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Retrospective Analysis of Radiation Dose According to Operator Experience During Percutaneous Coronary Interventions in Acute ST-Elevation Myocardial Infarction

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Abstract

Introduction: Primary percutaneous coronary intervention (pPCI) is the standard reperfusion treatment for patients with STEMI. The procedure involves exposure to ionising radiation and the administration of contrast media, with patient characteristics, procedural complexity, and operator experience potentially influencing the level of exposure.

Aim: To analyze the association between operator experience and radiation dose, with particular emphasis on cumulative air kerma (CAK).

Participants and Methods: A retrospective analysis was conducted on 1,140 patients with STEMI treated with pPCI between January 1, 2021, and December 31, 2025. Patients were divided according to admission troponin levels into a normal-troponin group (n = 293) and an elevated-troponin group (n = 847). Ten interventional cardiologists were categorised according to experience as senior, mid-experienced, and junior operators. CAK, fluoroscopy time, contrast media volume, age, and sex were analysed. Differences were assessed using ANOVA with Duncan's post-hoc test, while independent predictors were analyzed using multivariable linear regression.

Results: In the normal-troponin group, no significant differences were found between operator groups in CAK, fluoroscopy time, or contrast media volume. In the elevated-troponin group, operator experience was significantly associated with CAK ($F = 11.6$; $p < 0.001$), fluoroscopy time ($F = 4.2$; $p = 0.0151$), and contrast media volume ($F = 13.9$; $p < 0.001$). The highest mean CAK was recorded among junior operators (2254.2 mGy), and the lowest among mid-experienced operators (1561.5 mGy). Multivariable analysis identified sex and age as independent predictors of higher CAK, whereas operator experience was not an independent predictor. Greater operator experience was independently associated with lower contrast media use.

Conclusion: The association between operator experience and procedural parameters was most pronounced in patients with elevated troponin levels. After adjustment, CAK was primarily associated with patient characteristics, whereas contrast media use remained associated with operator experience. Optimization of pPCI should include the ALARA principle, individualized procedures, rational use of contrast media, and continuous education and supervision of less experienced operators.

Keywords: STEMI; primary percutaneous coronary intervention; cumulative air kerma; fluoroscopy; contrast media; operator experience; radiation protection.

Introduction

Acute ST-segment elevation myocardial infarction (STEMI) is a medical emergency most commonly caused by acute occlusion of a coronary artery, resulting in myocardial ischemia and necrosis. Timely restoration of coronary blood flow is the cornerstone of treatment, as the duration of ischemia directly affects the extent of myocardial damage. Primary percutaneous coronary intervention (pPCI) is the standard reperfusion treatment when it can be performed within the recommended time frame [1,2].

pPCI involves coronary angiography and, depending on the findings, interventional treatment of the coronary le-

sion. Since the procedure is performed using fluoroscopy and angiographic acquisition, the patient is exposed to ionizing radiation during the intervention. The level of exposure depends on numerous factors, including patient characteristics, the complexity of coronary anatomy, the number of treated lesions and vessels, the procedural technique, and operator experience [3–6].

Cumulative air kerma (CAK) is one of the most important indicators of patient radiation exposure during interventional procedures. In addition to CAK, fluoroscopy time is frequently used as a procedural indicator, while the volume of administered contrast media represents an important measure of the rationality and safety of the intervention.

Previous studies have shown that operator and center experience may be associated with patient radiation exposure during coronary interventions [3,4,8]. However, radiation dose is not determined solely by the operator. Patient characteristics and procedural complexity may have a substantial impact; therefore, differences between operators should be interpreted within the appropriate clinical context.

The aim of this study was to analyse the association between operator experience and radiation dose during pPCI in patients with STEMI, with particular emphasis on CAK. Secondary objectives were to analyse the association between operator experience and fluoroscopy duration and contrast media volume in groups of patients with normal and elevated troponin levels, and to assess the variability of these parameters between operators.

Participants and Methods

Participants

A retrospective study was conducted at the Department of Cardiovascular Diseases of University Hospital Centre Zagreb, within the Division of Invasive and Interventional Cardiology.

A total of **1,140 patients with STEMI** treated between January 1, 2021, and December 31, 2025, were included in the study. Patients were divided into two groups according to their troponin levels at admission: the normal-troponin group consisted of 293 patients, while the elevated-troponin group consisted of 847 patients. All patients were hospitalised within 12 hours of symptom onset, and pPCI was indicated. Patients for whom complete data on radiation dose, fluoroscopy time, or contrast media use were unavailable were excluded from the analysis.

The study included 10 interventional cardiologists divided into three groups according to their experience working in the cardiac catheterisation laboratory: **senior operators** (10–15 years of experience), **mid-experienced operators** (5–10 years), and **junior operators** (1–5 years).

Analyzed Parameters

Patient age and sex, as well as three main procedural parameters, were analysed: cumulative air kerma (CAK), fluoroscopy time, and the volume of administered contrast media.

All procedures were performed using a Siemens Artis Zee angiographic system (Siemens Healthineers, Germany). Pulsed fluoroscopy and image acquisition at 15 frames per second were used. The primary outcome of the study was CAK, expressed in mGy, while the secondary outcomes were fluoroscopy time, expressed in minutes, and contrast media volume, expressed in mL.

Statistical Analysis

Continuous variables were described using the mean and standard deviation or the median and range, depending on the distribution of the data. Differences between operator experience groups were analyzed using one-way ANOVA, and Duncan's post-hoc test was used when statistically significant results were obtained.

The effects of demographic and operator-related factors on CAK, fluoroscopy time, and contrast media volume were assessed using multivariable linear regression. Standardized regression coefficients (β), p-values, R, and R^2 were reported. The level of statistical significance was set at $p < 0.05$.

Results

The analysis included 293 patients with normal troponin levels and 847 patients with elevated troponin levels. In the normal-troponin group, the highest number of procedures was performed by senior operators (n = 141), followed by junior operators (n = 88) and mid-experienced operators (n = 64).

Patients with Normal Troponin Levels

In this group (Table 1), no statistically significant differences were found between operator experience groups in CAK, fluoroscopy time, or contrast media volume.

The mean CAK was **1795.4 mGy** among senior operators, **1890.0 mGy** among mid-experienced operators, and **2168.2 mGy** among junior operators. Although there

Table 1. Basic procedural parameters according to operator experience in STEMI patients with normal troponin levels

Parameter	Senior (n=141)	Mid-experienced (n=64)	Junior (n=88)	F	p
CAK (mGy), $\bar{X}$ ± SD	1795,4 ± 1152,9	1890,0 ± 1498,8	2168,2 ± 1563,0	2,1	0,1273
Fluoroscopy time (min), $\bar{X}$ ± SD	28,3 ± 16,5	11,8 ± 9,6	13,1 ± 11,1	0,5	0,6261
Contrast media (mL), $\bar{X}$ ± SD	182,6 ± 88,5	185,3 ± 91,5	197,7 ± 102,4	0,8	0,4642
Age (years), $\bar{X}$ ± SD	61,6 ± 12,4	65,8 ± 12,6	64,0 ± 11,9	2,8	0,0631

Note: $\bar{X}$ – mean value; SD – standard deviation; CAK – cumulative air kerma.

Table 2. Basic procedural parameters according to operator experience in STEMI patients with elevated troponin levels

Parameter	Senior (n=412)	Mid-experienced (n=214)	Junior (n=221)	F	p
CAK (mGy), $\bar{X}$ ± SD	1879,9 ± 1294,8	1561,5 ± 1227,5	2254,2 ± 2023,6	11,6	<0,001
Fluoroscopy time (min), $\bar{X}$ ± SD	12,4 ± 8,1	10,2 ± 8,8	12,9 ± 14,2	4,2	0,0151
Contrast media (mL), $\bar{X}$ ± SD	207,9 ± 101,0	167,8 ± 71,9	207,7 ± 105,7	13,9	<0,001
Age (years), $\bar{X}$	63,0	63,0	64,0	0,2	0,8328

Note: $\bar{X}$ – mean value; SD – standard deviation; CAK – cumulative air kerma.

was a trend toward higher radiation doses among less experienced operators, the difference was not statistically significant ($F = 2.1$; $p = 0.1273$).

Fluoroscopy time also did not differ significantly between the groups ($F = 0.5$; $p = 0.6261$), nor did the volume of administered contrast media ($F = 0.8$; $p = 0.4642$).

Patients with Elevated Troponin Levels

In contrast to the previous group, statistically significant differences between operator experience groups were observed in patients with elevated troponin levels (Table 2).

The mean CAK was **1879.9 mGy** among senior operators, **1561.5 mGy** among mid-experienced operators, and **2254.2 mGy** among junior operators. The difference was statistically significant ($F = 11.6$; $p < 0.001$).

A statistically significant difference was also found in fluoroscopy time ($F = 4.2$; $p = 0.0151$). The shortest fluoroscopy time was recorded among mid-experienced operators.

The most pronounced difference was observed in contrast media volume ($F = 13.9$; $p < 0.001$). Mid-experienced operators used an average of **167.8 mL**, compared with **207.9 mL** among senior operators and **207.7 mL** among junior operators.

Patient age did not differ significantly between operator groups ($F = 0.2$; $p = 0.8328$).

Multivariable Analysis

The multivariable model for CAK was statistically significant ($R = 0.17$; $R^2 = 0.03$; $p < 0.001$), but explained only approximately 3% of the variability. Independent predictors of higher CAK were sex ($\beta = 0.17$; $p < 0.001$) and age ($\beta = 0.09$; $p = 0.003$), whereas operator experience was not an independent predictor.

The model for fluoroscopy time was not statistically significant ($R = 0.07$; $R^2 = 0.001$; $p = 0.287$).

The model for contrast media volume was statistically significant ($R = 0.18$; $R^2 = 0.03$; $p < 0.001$). Higher contrast media volume was associated with sex and age, whereas greater operator experience was associated with lower contrast media use ($\beta = -0.10$; $p < 0.001$) (Table 3).

Discussion

The main finding of this study was that the association between operator experience and procedural parameters was most clearly evident in patients with elevated troponin levels. In this group, operator experience was associated with CAK, fluoroscopy time, and contrast media volume, whereas such differences were not confirmed in patients with normal troponin levels.

In the normal-troponin group, there was a trend toward higher CAK among junior operators, but the difference was not statistically significant. This finding indicates that operator experience alone is insufficient to explain differences in radiation exposure. The substantial within-group variability, particularly in fluoroscopy time, may be attributable to differences in the complexity of individual procedures.

In the elevated-troponin group, the differences were more pronounced. Junior operators had the highest mean CAK, whereas mid-experienced operators had the lowest. A similar pattern was observed for fluoroscopy time and, particularly, contrast media volume. However, this finding does not imply that mid-experienced operators are generally more efficient than senior operators. Operator selection and case complexity may be influenced by numerous factors that were not captured in this retrospective analysis.

Table 3. Multivariable regression analysis of predictors of CAK, fluoroscopy time, and contrast media volume

Predictor	CAK β	p	Fluoroscopy β	p	Contrast β	p
Sex	0,17	<0,001*	0,02	0,515	0,11	<0,001*
Procedure year	0,02	0,493	−0,04	0,197	−0,05	0,076
Diagnosis	0,00	0,888	0,05	0,076	−0,05	0,108
Operator experience	−0,04	0,190	−0,03	0,385	−0,10	<0,001*
Age	0,09	0,003*	0,00	0,878	0,07	0,027*
Model R	0,17	<0,001*	0,07	0,287	0,18	<0,001*
Model R^2	0,03		0,001		0,03	

Note: β – standardizirani regresijski koeficijent; R – koeficijent multiple korelacije; R^2 – koeficijent determinacije; * $p < 0,05$.

The result of the multivariable analysis of CAK is particularly important. Although operator experience was associated with differences in CAK in the univariable analysis of patients with elevated troponin levels, it was not an independent predictor after adjustment. Patient sex and age were identified as independent predictors of higher CAK. The low R^2 value, approximately 3%, indicates that most of the variability in CAK remains unexplained by the variables included in the model.

This finding is expected given the complexity of pPCI procedures. Radiation dose may be influenced by the number and type of lesions, the number of treated vessels, calcifications, vessel tortuosity, the number of stents, vascular access, additional angiographic projections, and procedural complications. Future analyses should incorporate such indicators to enable a more precise assessment of the effect of operator experience.

Fluoroscopy time proved to be the least predictable parameter. Although a difference between operator groups was observed in patients with elevated troponin levels, the multivariable model was not significant. Therefore, fluoroscopy time should not be used as an isolated indicator of operator performance quality but should be interpreted in relation to procedural complexity.

In contrast to fluoroscopy time, contrast media volume showed a clearer association with operator experience. Greater experience remained independently associated with lower contrast media use. This represents an important practical finding, as rational use of contrast media can be improved through education, standardization, and supervision, particularly among less experienced operators.

The results are consistent with previous studies indicating an influence of operator and center experience on patient exposure during coronary interventions [3,4,8]. At the same time, a study by Balter et al. demonstrated that changes in procedural practices, optimisation of projections, and more rational use of image acquisitions can substantially reduce patient exposure [10].

From a practical perspective, the results support a multidimensional approach to pPCI optimisation. Application of the ALARA principle should include appropriate collimation, rational selection of projections, avoidance of unnecessary acquisitions, and optimal angiographic system settings. At the same time, unnecessary repeated contrast injections should be limited, and required projections should be planned before image acquisition.

Particular attention should be directed toward the education and supervision of junior operators in clinically demanding cases. In this group, junior operators had the highest CAK and greater contrast media use. Continuous monitoring of CAK, fluoroscopy time, and contrast media volume may enable the identification of extreme values and facilitate targeted improvement of procedural practices.

Study Limitations

The main limitations of the study arise from its retrospective design and the fact that it was conducted at a single center. Not all anatomical and procedural factors that may influence radiation exposure and procedure duration were included in the analysis. In particular, detailed indicators of lesion complexity, the number of treated vessels and stents, vascular access, and procedural complications were not available.

Furthermore, categorising operators according to years of experience may not fully reflect actual procedural competence. Differences may exist within individual groups in terms of the total number of procedures performed and experience with complex interventions.

Conclusion

In patients with STEMI, operator experience showed the strongest association with procedural parameters in the group with elevated troponin levels. In this group, significant differences were observed in CAK, fluoroscopy time, and contrast media volume, whereas such differences were not confirmed in patients with normal troponin levels.

Multivariable analysis showed that CAK was primarily dependent on patient characteristics, with sex and age identified as independent predictors, whereas operator experience was not significant after adjustment. In contrast, operator experience was independently associated with lower contrast media use.

The results confirm that optimisation of safety during pPCI cannot focus solely on operator experience. An individualised patient approach, assessment of procedural complexity, application of the ALARA principle, rational use of contrast media, and continuous education and supervision of less experienced operators are required.

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Retrospektivna analiza doze zračenja s obzirom na iskustvo operatera tijekom perkutanih koronarnih intervencija u akutnom infarktu miokarda sa ST-elevacijom

Sažetak

Uvod: Primarna perkutana koronarna intervencija (pPCI) standardni je oblik reperfuzijskog liječenja bolesnika sa STEMI-jem. Postupak uključuje izlaganje ionizirajućem zračenju i primjenu kontrastnog sredstva, pri čemu na razinu izloženosti mogu utjecati karakteristike bolesnika, složenost zahvata i iskustvo operatera.

Cilj: Analizirati povezanost iskustva operatera s dozom zračenja, uz poseban naglasak na kumulativnu zračnu kermu (CAK).

Ispitanici i metode: Provedena je retrospektivna analiza 1140 bolesnika sa STEMI-jem liječenih pPCI metodom od 1. siječnja 2021. do 31. prosinca 2025. Bolesnici su podijeljeni prema vrijednosti troponina pri prijemu na skupinu s urednim (n = 293) i povišenim troponinom (n = 847). Deset interventnih kardiologa podijeljeno je prema iskustvu na seniore, srednje iskusne operatere i juniore. Analizirani su CAK, fluoroskopsko vrijeme, količina kontrastnog sredstva, dob i spol. Razlike su analizirane ANOVA-om s Duncanovim post-hoc testom, a neovisni prediktori multivarijatnom linearnom regresijom.

Rezultati: U skupini s urednim troponinom nisu utvrđene značajne razlike između skupina operatera u CAK-u, fluoroskopskom vremenu ni količini kontrasta. U skupini s povišenim troponinom iskustvo operatera bilo je značajno povezano s CAK-om ($F = 11,6$; $p < 0,001$), fluoroskopskim vremenom ($F = 4,2$; $p = 0,0151$) i količinom kontrasta ($F = 13,9$; $p < 0,001$). Najviša srednja CAK zabilježena je kod juniora (2254,2 mGy), a najniža kod srednje iskusnih operatera (1561,5 mGy). Multivarijatnom analizom spol i dob utvrđeni su kao neovisni prediktori veće CAK, dok iskustvo operatera nije bilo neovisni prediktor. Veće iskustvo bilo je neovisno povezano s manjom potrošnjom kontrasta.

Zaključak: Povezanost iskustva operatera s proceduralnim parametrima bila je najizraženija u bolesnika s povišenim troponinom. Nakon prilagodbe, CAK je prvenstveno bila povezana s karakteristikama bolesnika, dok je potrošnja kontrasta ostala povezana s iskustvom operatera. Optimizacija pPCI-ja treba uključivati načelo ALARA, individualizaciju postupka, racionalnu primjenu kontrasta te kontinuiranu edukaciju i superviziju manje iskusnih operatera.

Ključne riječi: STEMI; primarna perkutana koronarna intervencija; kumulativna zračna kerma; fluoroskopija; kontrastno sredstvo; iskustvo operatera; radiološka zaštita