Occupational radiation exposure in femoral artery approach is higher than radial artery approach during coronary angiography or percutaneous coronary intervention

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Medical radiation exposure is a significant concern for interventional cardiologists (IC). This study was aimed at estimating the radiation exposure of IC operators and assistants in real clinical practice. The radiation exposure of the operator and assistant was evaluated by conducting two types of procedures via coronary angiography (CAG) and percutaneous coronary intervention (PCI) on 1090 patients in 11 cardiovascular centers in Korea. Radiation exposure was measured using an electronic personal dosimeter (EPD). EPD were attached at 3 points on each participant: on the apron on the left anterior chest (A1), under the apron on the sternum (A2), and on the thyroid shield (T). Average radiation exposure (ARE) of operators at A1, A2, and T was 19.219 uSv, 4.398 uSv, and 16.949 uSv during CAG and 68.618 uSv, 15.213 uSv, and 51.197 uSv during PCI, respectively. ARE of assistants at A1, A2, and T was 4.941 uSv, 0.860 uSv, and 5.232 uSv during CAG and 20.517 uSv, 4.455 uSv, and 16.109 uSv during PCI, respectively. AED of operator was 3.4 times greater during PCI than during CAG.

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The use of ionizing radiation in invasive cardiology procedures such as coronary angiography (CAG) and percutaneous coronary intervention (PCI) is customary; however, during the last 10 years, issues related to radiation hazards and injury have been raised, which increases the need to include long-term cancer risk due to ionizing radiation in the risk-benefit assessment of diagnostic or therapeutic procedures. Medical radiation exposure is a significant concern for interventional cardiologists because the workload and complexity of procedures have increased over the past few years without a corresponding increase in the number of interventional cardiologists, who represent the most important group of medical specialists involved in medical radiation practices. According to a report published by the International Commission on Radiological Protection (ICRP) that discussed the importance of radiation protection of patients and medical staff in the interventional cardiovascular field, interventional procedures may increase the risk of skin injury or cancer to both the patient as well as the staff. Several aspects of medical radiation safety in the practice of interventional cardiology have been addressed by the American College of Cardiology in a consensus document. According to the UNSCEAR 2000 report of the United Nations, fluoroscopic procedures are the largest source of occupational radiation exposure in medicine by far. The purpose of our study was to monitor and estimate the occupational radiation exposure of interventional cardiology operators and assistants during coronary angiography (CAG) and percutaneous coronary intervention (PCI) procedures in real clinical practice at the Korean Cardiovascular Center.

### Results

This study was performed on 682 male and 408 female patients, between 28 and 102 years of age, with an average age of 66.09. The weight of the patients ranged from 24.19 kg to 103 kg, with an average of 64.42 kg, and their height was between 126.00 cm and 188.00 cm, the average being 161.50 cm. The subjects were divided into two groups: the first group received the CAG procedure and the second group received the PCI procedure.

The CAG procedure was carried out on 801 patients and the PCI procedure was carried out on 289 patients. In the CAG procedure, the average exposure doses at A1, A2, and T to the operator were found to be 19.219 μSv, 4.398 μSv, and 16.949 μSv, respectively; the average exposure doses at A1, A2, and T to the assistant were 4.941 μSv, 0.860 μSv, and 5.232 μSv, respectively (Table 1). The average ED in CAG procedures was 8.584 μSv and 2.638 μSv to operator and assistant, respectively (Fig. 1). The average ED to operator and assistant in transfemoral artery approach procedures was 10.101 μSv and 3.592 μSv, respectively, showing that the average ED to operator is 3.6 times higher than for an assistant. The average ED to operator and assistant in transradial artery approach procedures was 25.694 μSv and 7.179 μSv, respectively; hence, for an operator, it is 3.6 times higher than for an assistant. In the case of the transradial artery and the transfemoral artery approach procedures taken together, the average ED to operator is 2.2 times higher than that to assistant.

### Table 1. Average effective dose of interventional cardiology operator & assistants in femoral & radial artery approach procedures. CAG: coronary angiography, PCI: percutaneous coronary intervention, ED: effective dose.

| Procedure                  | Operator ED (μSv) | Assistant ED (μSv) | Operator ED (μSv) | Assistant ED (μSv) |
|----------------------------|-------------------|--------------------|-------------------|--------------------|
| **Femoral artery approach**|                   |                    |                   |                    |
| Average                    | 10.101            | 3.592              | 42.888            | 11.298             |
| Standard deviation         | 10.892            | 4.852              | 50.192            | 13.059             |
| Minimum                    | 0.100             | 0.050              | 0.750             | 0.300              |
| Maximum                    | 39.560            | 24.370             | 249.870           | 54.660             |
| **Radial artery approach** |                   |                    |                   |                    |
| Average                    | 8.490             | 2.579              | 25.694            | 7.179              |
| Standard deviation         | 11.771            | 6.317              | 27.858            | 8.295              |
| Minimum                    | 0.050             | 0.050              | 0.200             | 0.050              |
| Maximum                    | 167.980           | 140.420            | 160.640           | 62.470             |
| **Femoral & radial artery**|                   |                    |                   |                    |
| Average                    | 69.460            | 32.160             |                   |                    |
| Standard deviation         | 70.097            | 27.476             |                   |                    |
| Minimum                    | 10.620            | 7.650              |                   |                    |
| Maximum                    | 163.790           | 71.050             |                   |                    |
(Table 2, Fig. 2). In the PCI procedure, the patient average cumulative fluoroscopy time for the transfemoral artery approach and the transradial artery approach was 1348.34 sec and 990.69 sec respectively (Table 3).

By correlation analysis, the correlation coefficient between the average ED and approach vessel was found to be $-0.131$ ($p < 0.01$) and $-0.077$ ($p < 0.5$) to operator and assistant, respectively. (Fig. 3). Both correlation coefficients show low significant connection between the average ED to operator and assistant and the approach vessel.

Table 2. Measurement values ($\mu$Sv) of exposure dose for each dosimeter. CAG: coronary angiography, PCI: percutaneous coronary intervention.

| Procedure | Operator A1 | Operator A2 | Operator T | Assistant A1 | Assistant A2 | Assistant T |
|-----------|-------------|-------------|------------|--------------|-------------|------------|
| CAG       | 19.219      | 4.398       | 16.949     | 4.941        | 0.860       | 5.232      |
| Standard deviation | 30.808 | 12.657 | 23.235 | 8.208 | 2.028 | 12.443 |
| Minimum   | 0.060       | 0.010       | 0.010      | 0.010        | 0.010       | 0.040      |
| Maximum   | 463.830     | 256.470     | 331.050    | 133.590      | 29.310      | 280.000    |
| PCI       | 68.618      | 15.213      | 57.193     | 20.571       | 4.455       | 16.109     |
| Standard deviation | 79.385 | 30.860 | 67.029 | 35.583 | 9.932 | 19.905 |
| Minimum   | 0.400       | 0.100       | 0.380      | 0.130        | 0.030       | 0.100      |
| Maximum   | 497.640     | 319.800     | 491.470    | 372.890      | 79.980      | 141.000    |

Figure 1. Effective dose of CAG and PCI procedures for cardiology operator and assistants.

Figure 2. Comparison of average effective dose in radial and femoral artery approaches in CAG and PCI procedures, between cardiology operator and assistants.
The correlation coefficients between the cumulative fluoroscopy time and the product of cumulative dose per patient and average ED to operator and assistant are 0.678 (0.01 < p), 0.548 (0.01 < p), 0.629 (0.01 < p), and 0.453 (0.01 < p), respectively (Fig. 4). All the correlation coefficients show a strong significant correlation.

Discussion

There is great concern about the potential effects of occupational radiation exposure on interventional cardiology staff and assistants performing CAG and PCI procedures, as they are exposed to high radiation levels. Therefore, it was necessary to estimate the ED to operator and assistant during these procedures. According to the results obtained, the average ED to operator in CAG and PCI procedures was 8.584 µSv and 28.977 µSv, respectively. If an operator undergoes four procedures per week, the annual estimated ED would be equivalent to approximately 8.204 mSv for CAG and 27.817 mSv for PCI. By the same estimation, the annual ED to an assistant would be 2.532 mSv for CAG and 7.839 mSv for PCI. According to the ICRP publication 103, the annual occupational radiation exposure limit should be under 50 mSv in a year with an average of 100 mSv in 5 years. The results of this study show that the average ED to an operator in PCI may exceed 100 mSv in 5 years. In a situation of planned exposure, the revised equivalent dose limit for the lens of the eye is 20 mSv per year which is the average over 5 consecutive years (i.e., 100 mSv in 5 years), and 50 mSv in any single year. In this study, the T exposure dose is equal to the exposure dose of the unprotected eye and thyroid. The eye and thyroid are sensitive organs for radiation exposure; hence, the annual equivalent dose for these was assumed to be 16.290 mSv per year. This value is approximately equal to the annual dose limitation of the eye of 20 mSv per year.

Radiation doses measured in this study are comparable to those reported in previous studies.

Table 3. Average patient radiation dose in transfemoral & transradial artery approach procedures. CAG: coronary angiography, PCI: percutaneous coronary intervention, Cum Fluoro time: cumulated fluoroscopy time, Cum Fluoro KAP: cumulated fluoroscopy kerma area product, Cum Exposure KAP: cumulated exposure kerma area product, Total KAP: total kerma area product.

Figure 3. The interaction equation of cumulative fluoroscopy time of a patient with average ED to operator and assistant.
The results of this study show that the average ED to operator and assistant are higher than those reported in the previous studies of 201011–14. On the CAG, ED of operator in this study was similar to the 2014 study of Georgios Christopoulos et al. but over half15,16 when compared to the Eltigani Abdelaal et al. study and Helmut W. Lange et al. study. Additionally, on the PCI, ED of operator in this study was 141% higher than in the Georgios Christopoulos et al. study17.

This study shows that operator exposure in transfemoral artery approach procedures was higher than that of transradial artery approach procedures. This matches the tentative results of the Lange et al. study12,18 and the Michael et al. study19.

This result shows that other factors such as distance from radial source and fluoroscopy time have greater impact on operator and assistant exposure dose than the insertion sites.

Operator exposure can be reduced by increasing the distance from the x-ray source (inverse-square law) and by reducing operator and patient exposure time. In 2006, Marque, N et al. studied the effect of the extension tube on operator radiation exposure during coronary procedures performed through the radial artery approach16. As a result, a non-significant trend towards lower left-arm operator exposure was noted in the extension catheter group (28.7 ± 31.0 μSv vs. 38.4 ± 44.2 μSv, p = 0.0739). No significant difference was noted in relation to the type of procedure. In this study of real clinical patient observations, fluoroscopy times and kerma area products in the transfemoral artery approach procedure were longer and higher than that of transradial artery approach procedures; the results followed an increase in patient and operator exposure dose.

Lange HW et al.’ study and Michael TT study showed that radiation exposure in the transradial artery approach was higher than that in the transfemoral artery approach12,18. Michael TT et al. reported that transradial artery approach diagnostic CAG was associated with operator radiation exposure compared with transfemoral angiography in patients who had previously undergone CABG surgery. In this study, transradial artery approaches had longer fluoroscopy times than transfemoral artery approaches (8.5 ± 4.7 min vs. 12.7 ± 6.6 min, p < 0.01)12. Also, in the study of Lange HW et al. although it is not the main aim of this study, fluoroscopy time with the transradial artery approach was longer than that of the transfemoral artery approach (2.7 ± 1.4 min vs. versus 2.1 ± 1.1 min, p < 0.001) and operator radiation dose with standard protection was 20.9 ± 13.8 μSv in the transradial artery approach group and 15.3 ± 10.4 μSv in the femoral artery approach group (p < 0.001).[20] Consequently, fluoroscopic time may be the one of several potent factors determining radiation exposure. Under real clinical conditions, the transradial artery approach was done in patients with complex and unfavorable conditions. In 2013, Wimmer NJ et al. analyzed the real world data from patients who underwent PCI without intra-aortic balloon pump or other mechanical support at 5 institutions in Massachusetts using either transfemoral or transradial arterial access. In this study, the transfemoral approach is used more frequently in patients with prior MI, prior stroke, prior CPI, prior CABG, peripheral artery disease, dialysis, cardiogenic shock, and emergency situation. These unfavorable conditions usually result in longer procedure times. Therefore, the results of our study explain why the transfemoral artery approach had higher operator radiation doses than the transradial artery approach.

In addition, a significant link is found relating the cumulative dose area product and cumulative fluoroscopy time with the occupational radiation dose measured by the electronic personal dosimeters (EPD) and ED. Occupational radiation dose measurement is an important part of reducing radiation exposure of operator and assistant. It is evident from the results that the operator can lower their own level of risk if they are aware of the need for radiation exposure reduction for their patients. ED to the operator and assistant is mainly the scattered radiation from patients. Thus, if patients receive less radiation, then the operator and assistant will also be exposed to less scattered radiation.

The limitation of this study is that dividing the RT and LT sides was not considered in transradial artery approach procedures. In the Javier Fernandez-Portales et al. study, it was shown that anatomic differences of RT and LT sides of the transradial artery could influence the procedure complex, and also affect the success rate and
duration of the procedures. From that point of view, dividing the RT and LT sides is not necessary in transradial artery approach procedures because the average cumulative fluoroscopy time was used in this study.

Our next plan is for the continuous monitoring of occupational radiation exposure in interventional cardiology staff and assistants and in-patient radiation exposure doses during CAG and PCI.

Conclusions

The average ED of operator and assistant during PCI was about 3.4 and 3.1 times greater than during CAG. For the CAG procedures, average ED of operator and assistant between transradial approach and transfemoral approach had similar values. For the PCI procedures, average ED of operator and assistant via transfemoral approach was about 2 times higher than via transradial approach. In medical radiation practice, reducing radiation exposure for both patients and operators is a universal goal. As a result of this study, the occupational radiation dose to the interventional cardiology operator and assistant was found to have various values. Therefore, interventional cardiology operator and assistant should use the appropriate protection devices for CAG and PCI procedures, be aware of radiation effects, and make efforts to reduce the radiation exposure dose for both the operator and assistant.

Methods

The subjects in this study were 1090 patients on whom coronary angiography (CAG) and percutaneous coronary intervention (PCI) procedures were carried out between August 2016 and October 2017 in 11 cardiovascular centers of university hospitals in Korea.

Occupational radiation exposure dose to operator and assistant was determined using the electronic personal dosimeters (SPD-9100, SFT technology, Korea): the first one was worn on the trunk of the body under the apron (A2), the second outside the apron (A1) at the level of the sternum on the chest, and a third one was worn on the outside of the thyroid protector (T). Each dosimeter was corrected by the Korea Research Institute of Standards and Science and the dosimeter correction factor, k, was 1.00–1.01, with an uncertainty of 7.4%. The dosimeter accuracy was +10% to –10%. The dosimeter under the apron provided an estimated dose, A2, to the organs of the shielded region while that worn outside the thyroid protector, T, provided the estimated dose to the organs of the head and neck, including the thyroid and eye lenses. The effective dose was calculated by substituting the values of A2 and T in Eq. 1. The NCRP report 122 published specific recommendations for calculating the effective dose (ED) when protective aprons were worn during diagnostic and interventional medical procedures.

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\text{Effective dose} = 0.025T + 0.5A2
\]  

The frequency and bivariate correlation analyses were performed using SPSS Version 22 software. (IBM Corporation, USA) This study complied with the Portability and Accountability Act and was approved by the respective institutional review boards of each hospital. This study was approved by institutional review boards of Kangwon national university and approval number of this study is KNUIRB-2015-11-004-003. All participants provided written informed consent.

Received: 4 March 2019; Accepted: 17 March 2020; Published online: 28 April 2020

References

1. Hirshfeld, J. W. et al. 2018 ACC/HRS/NASCI/SCAI/SCCT expert consensus document on optimal use of ionizing radiation in cardiovascular imaging: best practices for safety and effectiveness: a report of the American College of Cardiology Task Force on Expert Consensus Decision Pathways. J. Am. Coll. Cardiol. 71(24), e283–e351. https://doi.org/10.1016/j.jacc.2018.02.016 (2018).
2. Picano, E. & Vano, E. The radiation issue in cardiology: the time for action is now. Cardiovasc. Ultrasound. 9(1), 35. https://doi.org/10.1186/1476-7120-9-35 (2011).
3. Vano, E., Gonzalez, L., Fernandez, J. M., Alfonso, F. & Macaya, C. Occupational radiation doses in interventional cardiology: a 15-year follow-up. Br. J. Radiol. 79(941), 383–388. https://doi.org/10.1259/bjr/26829723 (2006).
4. Cousins, C. et al. ICRP publication 120: radiological protection in cardiology. Ann. ICRP 42(1), 1–125. https://doi.org/10.1016/j.icrp.2012.09.001 (2013).
5. Limbacher, M., Douglas, P. S. & Germano, G. Radiation safety in the practice of cardiology. J. Am. Coll. Cardiol. 31(4), 892–915 (1998).
6. United nations. Scientific committee on the effects of atomic radiation. Sources and effects of ionizing radiation: sources. United Nations Publications (2000).
7. PROTECTION, Radiological. ICRP publication 60. ICRP 21(1–3). Preprint at, http://www.icrp.org/publication.asp?id=icrp%20publication%2060 (1991).
8. PROTECTION, Radiological. ICRP publication 103. ICRP, 2007. 37(2–4). Preprint at, http://www.icrp.org/publication.asp?id=icrp%20Publication%20103 (2007).
9. Stewart, F. A. 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. Ann. ICRP 41(1), 1–322. https://doi.org/10.1016/j.icrp.2012.02.001 (2012).
10. Amano Y. Radiation protection and safety of radiation sources: international basic safety standards (2011).
11. Delichas, M. et al. Radiation exposure to cardiologists performing interventional cardiology procedures. Eur. J. Radio. 48(3), 268–273. https://doi.org/10.1016/S0702-848X(03)00007-X (2003).
12. Lange, H. V. & von Boetticher, H. Randomized comparison of operator radiation exposure during coronary angiography and intervention by radial or femoral approach. Catheter. Cardiovasc. Interv. 67(1), 12–16. https://doi.org/10.1002/ccd.20341 (2006).
13. Trianni, A. et al. Patient skin dosimetry in haemodynamic and electrophysiology interventional cardiology. Radiat. Prot. Dosimetry. 117(1–3), 241–246. https://doi.org/10.1093/rpd/nci756 (2005).
14. Gott, H. et al. Investigation of occupational radiation exposure during interventional cardiac catheterisations performed via radial artery. Radiat. Prot. Dosimetry. 117(1–3), 107–110. https://doi.org/10.1093/rpd/nci763 (2005).
15. Abdelal, E. et al. Effectiveness of low rate fluoroscopy at reducing operator and patient radiation dose during transradial coronary angiography and interventions. JACC Cardiovasc. Interv. 7(5), 567–574. https://doi.org/10.1016/j.jcin.2014.02.005 (2014).
16. Lange, H. W. & Von Boetticher, H. Reduction of operator radiation dose by a pelvic lead shield during cardiac catheterization by radial access: comparison with femoral access. *JACC Cardiovasc. Interv.* 5(4), 445–459, https://doi.org/10.1016/j.jcin.2011.12.013 (2012).

17. Christopoulos, G. *et al.* Effect of a real-time radiation monitoring device on operator radiation exposure during cardiac catheterization: the radiation reduction during cardiac catheterization using real-time monitoring study. *Circ. Cardiovasc. Interv.* 7(6), 744–750, https://doi.org/10.1161/CIRCINTERVENTIONS.114.001974 (2014).

18. Lange, H. W. & von Boetticher, H. Reduction of operator radiation dose by a pelvic lead shield during cardiac catheterization by radial access: comparison with femoral access. *JACC Cardiovasc. Interv.* 5(4), 445–449, https://doi.org/10.1016/j.jcin.2011.12.013 (2012).

19. Michael, T. T. *et al.* A randomized comparison of the transradial and transfemoral approaches for coronary artery bypass graft angiography and intervention: the RADIAL-CABG Trial (RADIAL Versus Femoral Access for Coronary Artery Bypass Graft Angiography and Intervention). *JACC Cardiovasc. Interv.* 6(11), 1138–1144, https://doi.org/10.1016/j.jcin.2013.08.004 (2013).

20. Marque, N. *et al.* Impact of an extension tube on operator radiation exposure during coronary procedures performed through the radial approach. *Arch. cardiovascular Dis.* 102(11), 749–754, https://doi.org/10.1016/j.acvd.2009.09.006 (2006).

21. Wimmer, N. J. *et al.* Risk-treatment paradox in the selection of transradial access for percutaneous coronary intervention. *J. Am. Heart Assoc.* 2(3), e000174, https://doi.org/10.1161/JAHA.113.000174 (2013).

22. Rosenstein, M., Brateman, L. F., Claycamp, H. G., Poston, J. W. Sr. & Yoder R. C. Use of personal monitors to estimate effective dose equivalent and effective dose to workers for external exposure to low-LET radiation. *National Council on Radiation Protection and Measurements* (1995).

**Acknowledgements**

This study was funded by a research grant from the Korean Society of Cardiology (201501-01).

**Author contributions**

Jung-Su Kim and Byung-Ryul Cho conceptualized the designed research and wrote the manuscript. Bong-Ki Lee, Dong-Ryeol Ryu, Kwangjin Chun, Ho-Seok Kwon, Doo-il Kim, Sung-Yun Lee, Jin-Ok Jeong, Jang-Whan Bae, Jong-Seon Park, Youngkeun Ahn, Je-Keon Chae, Myeong-Ho Yoon, Seung-Hwan Lee, Jeonghan Yoon, Hyeon-Cheol Gwon and Donghoon Choi performed research and data collected. So-Ra Nam, Soon-Mu Kwon, Young-Hoon Roh analyzed data. All the authors were involved in revising the manuscript and checking for its accuracy.

**Competing interests**

The authors declare no competing interests.

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