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# Determinants of Radiation Exposure in the Cardiac Catheterization Laboratory: Influence of Procedure Type, Vascular Access, and Lesion Complexity in a Tertiary Care Center

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## Abstract

**Background:** Radiation exposure in the cardiac catheterization laboratory represents a critical concern for both patient safety and occupational health. Coronary angiography (CAG) and percutaneous coronary intervention (PCI) rely on fluoroscopic imaging, resulting in variable radiation doses influenced by procedural and anatomical factors.

**Methodology:** This retrospective observational study was conducted at Lady Reading Hospital, Peshawar, Pakistan, and included 300 consecutive adult patients (≥18 years) who underwent CAG or PCI between December 2024 and May 2025. Radiation exposure parameters, including fluoroscopy time and dose–area product (DAP), were automatically recorded by the angiography system. Patients were stratified according to procedure type (CAG vs. PCI), vascular access site (radial vs. femoral), and PCI complexity based on ACC/AHA lesion classification and procedural characteristics.

**Results:** PCI procedures were associated with significantly higher radiation exposure compared with diagnostic CAG, with longer fluoroscopy times (34.1 ± 3.1 vs. 4.5 ± 1.0 minutes) and higher DAP (152.4 ± 14.9 vs. 18.1 ± 2.8 Gy·cm²; $p < 0.001$). Overall radiation exposure was comparable between radial and femoral access. However, within the PCI subgroup, radial access was associated with significantly higher fluoroscopy time and DAP compared with femoral access ($p < 0.001$). Lesion complexity demonstrated a strong association with radiation exposure, with ACC/AHA B2/C lesions showing substantially higher fluoroscopy time (44.0 vs. 22.1 minutes) and DAP (201.9 vs. 108.9 Gy·cm²; $p < 0.001$).

**Conclusion:** Radiation exposure in the cardiac catheterization laboratory is primarily driven by procedure type and lesion complexity. While vascular access site does not significantly influence radiation exposure overall, radial access is associated with higher radiation burden within PCI procedures. These findings highlight the importance of targeted radiation-reduction strategies, particularly during complex interventions.

## Keywords

Radiation Exposure, Fluoroscopy, Coronary Angiography, Percutaneous Coronary Intervention, Radial Access, Femoral Access



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## Introduction

Contemporary cardiovascular procedures, including coronary angiography (CAG) and percutaneous coronary intervention (PCI), are routinely performed in cardiac catheterization laboratories using fluoroscopy and cineangiography. While these imaging modalities are indispensable for diagnosis and treatment, they expose patients and healthcare personnel to ionizing radiation, which carries both deterministic risks such as skin injury and cataract formation and stochastic risks, including malignancy[1-3]. With the global rise in cardiovascular interventions and increasing procedural complexity, radiation exposure has emerged as a significant patient safety and occupational health concern, reinforcing the importance of optimization strategies and adherence to the As Low As Reasonably Achievable (ALARA) principle[4,5].

Radiation exposure during cardiac catheterization is highly variable and influenced by multiple procedural factors. Among these, procedure type is a major determinant, with PCI consistently associated with higher radiation doses compared with diagnostic CAG due to longer fluoroscopy times, increased cine acquisition, and procedural complexity[6,7]. Prolonged procedure duration and repeated imaging acquisitions further contribute to cumulative radiation exposure[8].

The choice of vascular access site also plays an important role in modulating radiation exposure. Although transradial access has been widely adopted due to its well-established advantages in reducing vascular complications and improving patient outcomes, several studies have reported modest increases in radiation exposure compared with femoral access, particularly during complex interventions and in the early phases of operator experience[9-11]. These findings highlight the interplay between procedural approach and operator-dependent factors in determining radiation burden.

In addition to procedural characteristics, lesion complexity and patient-related factors significantly influence radiation exposure. Complex coronary lesions, including ACC/AHA type B2 and C lesions, chronic total occlusions, and bifurcation lesions, are associated with increased fluoroscopy time and radiation dose due to prolonged manipulation and the need for multiple imaging angles[12,13]. Furthermore, patient characteristics such as elevated body mass index may increase radiation exposure through automatic exposure control mechanisms[14].

Lady Reading Hospital (LRH), Peshawar, is a high-volume public-sector tertiary care center managing a diverse patient population with varying degrees of coronary disease complexity, often under resource-constrained conditions. Despite routine recording of radiation metrics such as fluoroscopy time and dose–area product (DAP), there is a paucity of locally generated data evaluating the determinants of radiation exposure in this setting. Such data are essential to contextualize international evidence and to inform locally relevant radiation-sparing strategies.

Therefore, the present study aimed to systematically evaluate the impact of procedure type, vascular access site, and lesion complexity on radiation exposure in the cardiac catheterization laboratory at LRH, Peshawar. By analyzing routinely collected procedural data, this study seeks to provide real-world insights and establish a foundation for improving radiation safety practices in similar high-volume clinical environments.

## Methodology

### Study Design

This study was designed as a retrospective observational analysis aimed at evaluating radiation exposure patterns in the cardiac catheterization laboratory. The retrospective design enabled the assessment of routinely collected procedural and radiation data without influencing clinical practice, thereby reflecting real-world conditions in a high-volume tertiary care setting.

### Ethics

The study was conducted in accordance with the principles outlined in the Declaration of Helsinki. Ethical approval was obtained from the Ethics Review Committee of Lady Reading Hospital (LRH), Peshawar (Study ID # 55/LRH/MTI). As this was a retrospective analysis of anonymized data, individual patient consent was waived in line with institutional policies.

**Setting**

The study was carried out in the cardiac catheterization laboratory of Lady Reading Hospital (LRH), Peshawar, Pakistan, a high-volume public-sector tertiary care center managing a broad spectrum of coronary artery disease cases, including a substantial proportion of complex interventions. Data were collected for procedures performed between December 2024 and May 2025.

**Participants**

The study included consecutive adult patients (aged ≥18 years) who underwent coronary angiography (CAG) or percutaneous coronary intervention (PCI) during the study period. Inclusion required the availability of complete procedural and radiation exposure data. Patients undergoing non-coronary procedures, such as structural heart interventions, congenital heart disease procedures, or electrophysiological studies, were excluded to maintain homogeneity of the study population.

**Variables**

The study variables were categorized into procedural characteristics, radiation exposure parameters, and lesion complexity indicators. Procedural variables included procedure type (CAG or PCI), vascular access site (radial or femoral), and total procedure duration. Radiation variables comprised fluoroscopy time (minutes) and dose–area product (DAP, Gy·cm²). Air kerma values were recorded when available; however, due to inconsistent documentation, they were not included in the primary analysis. Lesion complexity variables (for PCI cases) included number of vessels treated, ACC/AHA lesion classification (A–B1 vs. B2–C), and the presence of calcification, chronic total occlusion (CTO), and bifurcation lesions.

**Data Sources / Measurement**

Data were extracted from hospital records, including catheterization laboratory logs and electronic procedural databases. Radiation exposure metrics were automatically generated and recorded by the angiography system, ensuring objective and standardized measurement. Dose–area product and fluoroscopy time were directly obtained from system-generated dose reports, minimizing measurement bias. Additional procedural details, including cine acquisition parameters and procedure duration, were documented when available.

**Bias**

Several sources of bias were considered. Selection bias was minimized by including consecutive cases during the study period. However, inherent limitations of retrospective designs include potential information bias due to incomplete documentation, particularly for variables such as Air kerma. Confounding bias may also be present, as important variables such as patient body mass index (BMI), operator experience, procedural techniques, and equipment settings were not consistently available and therefore could not be adjusted for. These limitations were acknowledged in the study design and interpretation of results.

**Study Size**

A total of 300 consecutive procedures were included in the final analysis. The sample size was determined by the number of eligible cases available during the defined study period, reflecting a pragmatic approach typical of retrospective single-center studies. This sample size was considered sufficient to allow meaningful comparisons between procedural groups while maintaining statistical robustness.

**Quantitative Variables**

Continuous variables, including fluoroscopy time and DAP, were treated as quantitative variables and expressed as mean ± standard deviation or median with interquartile range, depending on data distribution. Categorical variables, such as procedure type, access site, and lesion classification, were expressed as frequencies and percentages. Lesion complexity was operationalized primarily using ACC/AHA classification (A/B1 vs. B2/C) for comparative analyses to preserve statistical power and avoid excessive subgrouping.

**Statistical Methods**

Statistical analysis was performed using SPSS version 26.0. Descriptive statistics were used to summarize baseline characteristics and radiation exposure parameters. The distribution of continuous variables was assessed to determine the appropriateness of parametric or non-parametric testing. Group comparisons were conducted using the Student's t-test or Mann–Whitney U test for continuous variables and the chi-square test or Fisher's exact test for categorical variables, as appropriate. A two-sided p-value <0.05 was considered statistically significant. Given the observational design and absence of complete covariate data, analyses were limited to univariable comparisons, and results were interpreted as associations rather than causal relationships.

## Results

### Participants

A total of 300 consecutive cardiac catheterization procedures were included in the final analysis, ensuring a comprehensive representation of real-world practice within the study period. Of these, 182 procedures (60.6%) were diagnostic coronary angiography (CAG), while 118 procedures (39.3%) were percutaneous coronary interventions (PCI). Regarding vascular access, 180 procedures (60%) were performed via radial access and 120 procedures (40%) via femoral access. Within the PCI subgroup, 70 procedures (59.3%) involved single-vessel intervention and 48 procedures (40.6%) involved multivessel intervention. A range of lesion complexities was observed, including ACC/AHA type A/B1 lesions (52.54%) and B2/C lesions (47.45%), along with calcified lesions (38.98%), bifurcation lesions (29.66%), and chronic total occlusions (17.79%). These baseline procedural and lesion characteristics are summarized in Table 1, providing context for subsequent comparative analyses.

### Descriptive Data

Radiation exposure parameters varied substantially across procedures and subgroups. Overall, continuous variables such as fluoroscopy time and dose–area product (DAP) demonstrated wide variability, reflecting differences in procedural complexity and duration. For the overall cohort, mean fluoroscopy times ranged broadly depending on procedure type and access site, while DAP values similarly reflected procedural intensity. Descriptive comparisons by vascular access site in the overall cohort demonstrated comparable mean fluoroscopy times (17.5 ± 13.5 minutes for radial vs. 17.8 ± 13.4 minutes for femoral) and DAP values (76.1 ± 61.5 vs. 78.2 ± 62.2 Gy·cm²), as detailed in Table 3A. These findings suggest relative homogeneity in radiation exposure at the aggregate level prior to subgroup stratification.

### Outcome Data

Radiation exposure outcomes differed markedly according to procedure type. PCI procedures were associated with significantly higher radiation exposure compared with diagnostic CAG. Specifically, the mean fluoroscopy time for PCI was 34.1 ± 3.1 minutes compared to 4.5 ± 1.0 minutes for CAG. Similarly, mean DAP values were substantially higher in PCI (152.4 ± 14.9 Gy·cm²) than in CAG (18.1 ± 2.8 Gy·cm²), with all comparisons demonstrating strong statistical significance ($p < 0.001$). These results are presented in Table 2, highlighting the pronounced impact of interventional procedures on radiation burden.

Within the PCI subgroup, further stratification revealed important differences based on vascular access. Radial PCI procedures demonstrated higher mean fluoroscopy time (36.08 ± 6.41 minutes) compared with femoral PCI (30.91 ± 5.97 minutes), along with higher DAP values (171.4 ± 37.6 vs. 138.2 ± 34.9 Gy·cm²), both statistically significant ($p < 0.001$). These subgroup findings are detailed in Table 3B, indicating that access-related differences become more apparent in interventional contexts.

Lesion complexity also showed a strong association with radiation exposure. Procedures involving ACC/AHA type B2/C lesions were associated with markedly higher fluoroscopy time (mean 44.0 minutes) compared with A/B1 lesions (mean 22.1 minutes), along with substantially increased DAP values (201.9 vs. 108.9 Gy·cm²), as summarized in Table 4 ($p < 0.001$ for both comparisons). These findings underscore the influence of anatomical complexity on radiation metrics.

### Main Results

The primary findings of this study demonstrate that radiation exposure in the cardiac catheterization laboratory is predominantly influenced by procedure type and lesion complexity. PCI procedures consistently resulted in significantly higher fluoroscopy times and DAP compared with diagnostic CAG, confirming the substantial radiation burden associated with interventional procedures (Table 2).

While vascular access site did not significantly influence radiation exposure in the overall cohort (Table 3A), subgroup analysis revealed that radial access was associated with higher radiation exposure during PCI procedures (Table 3B), suggesting that procedural context modifies the effect of access site.

Furthermore, lesion complexity emerged as a major determinant of radiation exposure, with ACC/AHA B2/C lesions associated with approximately double the fluoroscopy time and substantially higher DAP compared with simpler lesions (Table 4).

Collectively, these findings indicate that procedural and anatomical complexity, rather than access site alone, are the dominant contributors to radiation exposure in this setting.

**Table 1: Baseline procedural characteristics.**

| Variables | Overall (n = 300) |
|---|---|
| Diagnostic coronary angiography, n (%) | 182 (60.6%) |
| Percutaneous coronary intervention, n (%) | 118 (39.3%) |
| Radial access, n (%) | 180 (60%) |
| Femoral access, n (%) | 120 (40%) |
| Single-vessel PCI, n (%) | 70 (59.3%) |
| Multivessel PCI, n (%) | 48 (40.6%) |
| ACC/AHA type A/B1 lesions, n (%) | 62 (52.54%) |
| ACC/AHA type B2/C lesions, n (%) | 56 (47.45%) |
| Calcified lesions, n (%) | 46 (38.98%) |
| Bifurcation lesions, n (%) | 35 (29.66%) |
| Chronic total occlusion, n (%) | 21 (17.79%) |
| Number of stents per procedure, mean ± SD | 1.74 ±0.83 |

**Table 2: Radiation exposure according to procedure type.**

| Parameter | CAG | PCI | p-value |
|---|---|---|---|
| Fluoroscopy time, min (mean ± SD) | 4.5 ± 1.0 | 34.1 ± 3.1 | <0.001* |
| Fluoroscopy time, min (median) | 4.0 | 34.2 | <0.001* |
| DAP, Gy·cm² (mean ± SD) | 18.1 ± 2.8 | 152.4 ± 14.9 | <0.001* |
| DAP, Gy·cm² (median) | 18.2 | 152.8 | <0.001* |

*p<0.05 is considered significant.

**Table 3A: Radiation exposure by vascular access site (overall).**

| Parameter | Radial Access | Femoral Access | p-value |
|---|---|---|---|
| Fluoroscopy time, min (mean ± SD) | 17.5 ± 13.5 | 17.8 ± 13.4 | 0.850 |
| DAP, Gy·cm² (mean ± SD) | 76.1 ± 61.5 | 78.2 ± 62.2 | 0.774 |

**Table 3B: Radiation exposure by vascular access site (PCI Subgroups).**

| Parameter | Radial PCI (n=70) | Femoral PCI (n=48) | p-value |
|---|---|---|---|
| **Fluoroscopy time (min)** | 36.08 ± 6.41 | 30.91 ± 5.97 | <0.001* |
| **DAP (Gy·cm²)** | 171.4 ± 37.6 | 138.2 ± 34.9 | <0.001* |

*p<0.05 is considered significant.

**Table 4: Radiation exposure on basis of lesion complexity (PCI subgroups).**

| Parameter | ACC/AHA A/B1 | ACC/AHA B2/C | P value |
|---|---|---|---|
| **Fluoroscopy time, min (mean)** | 22.1 | 44.0 | <0.001* |
| **DAP, Gy·cm² (mean)** | 108.9 | 201.9 | <0.001* |

*p<0.05 is considered significant.

## Discussion

In this retrospective analysis of radiation exposure in the cardiac catheterization laboratory at Lady Reading Hospital (LRH), Peshawar, we examined the influence of procedure type, vascular access site, and lesion complexity on radiation burden. The findings provide important real-world insights from a high-volume tertiary care setting and align with, while also extending, existing literature.

The most prominent observation of this study is that procedure type is the primary determinant of radiation exposure. PCI procedures were associated with significantly higher fluoroscopy time and dose–area product (DAP) compared with diagnostic coronary angiography (CAG). This finding is consistent with established evidence demonstrating that interventional procedures, particularly those involving complex coronary anatomy, require prolonged fluoroscopic guidance and repeated cine acquisitions, thereby increasing cumulative radiation exposure[6,7]. Previous studies have similarly reported that procedural duration and technical complexity are key contributors to radiation dose escalation in interventional cardiology[8,15,16]. Our results reinforce the concept that PCI inherently carries a higher radiation burden and underscore the importance of targeted dose-reduction strategies during interventional procedures.

With respect to vascular access, our study demonstrated no significant difference in radiation exposure between radial and femoral approaches in the overall cohort. This observation is in agreement with studies conducted in experienced centers where operator proficiency mitigates differences between access routes[17]. However, within the PCI subgroup, radial access was associated with significantly higher fluoroscopy time and DAP compared with femoral access[18,19]. This finding is consistent with prior reports suggesting modestly increased radiation exposure during transradial interventions, particularly in complex procedures or during early phases of the learning curve[9-11]. Several factors may explain this observation. First, radial access is often preferentially used in more complex or multivessel interventions, which inherently require longer procedural times. Second, catheter manipulation and anatomical challenges associated with the radial route may prolong fluoroscopy time. Third, procedural ergonomics, particularly during right radial access, may increase scatter radiation and contribute to higher measured doses. Importantly, these findings should be interpreted in the context of the well-established clinical benefits of radial access, including reduced bleeding and vascular complications, and should not discourage its use but rather emphasize the need for enhanced radiation safety training and optimization techniques.

Lesion complexity emerged as a major determinant of radiation exposure in our study. Procedures involving ACC/AHA type B2/C lesions demonstrated substantially higher fluoroscopy time and DAP compared with simpler A/B1 lesions.

This observation is supported by existing literature, which consistently shows that complex lesions, including chronic total occlusions, bifurcations, and heavily calcified segments, require prolonged fluoroscopy, multiple angiographic projections, and advanced interventional techniques, all of which contribute to increased radiation exposure[12,13]. Our findings highlight that anatomical complexity, rather than procedural approach alone, plays a central role in determining radiation burden.

The results of this study also provide important regional context. Data from Pakistan and similar healthcare settings remain limited, and procedural variability in radiation exposure has been reported across different centers[20-22]. As a high-volume public-sector institution managing a diverse and often complex patient population under resource constraints, LRH represents a realistic model of routine clinical practice in such environments. Therefore, the radiation metrics observed in this study may serve as practical benchmarks for comparable centers. At the same time, caution is warranted in extrapolating these findings to lower-volume or technologically advanced centers, where differences in operator expertise and equipment may influence radiation exposure.

The findings emphasize that radiation exposure in the catheterization laboratory is a multifactorial phenomenon, primarily driven by procedural and anatomical complexity. These insights support the implementation of targeted strategies, including operator training, real-time dose monitoring, procedural planning, and adherence to radiation safety principles, to minimize exposure while maintaining procedural efficacy.

## Limitations

This study has several limitations that should be considered when interpreting the findings. First, the retrospective observational design limits the ability to establish causal relationships, and the results should therefore be interpreted as associations rather than determinants. Second, important confounding variables, including patient body mass index (BMI), operator experience, procedural techniques, fluoroscopy settings, and equipment variability, were not consistently available and could not be included in the analysis, potentially influencing radiation exposure outcomes.

Third, radiation assessment was limited to patient dose metrics, specifically fluoroscopy time and dose–area product (DAP). Air kerma, an important parameter for assessing deterministic radiation effects, was not consistently documented and therefore could not be incorporated into the primary analysis. Additionally, occupational radiation exposure to operators and catheterization laboratory staff was not evaluated, which limits the assessment of overall radiation safety implications.

Fourth, lesion complexity was primarily categorized using angiographic ACC/AHA classification, without incorporating functional assessment or intravascular imaging guidance, which may also influence procedural duration and radiation exposure. Finally, as a single-center study conducted in a high-volume public-sector hospital, the generalizability of these findings to other institutions with different patient populations, procedural volumes, operator expertise, and technological resources may be limited.

## Conclusion

In this retrospective study, radiation exposure in the cardiac catheterization laboratory was predominantly influenced by procedure type and lesion complexity. Percutaneous coronary intervention (PCI) was associated with substantially higher fluoroscopy time and dose–area product compared with diagnostic coronary angiography, reflecting the increased technical demands of interventional procedures. Lesion complexity further amplified radiation exposure, with ACC/AHA B2/C lesions demonstrating significantly greater radiation burden than simpler lesions.

While vascular access site did not significantly influence radiation exposure in the overall cohort, radial access was associated with higher radiation exposure within the PCI subgroup, likely reflecting procedural complexity and operator-related factors. These findings highlight that radiation exposure is primarily driven by procedural and anatomical factors rather than access site alone.

The results underscore the importance of implementing targeted radiation-reduction strategies, particularly during complex PCI procedures. Enhanced operator training, optimization of fluoroscopy techniques, and real-time radiation monitoring are essential to minimize exposure and improve both patient and occupational safety in contemporary cardiac catheterization practice.

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