>26</td>
<td>14.06 ± 4.92</td>
<td>3.85 ± 1.62</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

*aphysicians I, II cardiologists with precedent more than 20 years, physicians III cardiologists with precedent less than 15 years, physicians IV cardiologists with 4 years precedent*

**Table 3.** Lifetime radiation risk of Cancer incidence associated with X-Ray exposure From CA, PTCA, ablation, and electrophysiology tests. Values presented as mean ±1SD

<table>
<thead>
<tr>
<th>examination</th>
<th>No. of examination</th>
<th>Mean effective dose (mSv)</th>
<th>Cancer risk per 10000 case</th>
<th>Collective dose per year (man·Sv)</th>
<th>Number of additional cancers per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>65</td>
<td>1.71 ± 0.62</td>
<td>1.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PTCA</td>
<td>70</td>
<td>4.57 ± 2.63</td>
<td>3.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ablation</td>
<td>27</td>
<td>16.38 ± 5.18</td>
<td>13</td>
<td>0.0019</td>
<td>0.22</td>
</tr>
<tr>
<td>Electrophysiology</td>
<td>25</td>
<td>1.65 ± 0.58</td>
<td>1.3</td>
<td>0.0002</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Medical exposure is a major man-made source of irradiation (20, 21). Cardiology procedures have great benefits to patients but also subject them to remarkable radiation exposure. The population exposure from current diagnostic and therapeutic approaches has been growing in an incessant way (22, 23). On average, CA corresponds to a radiation exposure to the patient of about 300 chest X-rays, while PTCA corresponds to 1000 chest X-rays and ablation procedure up to 1500 chest X-rays (24-26). Various studies have evaluated the effect of different parameters on the patient dose during CC procedures. These parameters are associated with a high amount of patient absorption dose, type of the test and its complexity, cardiologist’s experience and sufficient knowledge of radiation protection rules, type of device, patient’s BMI, and etc. (27, 28). The medical community may have a suboptimal awareness of radiation effects. So, it is recommended to all physicians to minimize the radiation injury hazard to their patients, professional staff and themselves (29). It is obvious that the evaluation of the patient’s dose and its effective parameters help to optimize radiology techniques. So, this study aimed to evaluate the patient’s radiation dose during different CC techniques and compare them to the reference values as well as their cancer risk estimates.

In this study, among selected procedures, ablation yielded the highest DAP value and effective dose primarily due to the longer fluoroscopic time (table 1). Although the mean fluoroscopy time in our study was shorter than previous reports, the ablation requires a fluoroscopic time three times higher than the electrophysiological procedure, on average. In comparison to the previous studies, DAP values for the ablation procedure was relatively high. It also could be the result of the image intensifier (II) detector used in our study which was installed 22 years ago as well as the lack of scheduled quality control. This old image...
intensifier may reduce the brightness of images and increase patient's exposure (30).

Radiation doses in PTCA were also higher than CA procedures. These results are consistent with the previous findings (5, 14, 31). Since PTCA needed longer fluoroscopic times and more cineographic images therefore, the absorbed doses of patients increased during this process. It has been reported that cineradiography application for enhancement of the quality of images, is responsible for up to 60% of patient radiation dose, despite the fact that it contributing just 5% of exposure time (32). Therefore, limiting the number of cine images frames is an indispensable step to reducing patient radiation doses.

In addition, minimizing the fluoroscopy time with optimization of exposure parameters are of great importance. We evaluate the correlation between DAP and total exposure (figures 2). As expected there was a positive correlation between DAP and the total exposure time (p<0.05). The DAP values were increased for all catheterization tests by increasing the exposure time. Indeed, "time" is an effective factor in radiation protection as if it reduced, the patient's absorbed dose is reduced. The fluoroscopy time in our study was shorter than the other studies presented in tables 4 and 5, consequently, the DAP values are lower, for both CA and PTCA procedures. Therefore, these results show that CA and PTCA examinations may have acceptable conditions based on ALARA and optimization principles (33-35).

Several physicians with a different level of experience participated in this study. The effect of the cine recording on the total patient dose is presented in table 2. The result shows no clear correlation between the cardiologist's work experience and the patient's dose. This is similar to the study of Bouzarjomehri et al. (31), and I.stratis et al. (27), but in conflict with Tsapaki et al. study, who found a negative correlation between DAP values and physician's experience (36).

In the present study, we also find that BMI didn't play an important role in affecting DAP values in electrophysiology and ablation tests (P>0.05), which could be a result of limited sample size. However, there was a significant correlation between DAP values with BMI in CA and PTCA tests (P<0.05). These findings are consistent with previously documented reports (31, 37, 38), where increasing BMI, resulted in elevated patient absorption doses in CA and PTCA tests. Therefore, this is necessary to adjust exposure measures such as kVp and mA for obese patients to produce an appropriate image quality for accurate diagnosis (39, 40).

The mean effective dose calculated in this

Table 4. Comparison of results from this and other studies of CA and PTCA. Values presented as mean ±1SD

<table>
<thead>
<tr>
<th>Study</th>
<th>Patients</th>
<th>DAP (Gy.cm²)</th>
<th>Fluoroscopy time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CA</td>
<td>PTCA</td>
</tr>
<tr>
<td>This study</td>
<td>65</td>
<td>19.53±12.81</td>
<td>19.74±29.54</td>
</tr>
<tr>
<td>Eltigani(34)</td>
<td>184</td>
<td>30</td>
<td>75</td>
</tr>
<tr>
<td>Bouzarjomehri(31)</td>
<td>168</td>
<td>33</td>
<td>80.30</td>
</tr>
<tr>
<td>Padovani(33)</td>
<td>272</td>
<td>45</td>
<td>85</td>
</tr>
</tbody>
</table>

Table 5. Comparison of results from this and other studies of ablation and electrophysiology. Values presented as mean ±1SD

<table>
<thead>
<tr>
<th>Study</th>
<th>Patients</th>
<th>DAP (Gy.cm²)</th>
<th>Fluoroscopy time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ablation</td>
<td>electrophysiology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DAP</td>
<td>Fluoroscopy time</td>
</tr>
<tr>
<td>This study</td>
<td>27</td>
<td>153.34±105.32</td>
<td>14.88±5.62</td>
</tr>
<tr>
<td>Efstathopoulos(36)</td>
<td>24</td>
<td>48.70</td>
<td>12.5</td>
</tr>
<tr>
<td>McFadden(47)</td>
<td>50</td>
<td>123</td>
<td>16.03</td>
</tr>
<tr>
<td>Tsapaki(45)</td>
<td>100</td>
<td>83.5</td>
<td>21.6</td>
</tr>
<tr>
<td>Pantos(12)</td>
<td>407</td>
<td>54.6</td>
<td>14.5</td>
</tr>
</tbody>
</table>
study for CA and PTCA procedures (1.71 and 4.57, respectively) is lower than the result of Padovani et al. (33), Borretzen et al. (41), Bouzarjomehri et al. (42). Fatal malignancy risk due to CA and PTCA examinations was estimated at 1.3 and 3.6 per 10 000 cases, respectively based on current ICRP-60 and the BEIR VII estimation. These results can be due to the lower fluoroscopic times and the number of cineographic images than other studies. Also using the flat panel detector can be effective in reducing patient doses.

Base on BEIR VII report, fatal cancer risks due to the collective dose of ablation and electrophysiological examinations that were achieved in one year in Yazd were 0.22 and 0.03 person, whereas this risk factor due to CT examinations was 1.3 person (43). Unlike the increasing mean effective dose observed in ablation examination (16.38 mSv), the number of tests performed a year is low. It could be concluded that the cancer incidence is low, so there is no concern about the risk of cancer for ablation in Yazd.

This study suffers from some limitations. The main limitation of this study was the small number of patients, especially in ablation and electrophysiology tests. Another limitation is that the DAP and fluoroscopy evaluated only the radiation dose absorbed by the patient, whereas the radiation dosage to the operator was not directly measured.

**CONCLUSION**

This study aimed to evaluate the patient’s radiation dose during coronary angiography and angioplasty, ablation and electrophysiology procedures in a dedicated cardiac catheterization laboratory. We found a strong correlation between DAP and the fluoroscopy time in all of the catheterization procedures. Corresponding doses in CA, PTCA were in an optimal condition. The patient’s doses undergoing ablation is more than electrophysiological procedure. However, it could be concluded that the cancer incidence due to the collective dose of ablation is low.

**Conflicts of interest:** Declared none.

**REFERENCES**


Omidvar et al. / Patient dosimetry during cardiac catheterization


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