American Heart Journal Plus: Cardiology Research and Practice 52 (2025) 100512

Contents lists available at ScienceDirect

American Heart Journal Plus: Cardiology Research and Practice

journal homepage: www.sciencedirect.com/journal/american-heart-journal-plus-cardiology-research-and-practice

Research paper

Evaluation of a first of a kind robotic radiation protection technology to reduce scatter exposure during diagnostic procedures and percutaneous coronary interventions

Wojciech E. Krzyzanowski *, Pawel Radecki, Marta K. Szczerbińska, Kamil Dawidczyk, Mikołaj Kosek, Krzysztof Romanik, Wojciech Suchcicki, Dariusz Karwowski, Paweł R. Natkowski

Interventional Cardiology, Mazowiecki Szpital Specjalistyczny's, Ostroleka, Poland

ARTICLE INFO

Keywords:
Radiation safety
Interventional cardiology
X-ray scatter radiation
Radiation protection
Fluoroscopy
Cath-lab

ABSTRACT

Background: This study evaluated the effectiveness of the Radiaction system in providing comprehensive protection to medical personnel during fluoroscopy-guided procedures in an Interventional Cardiology (IC) laboratory. The system confines the imaging beam and blocks scatter radiation at its source, enhancing safety for the Cath lab staff.

Methods: A prospective, non-randomized, controlled study compared real-time procedures with and without Radiaction. Sensors were placed around the room and on the main physician to measure radiation exposure during 82 diagnostic and 24 interventional cases without the Radiaction system and 65 diagnostic and 39 interventional cases with Radiaction.

Results: Results demonstrated a significant reduction in radiation exposure with the Radiaction system. Across all cases, the overall reduction in radiation was 74.7 % for all sensor locations and 82.9 % for the main physician. Diagnostic procedures exhibited a reduction of 73 % with the Radiaction system and Interventional procedures demonstrated a 79 % reduction across all sensors with the Radiaction system. Calculations were conducted to estimate the reduction during the time that the system was deployed, revealing an 85.7 % reduction across all sensors and 95.1 % for the main physician, reflecting the full potential of the system when used during 100 % of the X-ray time. Users expressed high satisfaction with the system, citing its user-friendly nature, and seamless integration into clinical workflow.

Conclusions: The Radiaction system significantly reduced radiation exposure in all cases compared to cases conducted without Radiaction. These findings support the potential of the Radiaction system to offer full-body protection from scattered radiation to all medical personnel in the IC suite, emphasizing its value in enhancing occupational safety in medical environments.

Glossary

Radiaction System a robotic radiation protection system designed to reduce scatter radiation exposure during fluoroscopy-guided procedures.

Interventional Cardiology a branch of cardiology that deals with catheter-based treatment of heart diseases, often involving fluoroscopic guidance.

Percutaneous Coronary Intervention a non-surgical procedure used to treat the narrowing of the coronary arteries of the heart, performed in the Cath-lab.

Dose Area Product a quantity used in assessing the total amount of radiation delivered to a patient during a procedure, taking into account both the dose and the area exposed.

Hover Mode a feature of the Radiaction system that allows partial deployment of the shield system for radiation protection during X-Y table panning.

Tungsten a lead-free metal used for the Radiaction system's shields due

Abbreviations: PCI, percutaneous coronary interventions; IC, interventional cardiology; DAP, dose area product.

* Corresponding author at: Cardiology Department, Mazowiecki Szpital Specjalistyczny's, Ostroleka, Poland.
E-mail address: wojciech.krzyzanowski@szpital.ostroleka.pl (W.E. Krzyzanowski).

https://doi.org/10.1016/j.ahjo.2025.100512
Received 11 November 2024; Received in revised form 27 January 2025; Accepted 12 February 2025
Available online 21 February 2025

to its radiation blocking properties.

Anthropomorphic phantom a model that mimics human anatomy, used in experiments to study radiation exposure in a controlled manner.

1. Introduction

Radiation exposure remains a pivotal occupational concern in medical procedures, particularly during fluoroscopy-guided cases such as IC. While various imaging devices are crucial in treating patients, C-arm fluoroscopic machines maintain widespread use due to their ability to assess bone structure, intravascular injections, and needle placement regardless of gauge or insertion angle. However, the use of C-arm fluoroscopy exposes both patients and medical staff to significant radiation risks. Accumulation of small doses over prolonged periods can yield adverse health effects for workers in the ionizing radiation zone [1,2]. Studies have highlighted a higher incidence of conditions such as cataracts [3] and tumours among medical staff [4] regularly exposed to radiation, with specific patterns indicative of occupational exposure. Furthermore, a significant finding was the disproportionate occurrence of tumours on the left side of the brain. In a study of 26 interventional physicians with brain tumours, 85 % had malignancies on the left side of the brain, suggesting a link between occupational radiation exposure and the predominance of left-sided brain tumours.

Radiation safety awareness and conscientious practice are paramount for minimizing exposure and mitigating potential adverse biological effects. Traditionally, medical personnel have relied on personal protective equipment such as lead aprons, goggles, leaded caps, and thyroid collars to mitigate radiation exposure [5]. However, these methods offer limited protection and do not address exposure from scatter and leakage radiation effectively. Recent protection products released on the market include suspended radiation protection systems and wheel-based leaded glass shields. These technologies primarily protect the main operator but could limit free movement [6], place barriers between the physician and the patient, and come with a significant learning curve, making them less ideal in a dynamic clinical environment.

The Radiaction system is designed to confine the imaging beam and block scattered radiation at its origin, providing comprehensive protection to all medical personnel in the operating room. Prehuman bench tests performed with a Rando anthropomorphic phantom (The RANDO® Phantom by The Phantom Laboratory) demonstrated significant radiation reduction with the. Radiaction system: 93% for the main physician, 94% for the second physician, and an average of 91.5% across all Cath lab locations and commonly used angles [7].

This study evaluates the efficacy of the Radiaction system in a clinical IC laboratory during diagnostic and interventional cases, measuring its impact on reducing radiation exposure, integrating into clinical workflows, and its potential to provide enhanced protection to medical personnel in the IC suite.

2. Methods

This prospective non-randomized, controlled study aimed to evaluate the Radiaction system's efficacy by comparing radiation exposure levels in a clinical environment of interventional cardiology procedures with and without the Radiaction system.

2.1. The Radiaction system

The Radiaction system (Radiaction Ltd., Tel Aviv, Israel) is a state-of-the-art robotic system designed to enhance radiation protection during fluoroscopy-guided procedures. The system comprises two robotic upper and lower extendable shields mounted on the C-arm around the X-ray tube and image detector (Fig. 1A). These shields are made from lead-free radiation blocking material (tungsten) and utilize sensors and controls

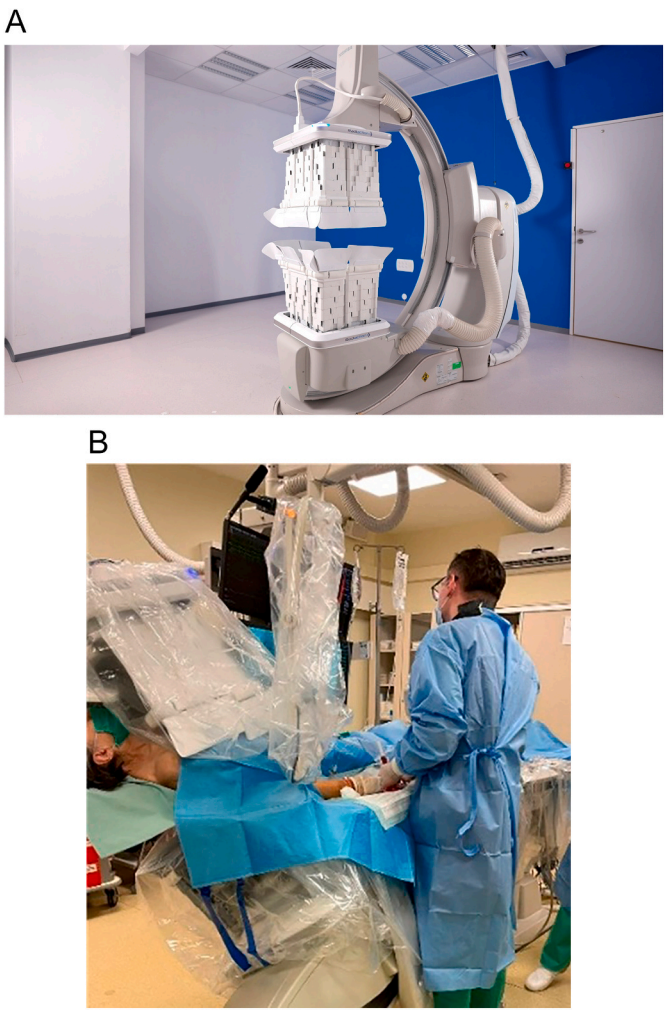

Fig. 1. A, B – The Radiaction shield.
A – The Radiaction system – a robotic radiation protection system that confines the imaging beam at its source. B – Real-time IC case with the Radiaction system employed.

to deploy and retract their attenuating segments, accommodating all C-arm angulations and table movements.

Controlled by the C-arm Operator, the system can be deployed and retracted via a table-mounted control panel, which includes indication lights to show the system's state. Before rotating the C-arm, the shields are retracted to allow undisturbed motion, or the shields can be retracted automatically with the help of built-in sensors. Once the C-arm reaches the desired angulation and position, the shields, along with their extending flexible flaps, can be deployed with a single button press, capturing the contour of the patient and table automatically using these highly sensitive sensors (Fig. 1B).

During x-y table panning, the Radiaction system can be deployed in hover mode, where the segments are partially deployed, allowing the table to be moved while still receiving radiation protection. This mode accommodates quick diagnostic cases and enhances the agility of the table and C-arm, as well as the turnover of patients.

The segments can also be preset to accommodate specific procedural needs. For instance, for superficial femoral artery access, the corner shield can be disabled so it does not deploy and allows for an access point and visibility (Fig. 1B).

2.2. Radiation measurements in the IC Laboratory

This study measured radiation exposure during 82 diagnostic and 24

interventional cases without the Radiaction system, followed by 65 diagnostic and 39 interventional cases with the system installed. Four highly sensitive radiation sensors were placed in the IC Lab and on the physician's body to capture real-time radiation exposure data. The results were then analyzed to determine the system's efficacy in reducing radiation exposure for medical personnel.

Sensor 1 was positioned on the monitor across the table from the primary physician at head height and sensor 2 was positioned on the monitor across the table from the typical position of the scrub in nurse/tech at head height. Sensor 3 was placed on the primary physician's upper body (on top of their lead apron), and sensor 4 on the primary physician's lower body (on top of their lead apron) (Fig. 2). Radiation measurements were taken at the Mazowiecki Szpital Specjalistyczny's IC suite during diagnostic and interventional procedures, before and after the installation of the Radiaction system. The Radiaction system was installed on the Toshiba/Canon Infinix-i Core Single Plane, Floor Mounted C-arm in the IC lab. The data was then normalized by the Dose Area Product (DAP) per procedure. In both setups, standard protection measures (i.e., table-mounted drapes and a ceiling-suspended shield) were used; therefore, the measured reduction levels reflect the added protection of the Radiaction system alone. The deployment rates of the Radiaction system were determined by calculating the proportion of the time the system was deployed relative to the total time the X-ray was in use, in each procedure. This was made possible by a sensor integrated into the Radiaction system, which monitored the system's state (retracted, deployed, or hover mode) each time radiation was detected in the Cath-lab. Using this sensor, the percentage of time in each state was calculated per case.

Reduction percentages were determined by calculating the median Dose/DAP measurements along with their 25th and 75th percentiles to provide a comprehensive analysis of the data distribution. The error for the median was estimated using the bootstrap method, which utilized resampling the data and calculating the median for each sample. The variability among these medians provided the standard error, quantifying the uncertainty in the median measurement without relying on distributional assumptions. Additionally, extrapolation was used to estimate the radiation reduction performance with the Radiaction shield deployed, predicting its potential effectiveness when used for 100 % of the X-ray exposure time, with projections based on observed data trends.

Highly sensitive sensors were used for radiation dose measurements (Supplementary Data - Fig. 1). The minimum sensitivity of the Thermo Fisher EPD TruDose Personal Dosimeters for clinical environments was 0.05 μSv/h. Data was collected per procedure and included: total procedure time, procedure type (classified as either Diagnostic or Interventional), patient's BMI and sensor dose from all sensors (μSv). In addition, after each procedure, the following data was recorded from the C-arms output: DAP - Dose Area Product (Gy/m^2), total fluoro time (min), total acquisition time (min), and total X-ray time (min). To compare data from control and study cases while accounting for uncontrollable variables that affect the radiation emission in the room (BMI, X-ray current consumption, temperature, fluoro time etc.), dose measurements from all sensors (μSv) were all normalized by the Dose Area Product (DAP) ($Gy \times m\hat{}2$) provided by the fluoroscopy system and all measured comparisons were calculated using the normalized data.

After all data were collected, the radiation reduction for cases with the system used for the whole procedure was estimated using simple proportional scaling based on the observed reduction at partial use. For cases where the system was used for a portion of the procedure, the reduction for full usage was extrapolated as follows:

$$x = \frac{R_{observed} * 100}{U_{observed}}$$

where $R_{observed}$ is the observed radiation reduction and $U_{observed}$ is the correlating usage percentage.

At the end of the study, physicians were given a survey of feedback questions related to using the Radiaction system during their procedures to evaluate the integration into their clinical flow as well as their satisfaction with the system.

2.3. Statistical analysis

Mann-Whitney tests were conducted separately for each procedure type to test whether there were significant differences between the sensor's measurements when the system was deployed compared to when the system was not in use (Table 1). This test was selected since the measured radiation data did not distribute normally.

3. Results

During this study, 82 diagnostic cases and 24 interventional cases

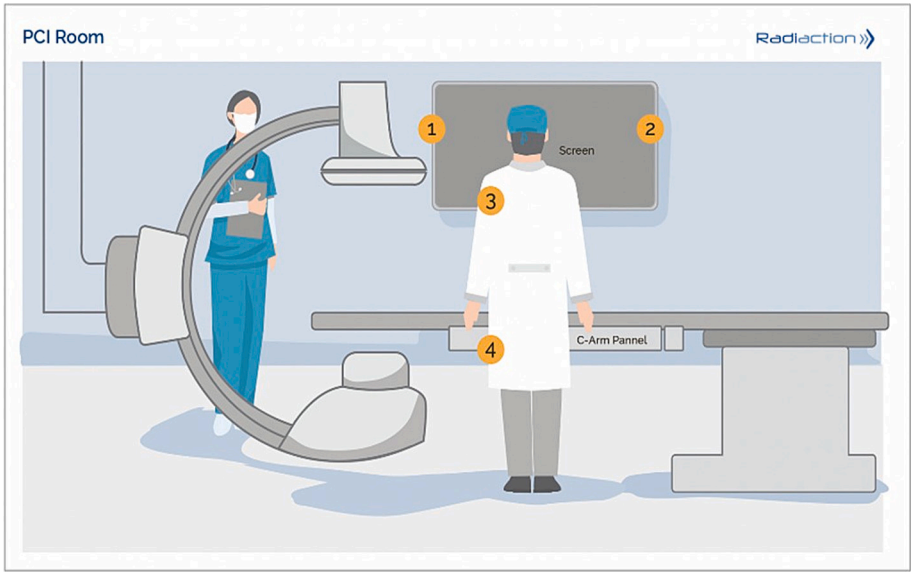

Fig. 2. Radiation sensor placement in the IC suite.
Radiation sensor placement in the IC suite. Sensor 1 – across the table from first physician, head height, sensor 2 – across the table from second physician or scrub in nurse/tech, head height, sensor 3 – on top of first physician's apron for upper body exposure, sensor 4 – on top of first physician's lead apron for lower body exposure.

Table 1
Mann–Whitney tests for each procedure type.

Procedure	Sensor	Radiaction in use	n	Mean rank	U
Diagnostic	1	Without	62	87.90	
		With	62	37.10	U(122) = 347, $p <$ .001
	2	Without	76	97.89	
		With	63	36.35	U(137) = 247, p < .001
	3	Without	45	71.73	
		With	56	34.34	U(99) = 327, p < .001
	4	Without	52	75.29	
		With	55	33.87	U(105) = 323, p < .001
IC	1	Without	17	39.35	
		With	37	22.05	U(52) = 113, p < .001
	2	Without	23	47.52	
		With	38	21.00	U(59), p < .001
	3	Without	18	39.61	
		With	31	16.52	U(47) = 16, p < .001
	4	Without	17	43.59	
		With	36	19.17	U(51) = 24,p < .001
All cases	1	Without	79	126.84	
		With	99	59.71	U(176) = 961, p < .001
	2	Without	99	145.17	
		With	101	56.71	U(198) = 577, p < .001
	3	Without	63	110.65	
		With	87	50.05	U(148) = 526, p < .001
	4	Without	69	118.61	
		With	92	52.79	U(159) = 579, p < .001

The Mann-Whitney test was conducted separately for each sensor location and procedure type (Diagnostic, Interventional, and all Cases) to test for differences between the sensors' measurements in the control and study phases. This test was selected since the radiation measured did not distribute normally, and the selected test does not assume a normal distribution in the dependent variable. The measurements were from tests in which the deployment rate was over 0.7.

were performed and documented in the IC suite without the Radiaction system installed and served as the control measurements. With the Radiaction system installed, 65 diagnostic cases, and 39 interventional cases were performed, documented, and compared to the control measurements to calculate normalized radiation exposure differences. There was no significant difference in the average BMI between the control and study cases: 29.3 compared to 29.5 respectively. The average procedure time was also similar across both groups, with control cases taking an average of 32.6 min and study cases taking an average of 40.8 min. Additionally, the average X-ray time showed no significant difference, with control cases averaging at 6.9 min and study cases averaging at 9.1 min (Table 2).

Table 2
Procedure details in control and study phases.

	All cases		Diagnostic cases		Interventional cases	
	Control	Study	Control	Study	Control	Study
BMI	29.39	29.55	29.54	29.22	28.85	29.55
Procedure time (min)	32.6	40.8	28.3	36.1	47	48.1
Fluoro time (min)	6.9	9.1	5.7	7.2	11	12.1

Average values for patient's BMI, procedure time, and X-ray time for control cases compared to study cases.

3.1. All cases

In all measured procedures, both diagnostic and interventional, radiation levels were significantly lower with the system installed compared to without it ($p < .001$ for all sensors and procedure types). The average median sensor reading in all cases without the Radiaction system was 78.73 μSv (range: 22.6–138.07 μSv) (Supplementary Table 1). With Radiaction the average median sensor reading was 25.23 μSv (range: 7.07–57.56 μSv).

The average median Dose/DAP for all sensors without Radiaction was 47,082 μSv/Gy*cm^2 (range: 14063.2–81,460.1 μSv/Gy*cm^2) and 13,009 μSv/Gy*cm^2 (range: 4055.6–31,015.6 μSv/Gy*cm^2) with Radiaction (Supplementary Table 2) with an average deployment rate of 87.1 % (Table 3).

The overall radiation reduction for all cases with an average deployment rate of 87.1 % was 74.7 % on average for all sensors (range: 62 % - 86.8 %) and 83 % for the main physician (Fig. 3).

The estimated reduction when the system is deployed for the entire procedure is 85.7 % across all sensors (range: 71.1 %–99.7 %) and 95 % for the main physician (Supplementary Table 3). It is important to note that during the study period, physicians did not consistently deploy the system throughout the entire case due to various factors, such as the learning curve of using the system, and the demands of emergency procedures. As a result, these estimates reflect the potential radiation reduction that could be achieved if the Radiaction system were deployed for 100 % of the X-ray exposure time during the entire procedure.

Table 3
Radiation results per sensor for all procedure types.

Procedure type	Control cases		Study cases	
	Procedures (n)	Avg Sensor 1 Dose/Dap	Procedures (n)	Avg Sensor 1 Dose/Dap
All cases	106	99,654.5	104	35,924.5
Diagnostic	82	91,972	65	32,227.8
Interventional	24	128,125	39	42,367.4

Procedure type	Control cases		Study cases	
	Procedures (n)	Avg Sensor 2 Dose/Dap	Procedures (n)	Avg Sensor 2 Dose/Dap
All cases	106	15,647.1	104	4706.4
Diagnostic	82	14,922.2	65	4411
Interventional	24	18,074.1	39	5171.8

Procedure type	Control cases		Study cases	
	Procedures (n)	Avg Sensor 3 Dose/Dap	Procedures (n)	Avg Sensor 3 Dose/Dap
All cases	106	91,408.3	104	17,755.3
Diagnostic	82	95,997.3	65	20,297.3
Interventional	24	79,425.8	39	13,344.4

Procedure type	Control cases		Study cases	
	Procedures (n)	Avg Sensor 4 Dose/Dap	Procedures (n)	Avg Sensor 4 Dose/Dap
All cases	106	48,074.8	104	8157.6
Diagnostic	82	49,747	65	8788.2
Interventional	24	43,244.2	39	7169.1

Results of radiation for all sensors for All Cases, Diagnostic Cases, and Interventional Cases (all units are in $\frac{\mu Sv}{Gy*m^2}$).

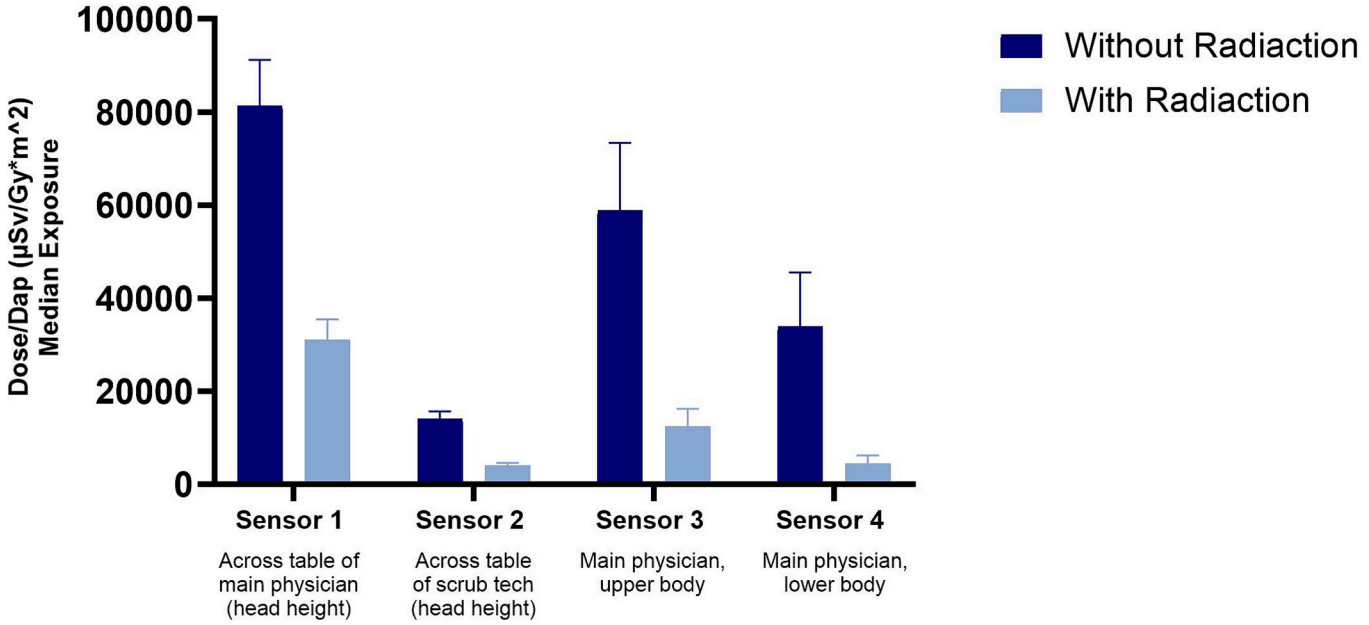

Fig. 3. Median radiation exposure for all sensors in all cases.
Median radiation exposure for all sensors in both diagnostic and interventional cases with and without Radiaction.

3.2. Diagnostic cases

In all diagnostic cases, the radiation levels with the Radiaction system were significantly lower than those without the system installed. The average median sensor reading in control cases was 68.76 µSv (range: 83.2–125.58 µSv), compared to 23.62 µSv (range: 6.25–52.45 µSv) in study cases (Supplementary Table 1).

In Diagnostic cases, the average median Dose/DAP across all sensors without Radiaction was 47,148.3 µSv/Gy*cm^2 (range: 12561.2–78,209.8 µSv/Gy*cm^2). With the average deployment rate being 87.4 %, the average median with Radiaction was 13,191.2 (range: 4061–29,423.1 µSv/Gy*cm^2) (Table 3, Supplementary Table 2).

The radiation reduction with an 87.4 % deployment rate of the Radiaction system was 73 % for all sensors (range: 62 %–86 %) and 81 % for the main physician (Fig. 4).

The estimated reduction in radiation when the system is deployed throughout the procedure is 83.7 % for all sensors (range: 71.4 %–98.6 %), and 93 % for the main physician (Supplementary Table 3). As mentioned above, it is important to note that during the study period, physicians did not consistently achieve full deployment of the Radiaction system throughout each case. Therefore, these estimates represent the potential radiation reduction achievable when the system is deployed for 100 % of the X-ray exposure time.

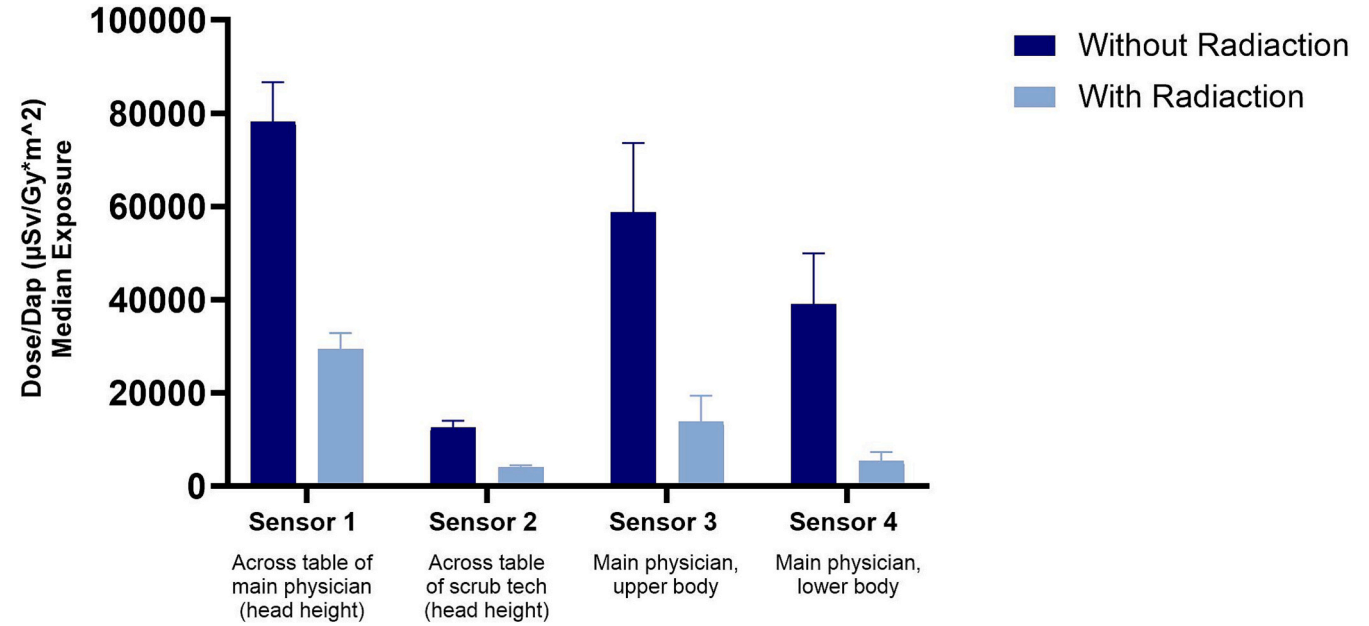

Fig. 4. Median radiation exposure for all sensors in diagnostic cases.
Median radiation exposure for all sensors in diagnostic cases with and without Radiaction.

3.3. Interventional cases

For interventional cases, radiation levels with the Radiaction system installed were statistically significantly lower than those without the shields. Without the Radiaction system the average median dose reading in interventional cases was 144.85 μSv (range: 48.52–252.91 μSv) compared to 30.93 μSv (range: 10.24–72.37 μSv) with the Radiaction system (Supplementary Table 1).

Without Radiaction the average median Dose/DAP was 52,691.8 μSv/Gy*cm^2 (range: 16515.1–102,281.1 μSv/Gy*cm^2) and with an 86.3 % deployment rate of Radiaction the average median was 12,578.9 μSv/Gy*cm^2 (range: 3956.5–33,675.2 μSv/Gy*cm^2) (Table 3, Supplementary Table 2).

The average radiation reduction with an average deployment rate of 86.3 % was 79 % for all sensors (range 67 %–87 %) and 85.5 % for the main physician (Fig. 5).

The estimated reduction with the Radiaction system deployed for the whole procedure is 91 % for all sensors (range: 77.7 %–99 %%) and 98.6 % for the main physician (Supplementary Table 3). These reductions represent the maximum potential with optimal utilization of the system.

3.4. User feedback

Five physicians were asked to complete 2 questionnaires: one after 2 weeks of using the Radiaction system and another at the end of the study. Their feedback ranked the Radiaction system highly in terms of safety, scoring 5.6 out of 7, ease of use at 5.8 out of 6, and integration into their workflow at 5.4 out of 6 (Supplementary Fig. 2A and B).

4. Discussion

The Radiaction system offers comprehensive full-body protection during fluoroscopy-guided procedures, significantly reducing radiation exposure. The results align with previous studies, confirming a significant decrease in radiation exposure in a clinical setting and high user satisfaction. Findings from this study and prior research suggest that the Radiaction system has the potential to enhance medical team safety by providing full-body radiation reduction for all interventional staff in the IC laboratory. In addition, the high reduction performance indicates that the Radiaction system has the potential to reduce the thickness and weight of heavy lead aprons currently used, thereby potentially minimizing the musculoskeletal issues associated with prolonged use of these aprons.

This study demonstrates a clear correlation between the duration of deployment rates and the reduction in radiation: the more the Radiaction system is used during a procedure, the greater the reduction in radiation levels. By maximizing the system's usage throughout the case leads to significantly enhanced radiation protection for the main physician and the medical team. As physicians performed more cases, their proficiency and correct usage of the system increased. This is evidenced by the higher use of 'Hover Mode' during diagnostic cases compared to the system's 'Fully Deployed' state during interventional cases, indicating the high level of system adoption and integration into the clinical practice (Supplementary Fig. 3A, B). This study also demonstrated how the system integrates seamlessly into clinical workflows and can be easily used in conjunction with other shielding systems in the lab to achieve the highest levels of radiation protection.

Sensor 1 exhibited lower reduction levels than the other sensors, likely due to incorrect placement of the sensor. It was positioned near the area lacking the system's back wall segment, which is necessary to accommodate all steep angles commonly used in cardiology procedures and to ensure patient comfort. This likely explains the reduced radiation reduction observed, especially in caudal angles.

Sensor 4, positioned to measure lower body radiation exposure of the main physician (an area typically subject to high radiation exposure) showed relatively lower radiation levels. This is likely attributed to the use of the table drape throughout the study stages (with and without the Radiaction system). Furthermore, this indicates that the observed decrease in this study is due solely to the Radiaction system.

4.1. Limitations

This study has several limitations that should be acknowledged. While the Radiaction system demonstrated a significant reduction in radiation exposure, achieving optimal results requires training and has a learning curve that differs per physician and per application of the specific procedure workflow. Even with such training, full utilization of the system was not consistently achieved. This variability was

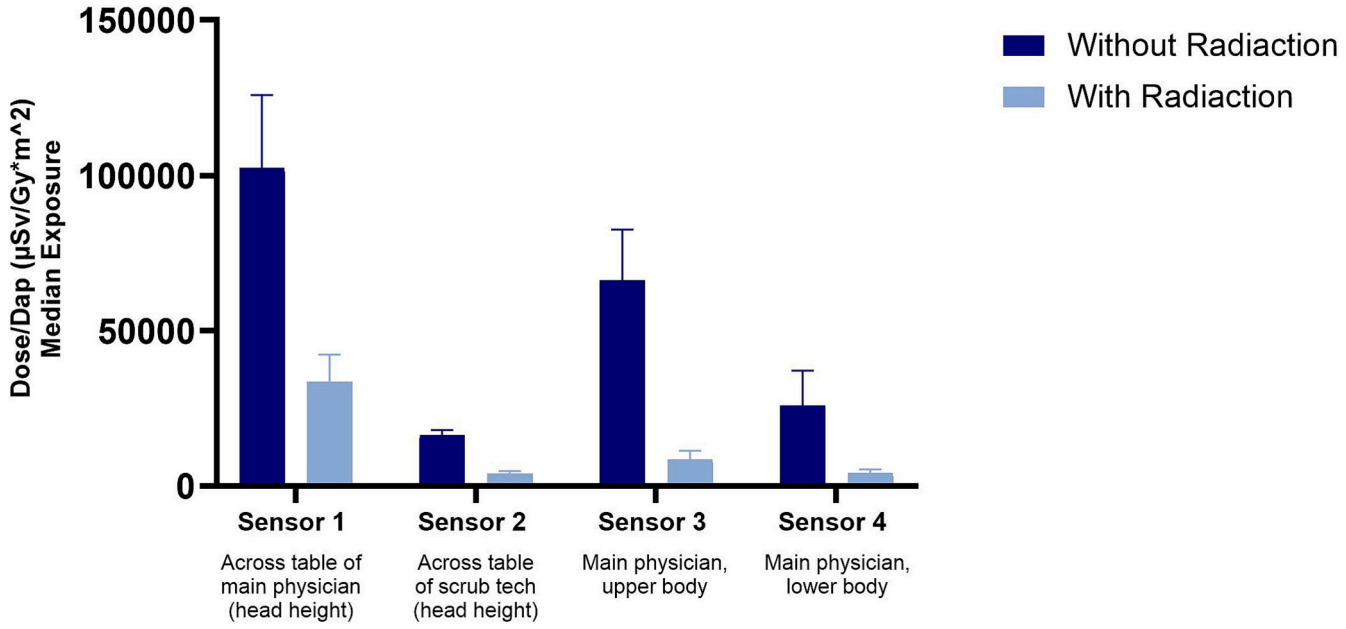

Fig. 5. Median radiation exposure for all sensors in interventional cases.
Median radiation exposure for all sensors in interventional cases with and without Radiaction.

influenced by several factors, including physician preferences and clinical emergencies that arose during procedures, among others. These findings highlight the value of consistent and frequent use of the system; the more effectively the system is utilized throughout the procedure, the greater the reduction in radiation exposure that can be achieved.

Additionally, while the reported reductions in radiation were substantial, further investigation is needed to evaluate the potential of reducing the thickness of wearable lead aprons in a dedicated study where radiation reduction is tested with the Radiaction system and light lead aprons.

Another limitation of this study is the large variance observed in intra-procedure comparisons between control and test data. The level of radiation exposure reduction fluctuated based on procedural differences, patient anatomy, and operator-dependent factors. This variability underscores the importance of standardized protocols and consistent system utilization across cases to achieve higher reduction levels.

Although this study did not specifically evaluate patient-level factors, such as mechanical ventilation setups, concerns related to claustrophobia, or emergency access to the patient during cases, there were instances where these factors were relevant, and no issues were reported. However, further research, focusing specifically on these aspects is needed to provide a more comprehensive assessment and ensure these considerations are adequately addressed.

While this study did not explicitly focus on the angulations of the C-arm during live cases, steeper angles were utilized but were not a focal part of the study. Further investigation and evaluation are needed to ensure consistent radiation protection across diverse procedural scenarios.

Finally, while significant reductions were observed across various sensor positions, scatter radiation levels are not uniform around the table. Further studies should focus on specific positions of medical staff by placing sensors on the scrub nurse, the circulating nurse/tech, and the anaesthesiologist (if relevant) to measure their specific radiation exposure levels with and without the Radiaction system.

5. Conclusions

During this study, for both diagnostic and interventional procedures, the radiation with the Radiaction system in use was statistically significantly lower than the radiation without the Radiaction system installed. In addition, the higher the deployment rates, the higher the reduction rates. This study further points to easy integration into the clinical workflow.

The Radiaction system can potentially have an essential role in full-body protection against scatter radiation for everyone working in the Cath lab. The Radiaction system has the potential to transform how medical personnel protect themselves, conceivably reducing the need for heavy lead apparel. With the added protection from Radiaction, it may be possible to significantly lessen the weight of lead required for adequate safety.

CRediT authorship contribution statement

Wojciech E. Krzyzanowski: Writing – review & editing, Writing – original draft, Conceptualization. **Pawel Radecki:** Writing – review & editing, Resources, Methodology, Investigation, Data curation. **Marta K. Szczerbińska:** Methodology, Investigation, Data curation. **Kamil Dawidczyk:** Investigation, Data curation. **Mikołaj Kosek:** Methodology, Investigation. **Krzysztof Romanik:** Investigation, Data curation. **Wojciech Suchcicki:** Validation, Investigation. **Dariusz Karwowski:** Project administration, Conceptualization. **Paweł R. Natkowski:** Methodology, Investigation.

Ethical statement

This study was conducted in accordance with all applicable ethical guidelines and regulations. As no direct human or animal subjects were involved in this research, formal ethical approval was not required. Data in this study were obtained from de-identified sources, ensuring that participant privacy and confidentiality were fully preserved.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or non-for-profit sectors.

Declaration of competing interest

The authors of Evaluation of a First of a Kind Robotic Radiation Protection Technology to Reduce Scatter Exposure During Diagnostic Procedures and Percutaneous Coronary Interventions declare no conflicts of interest relevant to this manuscript. No financial, personal or professional relationships influenced the conduct, analysis, or presentation of this study.

Acknowledgments

The authors thank the IC staff and all medical personnel who participated in this study for their dedication and expertise. We also thank the technical staff for their assistance and appreciate the institutional support from Mazowiecki Szpital Specjalistyczny's, Ostroleka, Poland.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ahjo.2025.100512.

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