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Evaluation of Procedure Doses and Staff Attitudes in Interventional Cardiology in Terms of Radiation Safety

Girişimsel Kardiyolojide Hasta Dozları ve Personel Tutumlarının Radyasyon Güvenliği Açısından Değerlendirilmesi

ABSTRACT

Objective: Ionizing radiation has long been used in the medical field. Catheter laboratories (cath labs) are recognized as areas where radiation exposure is notably high. This study aims to examine the levels of radiation exposure during various interventional procedures to raise awareness of this issue in Türkiye.

Methods: This study evaluated the procedure radiation doses (n = 2804) in the cath labs of four public hospitals with distinct characteristics. Radiation dose evaluation was conducted using Cumulative Air Kerma (CAK). The Kolmogorov-Smirnov test, Kruskal-Wallis H test, independent T-test, and Pearson correlation coefficient were utilized to analyze the data. A p-value of < 0.05 was considered statistically significant. Data were analyzed using IBM® Statistical Package for the Social Sciences (SPSS®) STATISTICS Version 26.0.0.0 (IBM Corporation, Armonk, New York, USA).

Results: The procedure radiation doses in the cath labs were documented. The findings are largely consistent with the literature. Notably, several outlier cases with extremely high radiation doses were identified [CAK (min-max) = 0.12 – 9.9 Gy]. Procedures such as chronic total occlusion (CTO) [Mean CAK: 3.8 (± 1.5) Gy] and percutaneous coronary interventions (PCI) [Mean CAK: 1.5 (± 1.4) Gy] were associated with high doses. Additionally, personnel attitudes toward radiation optimization in cath labs were found to be inadequate.

Conclusion: The incidence of high radiation exposure during interventional procedures may be higher than expected in Türkiye. Further research is necessary to identify predictors and implement preventive measures to reduce these rates. For this purpose, establishing diagnostic radiation reference levels (DRLs) could help monitor national radiation levels.

Keywords: Cath lab, health policy, patient safety, radiation protection

ÖZET

Amaç: Kardiyoloji kateter laboratuvarları birçok tanısal ve tedavi edici vaka gerçekleştirilmekte ve radyasyona maruz kalmanın oldukça yüksek olduğu bir alan olarak kabul edilmektedir. Bu çalışmanın amacı, kardiyoloji kateter laboratuvarında hastalara maruz kalan kümülatif radyasyon dozlarının (CAK) değerlendirilmesi ve personelin radyasyon optimizasyonuna yönelik tutumlarının ortaya konulmasıdır.

Yöntem: Bu çalışmada farklı özelliklere sahip dört devlet hastanesinin katater laboratuvarlarındaki hastaların radyasyon dozları (n = 2804) değerlendirilmiştir. Radyasyon dozu değerlendirmesi Kümülatif Air Kerma ölçütü ile yapılmıştır. Veriler, hastanelerde görev yapan araştırmacılar tarafından X-Ray cihazlarından ve hastane bilgi sisteminden elde edilmiştir. Hastanelerden elde edilen veriler yapılan işleme göre sınıflandırılmıştır.

Bulgular: Kateterdeki laboratuvar prosedürlerin hasta dozları çalışmada sunulmuştur. Bulgular büyük ölçüde literatürle uyumludur. Bununla birlikte, bulgular aynı zamanda birçok vakanın oldukça yüksek radyasyon dozlarına maruz kaldığını da göstermektedir. Özellikle Kronik Total Oklüzyon (KTO) ve Perkütan Koroner Girişim (PKG) girişimleri optimizasyon altında olmalıdır. Bu çalışmanın bir diğer önemli sonucu da, katater laboratuvarında çalışan personelin X-ray cihazlarının kullanımında radyasyon optimizasyonuna yönelik tutumları yeterli düzeyde değildir.

Sonuç: Bu çalışma bulgularına dayanarak, hasta ve personel güvenliği için radyasyon dozlarını takip edebilecek bir sağlık politikasına ihtiyaç vardır. Bu amaçla, ulusal düzeyde radyasyon seviyelerini izlemek için tanısal radyasyon referans (DRL) seviyeleri oluşturulabilir. Çalışanlar için hizmet içi eğitim planlanabilir ve sonuçların DRL ile takip edilmesi için bir süreci oluşturulabilir.

Anahtar Kelimeler: Kateter laboratuvarı, sağlık politikası, hasta güvenliği, radyasyondan korunma

ORIGINAL ARTICLE
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Ionizing radiation has been used in the medical field for many years to diagnose and treat patients. Its use has expanded with technological advancements and increased accessibility. One significant area of application is in cardiology catheterization laboratories (cath labs). With the aid of ionizing radiation, cardiology cath labs have been able to manage sudden and serious health conditions such as myocardial infarction (MI) more effectively. Additionally, advancements in medical technology have gradually increased the variety of diagnostic and treatment procedures performed in cath labs. Procedures that were previously possible only through surgical intervention can now be performed percutaneously and more quickly, thanks to ionizing radiation and medical technology. Consequently, hospitalization and recovery times have been reduced, costs have decreased, and patient satisfaction has improved. The cardiology community readily utilizes the full potential of ionizing radiation to benefit society. However, it raises an important question: *"How much radiation are patients exposed to?"* While many studies in international literature have sought answers to this question,[1-4] research specific to Türkiye has not yet been found in the literature.

The potential harm of ionizing radiation to human health has long been a topic of discussion in the scientific community. The benefits to patients from diagnosis and treatment have historically justified its use in medicine. The risks associated with ionizing radiation are typically classified under two categories in the literature.

Stochastic effects, which are health issues resulting from Deoxyribonucleic Acid (DNA) damage due to cumulative radiation exposure over time, can manifest in various ways and may occur without a clear dose threshold.[5,6] Unfortunately, no safe dose limit for stochastic effects of radiation in the human body has been definitely established.[6]

In a study conducted in the United States of America (USA), approximately 45% of the cumulative medical radiation per capita was attributed to interventional cardiologists. Furthermore, they were exposed to medical radiation 2-3 times more frequently than radiologists.[7] In this context, numerous studies have investigated the potential stochastic effects of medical radiation in cardiology cath labs.[6,8] Stochastic effects of ionizing radiation have been associated with various types of cancer in the literature.[9-11]

The deterministic effect of ionizing radiation includes acute health issues in patient tissue shortly after exposure. These effects may manifest as tissue reactions, hair loss, cataracts[12-18], and cardiovascular diseases.[19-21]

It is considered safe for radiation exposure to remain between 0-2 Gray (Gy) following a single procedure regarding deterministic effects. According to a study by Balter et al.,[18] it is necessary to monitor patients once the 2 Gy threshold is exceeded. While no damage is expected at doses of 2-5 Gy, patients should be advised to consult their physicians if they experience discomfort in the affected tissue. A follow-up is recommended for exposures between 5-10 Gy.[18] These findings serve as the foundation for this study.

This study aims to examine the levels of radiation exposure during various interventional procedures to raise awareness of this issue in Türkiye. It is anticipated that the findings will provide vital information to health managers and professionals regarding patient safety. While similar studies exist in international literature, this study represents the first of its kind in Türkiye.

ABBREVIATIONS

CAG	Coronary bypass angiograms
CAK	Cumulative Air Kerma
Cath labs	Catheter laboratories
CRT-D	Cardiac resynchronization therapy devices
CTO	Chronic total occlusion
DAP	Dose-Area Product
DNA	Deoxyribonucleic Acid
DRLs	Diagnostic radiation reference levels
EVAR	Endovascular abdominal aortic aneurysm repairs
FT	Fluoroscopy times
MI	Myocardial infarction
mSv	Millisieverts
PCI	Percutaneous coronary intervention

Materials and Methods

This section will present methodological details about the study group, data collection, and analysis process.

Universe and Sample

In this descriptive study, specific calculations for population and sample size were not conducted. According to 2021 data from the Turkish Ministry of Health, there are 294 cardiology catheterization laboratories in Türkiye. These laboratories are categorized into two different types: public (including University Hospitals affiliated with the Ministry of Health, Public Hospitals, University Hospitals, and Public-Private Partnership Hospitals) and private. Given the challenges of accessing data from all cath labs, four important public hospitals with diverse characteristics were selected. The characteristics of these public hospitals are presented below.

As illustrated in Table 1, this study was conducted in four different types of public hospitals in Türkiye: a University Hospital Affiliated with the Ministry of Health, a University Research and Application Hospital, another University Hospital, and a Public Hospital. These hospitals exhibit diverse features in terms of size, number of cath labs, patient cases, and personnel.

Data Collection

Data for the study were collected following ethics approval from the Clinical Research Ethics Committee of Gaziantep University, dated April 6, 2022, with the number 2022/112, and permissions from the participating centers. The research data were collected from X-ray devices and hospital information systems by researchers working in the hospitals, covering the period from January 1, 2023, to March 31, 2023. The data collected from the four hospitals were combined into a single data collection form created in Microsoft Excel 2016. The following criteria were adhered to during the data collection process:

- Cumulative Air Kerma (CAK) was recorded in mGy. CAK is the cumulative measurement of X-ray energy delivered to a specific reference point (isocentric point 15 cm above the table) in interventional radiology. It is directly related to the deterministic effects of radiation and represents the measurement unit closest to the patient tissue dose.[22,23]

Table 1. Hospital Characteristics Within the Research

Hospital Characteristic	Catheter Laboratory Characteristics	Personnel Characteristics
University Hospital, Affiliated with the Ministry of Health (1,520 Beds)	5 Catheter Laboratories (4 Mono, 1 Bi-Plane Devices) Approximately 17,000 Patients Per Year	26 Interventional Cardiologists 4 Interventional Radiologists 22 Assistants 28 Nurses 10 Radiology Technicians
University Research and Application Hospital (903 Beds)	2 Catheter Laboratories Approximately 7,000 Patients Per Year	5 Interventional Cardiologists 9 Assistants 6 Nurses 6 Radiology Technicians
University Hospital (1,150 Beds)	1 Catheter Laboratory Approximately 1,150 Patients Per Year	5 Interventional Cardiologists 11 Assistant Physicians 4 Nurses 4 Radiology Technicians
Public Hospital (303 Beds)	2 Catheter Laboratories Approximately 6,000 Patients Per Year	13 Interventional Cardiologists 10 Nurses 6 Technicians

- Fluoroscopy time was recorded in minutes.
- The Percutaneous Coronary Intervention (PCI) fluoroscopy time and dose levels across different types of hospitals were evaluated using PCI intervention values (*n* = 231), which were randomly selected from three of the hospitals involved in the research.
- Data on zoom usage, collimator usage, and dose selection were obtained by accessing the relevant images in the hospital's picture archiving and communication systems (PACS). These data were also used to evaluate personnel attitudes toward radiation optimization.

Data Categorization

The data from the hospitals were categorized based on the procedures performed. The classifications were as follows:

- Procedures solely for diagnostic purposes were categorized as "diagnostic."
- Procedures that were both diagnostic and interventional were categorized as "intervention."
- All peripheral diagnostic procedures (Lower Extremities, Renal, Carotid, etc.) were categorized as "peripheral angiograms" (PAG).
- Cases with very low frequency, such as Scopes (*n* = 8) and catheter implantations (*n* = 11), were excluded from the analysis.
- The categorization process was conducted under the supervision of cardiologists while evaluating patients' images.

Statistical Analysis

Descriptive statistics of the data utilized frequency, percentage, mean, standard deviation, minimum, maximum, and median. The assumption of normal distribution was evaluated using the Kolmogorov-Smirnov test. Group means for continuous variables were compared using the Independent Samples t-test and Kruskal-Wallis H test. The Pearson correlation coefficient was used to reveal relationships between continuous variables. A p-value of < 0.05 was considered statistically significant. Data analysis was performed using IBM® Statistical Package for the Social Sciences (SPSS®) STATISTICS Version 26.0.0.0 (IBM Corporation, Armonk, New York, USA).[24-27]

Results

This section presents the findings of the statistical analysis. Table 2 displays the distribution of procedures and fluoroscopy times (FT).

As illustrated in Table 2, 57.4% (*n* = 1610) of procedures were diagnostic in nature. Therapeutic interventions accounted for the remaining 42.6% (*n* = 1194). The most frequent procedure in cath labs was coronary angiography, representing 43.1% of cases (*n* = 1235). The leading interventional procedure was percutaneous coronary intervention combined with angiography, comprising 19.2% of interventions (*n* = 537).

Regarding duration, the longest procedures were interventional: implantable cardiac resynchronization therapy devices (CRT-D) averaged 39.96 minutes (± 31.49), endovascular abdominal aortic aneurysm repairs (EVAR) took 34.72 minutes (± 20.50), and chronic total occlusion (CTO) interventions lasted 24.89 minutes (± 10.62). Among diagnostic procedures, coronary bypass angiograms (CAG) were the lengthiest, averaging 6.42 minutes (± 5.26), followed by combined coronary and pulmonary angiograms (CAG + PAG) at 5.57 minutes (± 4.43). Coronary angiography, despite being the most common procedure, was the shortest, with an average duration of 3.23 minutes (± 3.10).

Table 3 presents data on the radiation doses (CAK) associated with different types of procedures.

As shown in Table 3, the CTO Intervention had the highest average radiation exposure, with a mean CAK of 3773.88 mGy (± 1497.16). In comparison, the mean CAK for CAG + PCI was 1522.01 mGy (± 1402.27) and for CAG + PCI Bypass was 1534.58 mGy (± 1788.14). The CRT-D Implantation procedure, which had the longest radiation duration, ranked seventh in terms of radiation exposure with 878.00 mGy (± 540.46). Additionally, no statistically significant differences were observed in procedure

Table 2. Fluoroscopy Time and Procedure Distribution in the Cath Labs

Type	n (%)	Procedure	n	%	*Fluoroscopy Time (min)				
					Minimum	Maximum	Median	Mean	(± SD)
Diagnostic	1610 (57.4)	CAG Bypass	89	3.20	1.07	34.05	5.05	6.42	5.26
		CAG + PAG	55	2.00	1.03	22.05	4.13	5.57	4.43
		Catheterization	27	1.00	1.02	21.02	4.07	5.52	5.13
		EPS	18	0.60	0.97	17.02	4.52	4.86	3.85
		Radial CAG	218	7.80	0.93	27.00	2.10	3.64	3.56
		PAG	186	6.60	1.00	19.57	2.12	3.41	2.79
		Femoral CAG	1017	36.30	0.93	39.08	2.02	3.23	3.10
Intervention	1194 (42.6)	CRT-D Implantation	6	0.20	10.07	98.57	32.07	39.96	31.49
		EVAR	40	1.40	12.00	92.00	29.00	34.72	20.50
		TAVI	39	1.40	6.02	108.33	17.12	24.95	23.15
		CTO Intervention	26	0.90	5.37	49.10	24.00	24.89	10.62
		ASD Closure	16	0.60	2.10	46.15	7.08	16.31	15.15
		Carotid Intervention	52	1.90	2.02	58.00	11.00	14.79	11.30
		Cerebrovascular Intervention	6	0.20	6.13	32.00	11.03	13.39	9.41
		RF Ablation	40	1.40	1.15	41.10	10.10	13.07	9.59
		CAG + PCI Bypass	31	1.10	4.02	28.08	11.07	12.78	7.15
		Lower Limb PTA	44	1.60	2.13	63.07	12.13	12.68	10.92
		PMBV	16	0.60	2.03	43.38	7.61	11.20	10.25
		CAG + PCI	537	19.20	1.08	90.90	7.15	9.94	9.02
		PCI	259	9.20	1.10	56.98	7.03	9.48	8.39
		ICD Implantation	18	0.60	3.03	39.08	5.62	9.23	10.57
		RADIAL CAG + PCI	24	0.90	2.10	25.02	5.13	6.74	4.69
		PACE Implantation	21	0.70	1.53	18.30	4.08	6.36	4.74
		CAG + LE PTA	16	0.60	1.02	12.98	3.21	5.14	4.15
		PDA Closure	3	0.10	3.00	5.00	4.12	4.04	1.00

ASD, Atrial Septal Defect; CAG, Coronary Angiogram; CRT-D, Cardiac Resynchronization Therapy Defibrillator; CTO, Chronic Total Occlusion; EPS, Electrophysiology Study; EVAR, Endovascular Aortic Aneurysm Repair; ICD, Implantable Cardioverter Defibrillator; PAG, Peripheral Angiogram; PCI, Percutaneous Coronary Intervention; PDA, Patent Ductus Arteriosus; PMBV, Percutaneous Mitral Balloon Valvuloplasty; PTA, Percutaneous Transluminal Angioplasty; RF, Radio Frequency; TAVI, Transcatheter Aortic Valve Implantation; (± SD), Standard Deviation.
*Fluoroscopy times do not include cine (acquisition) times.

duration and radiation dose between radial [Time: 2.10 min (± 3.64), CAK: 437.74 mGy (± 495.59)] and femoral CAG approaches [Time: 2.02 min (± 3.23), CAK: 417.08 mGy (± 577.85)], (*P* > 0.05). The distribution of radiation doses (CAK) across various procedures in catheter laboratories is depicted in Figure 1.

Figure 1 illustrates that the CAK for CTO intervention and CAG + PCI procedures reached the highest levels among all procedures performed in the catheter laboratory. Interestingly, more complex procedures such as Transcatheter Aortic Valve Implantation (TAVI) and EVAR exhibited lower radiation doses than the PCIs. Despite CTO interventions having the highest average and median CAK values, PCIs showed instances of extreme radiation doses. The graph also marks the radiation safety thresholds with lines at 2 Gy (Green), 3 Gy (Blue), and 5 Gy (Red), which many procedures exceeded. Some extreme cases even approached nearly 10 Gy CAK.

Table 4 complements these findings, showing that 91.2% (n = 2556) of the procedures recorded radiation doses below the

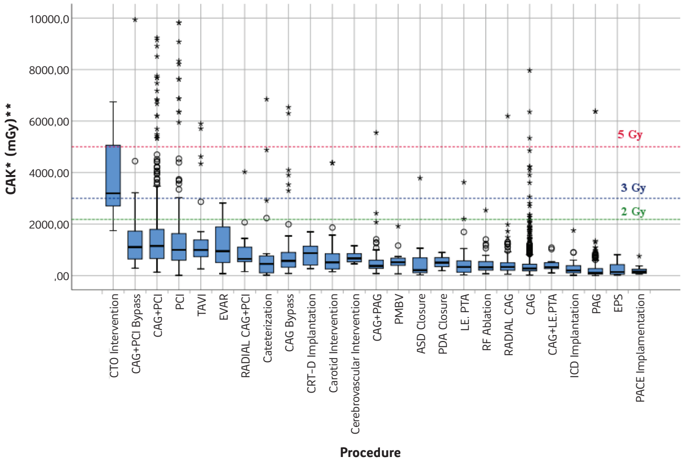

Figure 1. Distribution of radiation doses (CAK) by procedure type in the catheterization laboratory.
***CAK, Cumulative Air Kerma; **Milligray (radiation measure).**

Table 3. Procedure Doses (CAK, mGy) Based on Case Types

Case Type	Minimum	Maximum	Median	Mean	(± SD)
CTO Intervention	1748.00	6744.00	3194.00	3773.88	1497.16
CAG + PCI	133.00	9235.00	1148.00	1522.01	1402.27
CAG + PCI Bypass	288.25	9935.00	1104.90	1534.58	1788.14
PCI	7.80	9820.00	1000.00	1465.12	1618.91
TAVI	259.10	5900.00	995.00	1417.79	1368.22
EVAR	75.80	2819.00	946.30	1131.28	765.92
CRT-D Implantation	272.40	1700.00	872.05	878.00	540.46
Cerebrovascular Intervention	457.50	1158.00	668.10	722.50	252.52
RADIAL CAG + PCI	157.00	4029.00	647.00	939.29	783.69
CAG Bypass	82.00	6538.00	572.00	896.46	1123.96
MVP	68.00	1919.00	519.00	584.00	443.31
Carotid Intervention	152.10	4375.00	512.40	794.22	973.20
PDA Closure	189.00	899.00	501.00	529.67	355.87
Catheterization	16.00	6850.00	455.00	919.13	1592.64
CAG + PAG	79.00	5550.00	373.91	607.79	818.47
RADIAL CAG	55.20	6195.00	334.00	437.74	495.59
LE PTA	26.00	3625.00	332.56	492.44	638.70
CAG + LE** PTA	105.00	1085.99	331.85	408.03	283.02
RF Ablation	70.00	2540.00	320.50	479.78	463.54
CAG	18.00	7966.00	276.00	417.08	577.85
ASD Closure	29.00	3784.00	211.26	572.21	921.46
ICD Implantation	11.00	1755.00	199.55	367.47	435.80
PACE Implantation	56.79	755.04	151.33	193.68	157.25
EPS	21.50	813.00	140.50	264.11	266.76
PAG	1.20	6380.00	110.00	283.53	687.86

*CAK, Cumulative Air Kerma; LE, Lower Extremities.

Table 4. Distribution of Patient Radiation Doses (CAK) Based on Deterministic Effect Limits in the Catheter Laboratory

Limits	n	%
< 2 Gy	2556	91.2
2-3 Gy	122	4.4
3-5 Gy	75	2.7
5-10 Gy	51	1.8
Total	2804	100.0

2 Gy threshold, considered safe regarding deterministic effects. However, 4.4% (*n* = 122) of cases fell into the 2-3 Gy range, 2.7% (*n* = 75) were between 3-5 Gy, and 1.8% (*n* = 51) recorded doses between 5-10 Gy.

Upon reviewing Table 5, it was noted that 15 different procedure types (*n* = 126) exceeded 2 Gy of CAK.

Among the cases that exceeded the 2 Gy CAK, 47.2% (*n* = 117) involved CAG + PCI procedures, 17.7% (*n* = 44) were PCI alone, and 9.7% (*n* = 24) were CTO Interventions. The most significant observation so far is that patients can be exposed to high radiation levels across various procedure types, particularly in PCI and their combinations with CAG.

Table 5. Distribution of Procedure Types Exceeding 2 Gy in the Cath Lab

Procedure	n	%
CAG + PCI	117	47.2
PCI	44	17.7
CTO Intervention	24	9.7
CAG	21	8.5
EVAR	7	2.8
CAG Bypass	6	2.4
CAG + PCI Bypass	5	2.0
TAVI	5	2.0
Catheterization	4	1.6
CAG + PAG	3	1.2
Carotid Intervention	3	1.2
LE PTA	2	0.8
PAG	2	0.8
RADIAL CAG + PCI	2	0.8
ASD Closure	1	0.4
RADIAL CAG	1	0.4
RF Ablation	1	0.4
Total	248	100.0

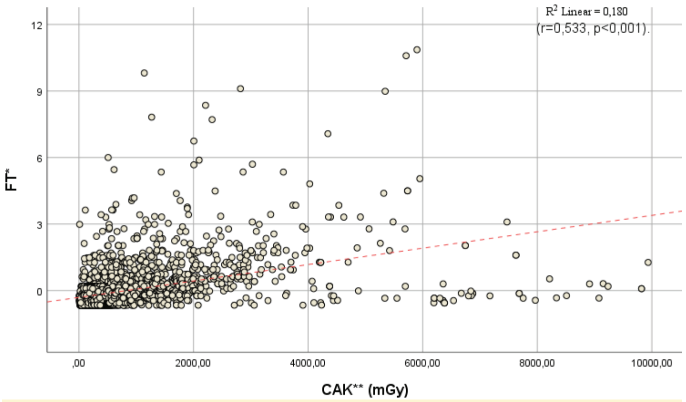

Figure 2. Relationship Between Fluoroscopy Time and CAK in the Cath Lab.
CAK, Cumulative Air Kerma (mGy); FT, Fluoroscopy Time (minutes); r: Spearman Correlation Coefficient.

Table 7. Personnel Attitudes Toward Radiation Optimization

Modality Usage		**n**	**%**
Zoom Usage		1699	60.6
Collimator Usage		72	2.6
Default Radiation Dose Usage		2804	100
Frame Per Second (FPS)	2.0	217	7.7
	4.0	67	2.4
	7.5	75	2.7
	10.0	218	7.8
	15.0	2226	79.4
	Total	2803	100.0

FPS: Frame Per Second.

Table 6. Evaluation of PCI Radiation Dose (CAK) and Fluoroscopy Time by Hospital Type

		n	**Median**	**Min-Max**	***P***	**Post-Hoc Analysis**
PCI Radiation Doses (CAK) mGy	Public Hospital[1] (303 Beds)	55	290.00	40-2494	< 0.001	1 < 2*** 1 < 3***
	University Hospital[2] (1150 Beds)	100	1163.00	220-4440		
	University Research and Application Hospital[3] (903 Beds)	76	914.44	243.98-4725.98		
PCI Fluoroscopy Time (min)	Public Hospital[1] (303 Beds)	55	2.12	0.93-47	< 0.001	1 < 2*** 1 < 3*** 3 < 2***
	University Hospital[2] (1150 Beds)	100	13.77	2.63-72.20		
	University Research and Application Hospital[3] (903 Beds)	76	7.04	2.08-38.05		
	Total	231				

P: Kruskal-Wallis H Test, Post-hoc; Mann-Whitney U test with Bonferroni Correction at 95% confidence interval. ****P* < 0.001, ***P* < 0.01, **P* < 0.05.

Moreover, a statistically significant positive correlation was observed between FT and CAK in this study ($r = 0.533$, $P < 0.001$) (Figure 2).

Table 6 reveals statistically significant differences in PCI radiation doses and fluoroscopy times across different types of hospitals ($P < 0.001$).

The radiation doses at the Public Hospital (Median = 290 mGy) were significantly lower than those at the University Hospital (Median = 1163 mGy) and the University Research and Application Hospital (Median = 914.44 mGy) ($P < 0.001$). Similarly, fluoroscopy times at the Public Hospital (Median = 2.12 min) were significantly lower compared to the University Hospital (Median = 13.77 min) and the University Research and Application Hospital (Median = 7.04 min) ($P < 0.001$). Additionally, fluoroscopy times at the University Hospital (Median = 13.77 min) were significantly higher than those at the University Research and Application Hospital (Median = 7.04 min) ($P < 0.001$).

Table 7 presents findings on healthcare personnel's attitudes toward radiation optimization using a cardiovascular X-ray device.

As depicted in Table 7, the zoom function was utilized in 60.6% of cases ($n = 1699$), whereas the collimator was used in only 2.6% of cases. All devices operated under factory default dose settings. Considering the selection of frame rate, 15 frames per second (FPS) were used in 79.4% of the cases ($n = 2226$).

Discussion

Each patient represents a unique project with inherent characteristics. Despite dividing healthcare into different specializations, it is important to remember that the human body comprises interconnected organs and systems. This highlights a risk in healthcare: specialization may sometimes overlook the body's holistic nature.

This narrow focus is also apparent in research studies on radiation levels in catheterization laboratories, which prioritize patient and employee safety. Although various diagnostic and interventional procedures are carried out under different classifications, each patient may receive multiple types of diagnostics and interventions in a single session due to their specific health needs. Consequently, it is crucial to assess radiation exposure on a per-patient basis rather than per procedure.

Radiation safety in catheter laboratories[4,7,23,28-30] and radiation doses from procedures[2,3,7,31-34] are frequently discussed in literature sources. However, these studies generally assess radiation doses on a procedural basis. In the research by Crowhurst et al.[31], as well as Ingwersen et al.[32], radiation doses in catheter laboratories were measured on a per-procedure basis using a Dose-Area Product (DAP) in Gy/cm^2. Similarly, Li et al.[3] and Mettler Jr. et al.[33] also managed radiation doses in cath labs per procedure but used the effective dose measurement in millisieverts (mSv). Miller[2] focused exclusively on diagnostic cases and utilized both effective dose (mSv) and DAP (Gy/cm^2) units. These studies in the literature are very important for revealing that radiation levels in catheter laboratories are higher than in other medical units, and for highlighting the radiation risks to which patients and staff are exposed on a procedure-by-procedure basis. However, these studies were insufficient to determine the cumulative radiation exposure from diagnostic and interventional procedures that many patients undergo in a single operation due to their health needs. In particular, the combined CAG and PCI procedures are associated with very high radiation levels in cath labs. Therefore, in this study, patient-based radiation doses were obtained by combining the procedures that patients typically undergo in the same operation. While many studies in the literature used DAP in Gy/cm^2 and effective dose in mSv to assess stochastic risks, this study employed the CAK in mGy as an indicator for the deterministic risks of radiation exposure.

In this study, the average CAK of CAGs was within safe limits for radiation-deterministic effects, consistent with findings in the literature.[3,32,33] Radiation doses from coronary interventions in the literature were primarily evaluated using effective dose (mSv) or DAP (Gy/cm^2) units. In these evaluations, PCI cases were studied as a single procedure,[32,33] despite typically being conducted alongside CAG. Whereas the average CAK for PCIs in the study by Al-Jabri et al.[35] was reported as 2.6 (1.8-3.9) Gy, in this study, the average CAK for PCIs was 1.5 (0.8-98) Gy. In the literature, with the exception of extreme values observed in PCI cases, it can generally be said that procedure doses remained within safe limits for radiation-deterministic effects.[33] Unlike previous studies, this study evaluated PCIs combined with CAG together. While a significant portion of these combined procedures remained within safe limits for deterministic effects, consistent with previous findings, several extreme CAK values were noted in these cases.

In the study by Suzuki et al.[34], the mean CAK of CTOs was reported as 1.0 (± 0.6) mGy. Conversely, in the study by Crowhurst et al.[31], the CAK of CTOs ranged from 1.8 Gy to 3.8 Gy, with a median of 2.4 Gy. This study found that CAK values for CTOs ranged from 1.7 to 6.8 Gy, with a mean of 3.8 (± 1.5) Gy and a median of 3.2 Gy. As seen in the literature and this study, the minimum CAK for CTOs generally starts at around 1 Gy, but very extreme values can occur depending on the cases. CTOs can be considered the most radiation-intensive procedure type, consistent with the literature.

Findings for lower extremity peripheral cases were consistent with previous studies. The effective dose for percutaneous transluminal angioplasty (PTA) in the literature ranged from 2.0 to 3.94 mSv.[3,32,33] The lower extremity interventions in this study stayed within deterministic safe limits, with a maximum CAK value of 3.6 Gy.

For structural heart disease procedures, variations in case durations and radiation exposures were significant. TAVI fluoroscopy times in the literature ranged from 15-34 minutes.[36-38] This study, however, recorded durations between 6-108 minutes, with a median of 17 minutes. Many studies assessed patient radiation doses in TAVI using the DAP unit.[2,38] In the study by Wilson-Stewart et al.[39], the median CAK of TAVIs was 670 (460-970) mGy ($n = 21$), while in this study, it was 995 (259-5900) mGy ($n = 40$). The difference is attributed to the extreme values caused by the high frequency of cases in this study.

In the study by Panuccio and Greenberg[30], the median CAK of EVAR procedures was 6.3 Gy ($n = 46$); in this study, it was 946 mGy. This difference is thought to be due to advancements in information, technology, and experience over time. As a result, both the operating room and fluoroscopy times have decreased, as noted in the literature.[38] While the median duration of EVARs was 82 minutes in the study by Panuccio et al.,[22] and 26 minutes in the study by Sailer et al.,[40] the mean duration was 29 minutes in this study. This finding underscores the relationship between FT and CAK. A positive correlation between CAK and FT in cath lab cases[22,35,38] was also detected in this study, consistent with previous literature findings that radial and femoral approaches to coronary diagnostic angiograms did not differ in FTs.[41]

PCI radiation doses and FT in university hospitals were found to be higher than in public hospitals. This disparity is attributed to the resident training process in university hospitals. The tendency for university and more comprehensive hospitals to perform more complex PCI procedures could also contribute to this finding. Consistent with this study's results, Lee[42] concluded that larger hospitals experienced higher radiation exposure because they performed more advanced examinations and treatments.

Limitations

Many parameters and calculations are required to determine the actual tissue dose for patients. This study is limited to CAK units derived from vascular X-ray devices, considering CAK the closest approximation to actual tissue dose. This study did not monitor patients for deterministic effects of ionizing radiation, evaluating only cumulative radiation levels by procedure type. Additionally, fluoroscopy times reported do not include cine (acquisition) times.

Conclusion

This research assessed ionizing radiation doses in catheterization laboratories using CAK units (mGy), a measurement closely representing tissue dose in patients. The findings largely align with the literature, indicating that the rates of high radiation exposure during interventional procedures could be higher than anticipated in Türkiye. This underscores the need for additional research to identify predictive factors and to develop strategies for minimizing exposure rates. Furthermore, further research is recommended to identify the factors influencing the notably high and variable radiation levels associated with PCI.

Given the specific characteristics of patients and their cases, there may be substantial exposure to radiation across various types of medical procedures. Such exposure, dictated by the necessities of each case, emphasizes the importance of monitoring radiation levels in patients to mitigate associated risks and to inform physicians decision-making in subsequent examinations. To this end, establishing Diagnostic Reference Levels (DRL) can be instrumental. DRLs serve as a benchmark for monitoring both minimal and maximal radiation exposures across different modalities and have been effectively used in many countries for years. The implementation of DRLs has been effective in reducing radiation levels on a procedural basis over time through radiation optimization efforts.[43-49]

Additionally, a significant finding of this study is that the attitudes of personnel in the catheterization laboratory toward radiation optimization using X-ray devices are inadequate. To address this, in-service training for employees can be planned, along with the establishment of a follow-up process that leverages DRLs.

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