Comparison of Five Developed Algorithms to Estimate Staff Effective Dose in Interventional Cardiology: Are They Interchangeable?

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Introduction: Interventional procedures are becoming substantial contributors to collective radiation dose due to their increasing rate of application. This study examined the relationships between effective dose data derived from five developed algorithms (Netherlands Commission on Radiation Dosimetry (NCS) and National Council on Radiation Protection and Measurements (NCRPs) algorithms for single dosimetry and Niklason, NCRPd and Clerinx algorithms for double dosimetry) to assess whether they can be used interchangeably in the assessment of staff effective dose in interventional cardiology. Material and Methods: The study population consisted of thirteen radiation workers (eight cardiologists, two technicians and three nurses) were involved in cardiac interventional procedures. Effective doses with thermoluminescence dosemeters were estimated for the duration of two months using five algorithms. The linear correlation and Bland-Altman analysis were performed to assess relationships and the agreement between effective doses calculated by the algorithms respectively. Results and Conclusion: We found significant correlation coefficients between the all effective doses calculated using the algorithms. Comparisons of two algorithms showed significant differences between estimated effective doses (p < 0.05) with the exception of results obtained by NCS versus NCRPd and NCS versus Niklason algorithms (p > 0.05). Limit of agreements were wide (NCS vs. NCRPd: −0.406 to 0.280 mSv and NCS vs. Niklason: −0.035 to 0.401 mSv, respectively) and considerable disagreement was found between these algorithms and despite strong correlations, should not be used interchangeably for assessment of effective dose.

Keywords: Staff Effective Dose, Interventional Cardiology, Agreement.

1. INTRODUCTION

Interventional procedures are becoming substantial contributors to collective radiation dose due to their increasing rate of application. Cardiac catheterization laboratory is generally considered an area where exposure to radiation is particularly high and the working staff is at a potential high risk to radiation exposure.¹,² The fluoroscopic X-ray machine is the main source of radiation in the catheterization laboratory. Every time a primary X-ray beam is produced, the scattered radiation from the patient’s body is the principal source of staff radiation.³

Assessment of radiation dose is considered to be the first step in applying dose-reduction strategies.⁴ According to International Commission on Radiological Protection (ICRP) publication 60 and European Union Directive, radiation dose to workers should be expressed in terms of effective dose,⁵ ⁶ a quantity that is related to the risk of equivalent whole body exposure or stochastic radiation risk.⁷ Effective dose can be determined as the sum of the weighted equivalent doses in 12 critical organs:

\[
\text{Effective dose} = \sum_{T} w_{T} \times H_{T}
\]

where \(w_{T}\) is the tissue weighting factor and \(H_{T}\) is the equivalent dose to tissue \(T\). It is important to effectively estimate radiation doses during high dose examinations acquired by cardiac catheterization laboratory personnel. However, it is not practical in the work environment to measure the exact absorbed doses in the various organs and tissues necessary to compute equivalent and effective dose directly. Therefore, several indirect methods have been proposed.⁸ ⁹ Equivalent dose can be indicated through reading from dosemeters appropriately located on the body and therefore, a number of quantitative relationships between whole body effective dose and partial dose equivalent have been developed and are available in the literature.
Effective dose during cardiac procedures have been estimated by a variety of algorithms. For examples; Delichas et al. calculated the effective doses received by the 9 cardiologists during coronary angiography (CA) and percutaneous transluminal coronary angioplasty (PTCA) in two Greek hospitals using the method described by Niklason et al. Kuipers et al. monitored the exposure of 11 physicians and reported a linear relation between the effective doses calculated with Netherlands Commission on Radiation Dosimetry (NCS) single algorithm and the effective doses estimated with the NCRP and Clerinx algorithms for double dosimetry.11

The question is that; is it feasible to compare the effective doses estimated by different algorithms? In other words, does it matter if a specific algorithm is recruited to estimate effective dose? In view of this, we estimated the effective doses of staff members during cardiac interventional procedures (CA and PTCA) at cardiac catheterization laboratory using different single and double dosimetry algorithms and the aim of this study was to compare the five developed algorithms to determine whether they can be used interchangeably in the assessment of effective dose.

2. MATERIAL AND METHODS

2.1. Study Population

The exposure of thirteen staff members involving in interventional cardiology procedures (eight cardiologists, two technicians and three nurses) were measured for the duration of two months in a cardiac hospital in Rasht-Iran. The radiation staff members consented to participate in the study for measuring dose mainly from scattered radiation. The study protocol was approved by the local ethics committee.

The interventional procedures were performed with a General Electric X-ray system (GE Healthcare Medical Systems, Innova 2000s Cath Lab), the X-ray tube in the under-table position. All personnel were involved in cardiac interventional procedures (CA and PTCA). All the personnel in the room wore 0.5 mm Pb equivalent aprons and thyroid protective collars. The personnel were provided with two personal dosimeter badges (each badge contains 3 thermoluminescence dosimeters or TLDs); one of the badges worn under the protective apron and the other worn above the apron. Similarly 3 TLDs were wrapped and kept outside the radiation room and its reading used as background.

2.2. Thermoluminescence Dosemeters: TLDs

In this study, highly sensitive TLDs namely LiF:Mg, Cu, P (TLD-100H; Harshaw) were used to assess entrance surface dose. The TLDs wrapped in black nylon sachets to protect them from physical and chemical damage.

The calibration of the dosimetric system has been performed exposing TLDs free in air to a X-ray beam by Secondary Standard Dosimetry Laboratory (SSDL, Karaj, Iran) to acquire element correction coefficient (ECC) and dose calibration curve.10

The pre-exposure annealing for reuse was performed in an oven at 240 °C for 10 minutes followed by rapid cooling to room temperature. TLDs have been read with a TLD-reader using a hot nitrogen flux (Model Harshaw 3500, USA). A pre-readout annealing at 135 °C for 15 s was performed in the reader in order to eliminate the unstable low temperature peaks of lithium fluoride. The TL signal was acquired from 135 °C to 240 °C and hold at 240 °C for 20 s.

2.3. Algorithms

The effective doses for the duration of two months were calculated by means of five algorithms (Table I). First, the effective doses were calculated with two algorithms for single dosimetry using the Netherlands Commission on Radiation Dosimetry (NCS)11,12 and National Council on Radiation Protection and Measurements (NCRP) algorithms.8 According to Table I, the conversion factors were applied to the doses measured outside the lead apron (Houtside). Additionally the effective doses were calculated with three algorithms for double dosimetry using the Niklason algorithm,13 NCRP algorithm and an algorithm described by Clerinx et al.11,14 The conversion factors according to these algorithms were applied to the doses measured outside (Houtside) and under the lead apron (Hunder).

2.4. Statistical Analysis

All continuous variables were tested for normal distribution via the Shapiro-Wilk test and the results were expressed as mean ± standard deviation (SD). The paired sample t-test was used to test the significance of the difference between two algorithms. The linear correlation was calculated to assess the relationships between the effective doses calculated using different algorithms. In addition, Bland-Altman analysis was calculated to assess agreements between the calculated effective doses.15 All the statistical analyses were performed using the SPSS version 16 software package (SPSS Inc. Chicago, IL, USA) and statistical significance was defined as p < 0.05.

3. RESULTS

Table II shows the measured effective dose with use of these five algorithms among the medical workers.

Overall, cardiologists, technicians and nurses were involved in 146 (118 CA and 28 PTCA), 222 (164 CA and 58 PTCA) and 463 (327 CA and 136 PTCA) procedures, respectively. For nurses, the number of procedures and the cumulative effective doses were higher. The highest and lowest staff effective doses estimated using Clerinx et al. and NCRPs algorithms, respectively.

3.1. Correlation Study and Bland-Altman Analysis

Table III represents the correlation coefficients that were estimated to assess relationships between effective doses calculated using NCRPs, NCRPd, NCS, Clerinx and Niklason algorithms. We found significant correlation coefficients between all of effective doses calculated using the algorithms (range from r = 0.632, p = 0.021; correlation coefficient between NCRP algorithm using single dosemeter and Niklason algorithm to r = 1, p < 0.001;
correlation coefficient between NCRP algorithm using single dosimeter and NCS algorithm). As an example, Figure 1 shows that NCRP-calculated effective doses with two dosimeters significantly correlated with the Niklason-calculated effective doses in staff that imported to this study ($r = 0.913, p < 0.001$).

Bland-Altman analysis with 95% limit of agreements (LOA) (i.e., mean difference ± 1.96SD of the differences) was calculated to assess agreements between the effective doses calculated using the different algorithms (Table III). We found minimum bias (or mean difference) between NCRPd and NCS algorithms ($−0.063$ mSv) and maximum bias (0.268 mSv) between Clerinx and Niklason algorithms. As an example, Figure 2 shows the Bland-Altman plots between NCRPd and Niklason algorithms (mean differences: $−0.08 ± 0.01$ mSv, LOA: $±0.03$ mSv). Despite the relatively low bias and narrow LOA, there was significant difference between the means of effective doses estimated by these two algorithms ($p < 0.001$). There seems to be a relation between the differences and level of the effective dose.

Comparisons of two algorithms showed significant differences between estimated effective doses with the exception of results obtained by NCS versus NCRPd and NCS versus Niklason algorithms ($p = 0.278$ and $p = 0.752$, respectively, Table III). There was a relatively weak correlation coefficient between NCS and Niklason algorithms ($r = 0.63, p = 0.02$) and LOA was wide ($−0.035$ to $0.401$ mSv). However, there was a high correlation coefficient between NCS and NCRPd algorithms ($r = 0.89, p < 0.001$). Figure 3 shows the Bland-Altman plots between NCRPd and NCS algorithms (mean differences: $−0.06 ± 0.17$ mSv, LOA: $±0.33$ mSv). The graph displays considerable lack of agreement between the two algorithms, with discrepancy of up to 0.47 mSv. Despite the relatively low bias, the 95% LOA is wide and the NCRPd estimation may differ from the NCS estimation by 35% to 74% and the degree of agreement is not acceptable.

### 4. DISCUSSION

An optimized radiation protection practice including staff dose monitoring prevents high occupational exposure, well below the annual effective dose limit of 20 mSv. Effective dose or related variables during cardiac procedures have been estimated by a variety of algorithms. In this study, we examined the relationships between effective doses derived from five common algorithms (single and double dosimetry) to assess whether they can be used interchangeably in the assessment of staff effective dose in cardiac interventional procedures. Similar to the study conducted by Kuipers et al. that correlated NCRP, NCS and Clerinx algorithms (eight radiologist and three cardiologists), we found sufficiently strong correlation between effective doses estimated by the five developed algorithms. Moreover, we used Bland-Altman analysis

### Table III. Correlation coefficient, bias (mSv), significance and 95% limits of agreement between (mSv) the algorithms of assessing effective dose.

<table>
<thead>
<tr>
<th>Algorithm 1</th>
<th>Algorithm 2</th>
<th>Correlation r (p-value)</th>
<th>Bias (SD)</th>
<th>$p$-value</th>
<th>LOA (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCRPd</td>
<td>NCRPd</td>
<td>0.893 (−0.001)</td>
<td>0.069 (0.026)</td>
<td>$&lt; 0.001$</td>
<td>0.018 to 0.120</td>
</tr>
<tr>
<td>NCRPd</td>
<td>Niklason</td>
<td>0.913 (−0.001)</td>
<td>−0.081 (0.013)</td>
<td>$&lt; 0.001$</td>
<td>−0.056 to −0.106</td>
</tr>
<tr>
<td>NCRPd</td>
<td>NCS</td>
<td>0.894 (−0.001)</td>
<td>−0.063 (0.175)</td>
<td>0.278</td>
<td>−0.406 to 0.280</td>
</tr>
<tr>
<td>NCRPd</td>
<td>Clerinx</td>
<td>0.989 (−0.001)</td>
<td>0.227 (0.049)</td>
<td>$&lt; 0.001$</td>
<td>0.131 to 0.323</td>
</tr>
<tr>
<td>NCRPs</td>
<td>Niklason</td>
<td>0.632 (0.021)</td>
<td>0.117 (0.036)</td>
<td>$&lt; 0.001$</td>
<td>0.046 to 0.188</td>
</tr>
<tr>
<td>NCRPs</td>
<td>NCS</td>
<td>1.000 (−0.001)</td>
<td>0.108 (0.123)</td>
<td>0.036</td>
<td>−0.133 to 0.349</td>
</tr>
<tr>
<td>NCRPs</td>
<td>Clerinx</td>
<td>0.815 (0.001)</td>
<td>0.193 (0.057)</td>
<td>$&lt; 0.001$</td>
<td>0.081 to 0.365</td>
</tr>
<tr>
<td>NCS</td>
<td>Niklason</td>
<td>0.633 (0.020)</td>
<td>0.183 (0.111)</td>
<td>0.752</td>
<td>−0.035 to 0.401</td>
</tr>
<tr>
<td>NCS</td>
<td>Clerinx</td>
<td>0.816 (0.001)</td>
<td>0.259 (0.130)</td>
<td>0.012</td>
<td>0.004 to 0.514</td>
</tr>
<tr>
<td>Clerinx</td>
<td>Niklason</td>
<td>0.964 (−0.001)</td>
<td>0.268 (0.051)</td>
<td>$&lt; 0.001$</td>
<td>0.168 to 0.368</td>
</tr>
</tbody>
</table>

Notes: NCRPd = NCRP with double dosimetry, NCRPs = NCRP with single dosimetry, SD = Standard deviation, LOA = limits of agreement.
to assess agreement between the algorithms, which showed statistically significant difference (bias), or 95% LOA were wide and considerable disagreement was found between the algorithms. Since, data which seem to be in poor agreement can produce quite high correlation; different estimating algorithms should not be used interchangeably.

A number of authors as well as of NCRP and ICRP have recommended the necessity to derive effective dose for medical personnel sequentially.\textsuperscript{16–22} Collective doses and effective doses received by staff members working in fluoroscopic or interventional cardiology are increasing each year and occupational dosimetry is gaining more importance than before. There are several reasons for this trend. First, there are more medical centers that have begun to perform these procedures and the number of patients is increasing. Second, there is an expansion of staff number working in cardiology departments; this is due to the increase in complexity of procedures performed.\textsuperscript{23} Therefore, it is important to estimate the dose received by personnel frequently. Our study showed that different algorithms do not provide interchangeable values, supporting the conclusion that the serial assessment of effective dose with different techniques should be avoided and the same algorithm should be used for each follow-up assessment.

ICRP Report 85 recommends the use of two personal dosemeters to estimate the effective doses of physicians performing interventional procedures being more accurate.\textsuperscript{23} Despite this recommendation, double dosimetry is not a common practice in Iranian physicians. Many staff uses a single dosemeter outside the lead apron to determine their exposure from interventional procedures. Of course, the use of two personal dosemeters instead one is more expensive. Kuipers et al. reported that the extra annual cost for the extra personal dosemeters was about 64 € per physician in 2009 while it is questionable whether the accuracy increases by double dosimetry.\textsuperscript{11} The lack of agreement between single and double algorithms might lead to important health consequences for medical staff members and this is extremely relevant when applied to different methods of assessing the effective dose.

Several limitations are to be noted in this study. First, our study has been conducted on a small number of staff. The second limitation is that we only used the most common and widely used algorithms to estimate the effective dose. Further phantomic studies may be necessary to demonstrate the best algorithm or algorithms that could estimate effective dose accurately.

5. CONCLUSION
Our results show that the use of different algorithms can lead to different outcomes. Despite strong correlation between the methods, NCRPd, NCRPs, Niklason and NCS algorithms and the algorithm described by Clerinx et al. should not be used interchangeably for assessment of effective dose.

Conflict of Interest
The authors declare that they have no conflicts of interest.

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References and Notes


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