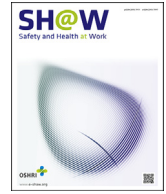




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Original Article

## Personal Protective Equipment Availability and Utilization Among Interventionalists

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## ABSTRACT

**Objective:** This study explored personal protective equipment (PPE) availability and PPE utilization among interventionalists in the catheterization laboratory, which is a highly contextualized workplace. **Methods:** This is a cross-sectional study using mixed methods. Participants (108) completed a survey. A hyperlink was sent to the participants, or they were asked to complete a paper-based survey. Purposively selected participants (54) were selected for individual (30) or group (six) interviews. The interviews were conducted at conferences, or appointments were made to see the participants. Logistic regression analysis was performed. The qualitative data were analyzed thematically.

**Results:** Lead glasses were consistently used 10.2% and never used 61.1% of the time. All forms of PPE were inconsistently used by 92.6% of participants. Women were 4.3 times more likely to report that PPE was not available. PPE compliance was related to fit and availability.

**Conclusions:** PPE use was inconsistent and not always available. Improving the culture of radiation protection in catheterization laboratories is essential to improve PPE compliance with the aim of protecting patients and operators. This culture of radiation protection must include all those involved including the users of PPE and the administrators and managers who are responsible for supplying sufficient, appropriate, fitting PPE for all workers requiring such protection.

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## 1. Introduction

Ionizing radiation is increasingly being used for diagnostic, therapeutic, and interventional procedures in medicine. The technology has advanced, resulting in equipment emitting lower radiation doses; however, procedures have become more complex and longer in duration, and this poses an increased occupational health risk to radiation healthcare workers (HCWs) [1,2]. The increase in fluoroscopic procedures necessitates the implementation of a culture of radiation protection (CRP) to produce a safer workplace [3].

The effects of radiation exposure may be stochastic or deterministic. These effects may include skin changes, carcinomas, and cataracts [4]. Skin changes may include burns and hair loss. Radiation-induced occupational malignancies are of the most dreaded consequences of ionizing radiation exposure [5]. This may be consequent of DNA damage or chromosomal aberrations [5]. The common malignancies include leukemia and thyroid, breast, and

brain cancers. The crystalline lenses of the eyes are of the most radiosensitive tissues in the body [6]. Data suggest that cataractogenesis may be stochastic rather than deterministic in effect and that changes may occur even at very low radiation dose exposure [7]. The pathogenesis of radiation-induced cataracts may be due to oxidation processes or damage to proteins [8].

A radiation protection program in the workplace is an important approach to mitigate the effects of ionizing radiation on health. Such a program would include management structures, policies, operating procedures, and organizational structures [1]. These organizational arrangements would include aspects such as the provision and maintenance of personal protective clothing, monitoring and evaluation of dosimeter readings, and training and education [1]. A well formulated radiation protection program will assist in establishing and sustaining a CRP. A CRP is a complex concept and is influenced by the core values, norms, and attitudes of those working in the catheterization laboratory (cath. lab) [9].

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The findings of a CRP in the South African context are extensively explored elsewhere [9].

The use of PPE is an important mitigating factor for preventing the stochastic and deterministic health effects of ionizing radiation [10]. Lighter and more robust PPE will offer better protection and increased compliance [5]. PPE includes ceiling-suspended screens, thyroid guards, lead aprons, and lead glasses [11]. PPE should be used properly and regularly for it to be beneficial. The consistent utilization of PPE is underpinned by availability, fit, and dexterity when performing procedures [12]. In a survey conducted in the USA, urology residents reported the lack of availability of PPE as a key reason for poor utilization [13].

Ceiling-suspended shields can reduce scatter radiation to the head, neck, and lens by 50–90%, depending on the positioning of the screen, but they are often not available in the cath. lab [14]. The screens may, however, hamper performing procedures with dexterity [14]. The screens are often used irregularly [15]. Thyroid guards and lead aprons are of the most consistently used PPE with up to 96% utilization reported [13]. Lead aprons are often reported as heavy and cumbersome to work with. Appropriate sizes especially for smaller users and women are sometimes not readily available. In a study conducted in Irish hospitals, Cremen and McNulty (2014) found that there were not sufficient and appropriately sized lead aprons at the sites surveyed in their study [16]. Lead glasses that fit properly and are worn consistently can reduce the dose to the eye by a factor of 3–5 [17]. The use of lead glasses is affected by their availability, the weight, the fit, and the ease with which the interventionalists can perform a procedure. A common complaint is that the glasses steam up during procedures and are heavy [17]. Lead glasses are frequently used inconsistently [13].

The aim of this article is to report on PPE utilization practices and availability of PPE among South African interventionalists.

## 2. Materials and methods

This study forms part of a larger study, the methods of which are described in detail elsewhere [18]. We had a quantitative component where we conducted a survey and collected data on demographics of the participants, risk factors for cataracts, occupational exposure to ionizing radiation, use and availability of PPE, and training in radiation safety. This article presents only the data on their use and availability of PPE. The participants who completed the survey were also invited to have their eyes screened for cataracts. We also had a qualitative component where we conducted interviews and gathered data on the perceptions of interventionalist to radiation safety and PPE availability and use. This article reports only on PPE availability and use. The participants who participated in the survey were not necessarily the same participants in the interviews and vice versa, but there were participants who participated in both parts of the study.

### 2.1. Study description

This was a cross-sectional mixed methods study. The data were collected at seven national conferences across South Africa in different South African cities including Johannesburg, Cape Town, and Bloemfontein. The conferences were the official conferences of the Radiology and Cardiology Societies of South Africa. They were conveniently chosen because we anticipated that there would be a large number of prospective participants who matched our inclusion criteria. We sent notices to the prospective delegates via the conference-organizing companies and the professional societies before the conferences informing them of the study and requesting that they participate in the study. A hyperlink was sent in this message, which directed the prospective delegates to details of the

study and the online survey. The inclusion criterion was that participants had to be interventionalists (radiologists and adult and pediatric cardiologists). We included radiologists and cardiologists because there are differences in their training, which may explain differences in their use of PPE. Interventionalists are defined as doctors who perform interventional procedures using fluoroscopy-guided ionizing radiation.

At the conference, announcements were made at all sessions requesting interventionalists to participate in the study. There were opportunities at some of the conferences for the researcher to explain the nature of the study and invite interventionalists to participate. The researcher and a research assistant directly approached delegates at the conference, explained the nature of the study, and invited them to participate in the study. We used a participant recruitment strategy and encouraged participants to ask their friends and colleagues to participate in the study. We held a competition at three of the conferences and had a lucky draw (to win a pair of lead glasses) for delegates who participated in the study.

Data were collected using an electronic survey questionnaire, EvaSys ([www.evasys.co.uk](http://www.evasys.co.uk)) or a paper-based questionnaire, and 108 interventionalists participated. The participants were not randomly selected. The electronically completed survey was matched to the participants at the conference. Delegates at the conference who wished to participate in the study but had not completed the online version of the survey were asked to complete a paper-based version of the study.

Participants (54) were purposively selected for in-depth interviews (30) and group interviews (six) until data saturation was reached. We decided that data saturation was researched when we started getting similar responses to questions. I called the radiology and cardiology departments at the medical universities in South Africa. I explained the study to the heads of department and asked to make an appointment with them if they were interested to participate in the study. The heads of department were asked to inform the specialists and registrars in their departments to participate in the study. Interested participants were then followed up via email to confirm their availability for the interview. Snowball sampling was used to get additional participants. After an interview, I asked participants to recommend colleagues they thought would be interested to participate in the study. I then followed up with these recommendations and arranged interviews if they were interested. Specialists in the private sector were also approached and mainly recruited by word of mouth. The participants were selected to include a diversity of interventionalists representing doctors who had just started working with ionizing radiation, mid-career professionals, senior professionals, and heads of department across the three categories of interventionalists.

### 2.2. Study definition of PPE utilization and fit and registrars

Consistent PPE utilization was defined as PPE use more than 70% of the time in the last month. We calculated consistent PPE use of all four PPE used viz. using the ceiling-suspended shield, the lead apron, the thyroid shield, and the lead glasses all the time. Lead glasses were poorly utilized, and we also looked at PPE if they were excluded. Fit of the PPE was a subjective recall of how the PPE generally fitted.

Registrars refer to doctors in the process of specializing and may also be known as residents.

### 2.3. Data analysis

The quantitative data were analyzed descriptively and analytically. Associations between PPE utilization and PPE availability were established. Regression models predicting for PPE utilization and PPE availability were constructed.

**Table 1**  
Demographic characteristics of 108 interventionalists

Variable	
<b>Gender, n(%)</b>	
Male	74 (68.5)
Female	34 (31.5)
<b>Age (years)</b>	
Mean (SD)	45.8 (9.9)
Range	30–69
<b>Weight (kg)</b>	
Mean (SD)	75 (13.8)
Range	45–110
<b>Height (cm)</b>	
Mean (SD)	172.5 (8.8)
Range	150–194
<b>BMI</b>	
Mean (SD)	25.1 (3.7)
Range	16.5–35.5
<b>Occupational category, n(%)</b>	
Radiologists	35 (32.4)
Adult cardiologists	41 (38.0)
Pediatric cardiologists	32 (29.6)
<b>Years worked with ionizing radiation</b>	
Median	10
IQR	5–17
Range	1–40
<b>Sector worked, n(%)</b>	
Public	47 (43.6)
Private	40 (37.0)
Both	21 (19.4)

SD, standard deviation; BMI, body mass index; IQR, interquartile range.

We analyzed the qualitative data using Braun and Clarke's steps [19,20]. The transcripts were transcribed verbatim. A thematic analysis was performed. The data were coded and arranged into categories and then grouped into themes using a deductive and inductive approach. The researchers initially independently analyzed the data and then debated themes and reached consensus on the final findings.

### 3. Ethical considerations

The study was approved by the Human Research Ethics Committee of the Faculty of Health Sciences of the University of the Free State (ECUFS 44/2015). All participants provided written informed

consent. Informed consent was implied when participants agreed to participate in the online questionnaire.

## 4. Results

### 4.1. Quantitative findings

In Table 1, the demographic characteristics of the population and its occupational categories are described.

Table 2 presents the different types of PPE used by participants and their reasons for inconsistent use. One hundred (92.6%) of the total participants (N = 108) did not consistently use all PPE simultaneously. If use of lead glasses was excluded from assessing consistent use, then 34 (31.5%) of the participants inconsistently used their PPE.

Table 3 tabulates the bivariate analysis where PPE availability and PPE utilization are the dependent variables. Bivariate analysis could not be performed for PPE utilization as the independent variable and for sex, occupation, PPE availability, and training in radiation safety as the dependent variable because in all cases, there were expected cells with less than five counts, and the assumptions were violated.

Table 4 presents two logistic regression models for PPE utilization and PPE availability and the dependent variables. Model 1 did not significantly predict PPE utilization,  $\chi^2 = 6.1$  ( $p = 0.642$ ), and the model only predicted 13.3% of the variance in PPE utilization.

Model 2 significantly predicted PPE availability,  $\chi^2 = 27.3$  ( $p < 0.000$ ), and the model predicted 29.9% of variance in PPE availability. In the *post hoc* analysis, sex and occupation were significant predictors of PPE utilization. Women were 4.3 times more likely than men to report the lack of PPE availability. Pediatric cardiologists were 6.8 times more likely to report the lack of PPE availability.

### 4.2. Qualitative findings

Participants reported greater readiness to use lead aprons and thyroid shields than for using lead glasses. PPE compliance was related to availability and fit. They were unlikely to use the PPE if it was cumbersome to wear, if it was difficult to perform procedures with, or if it was not easily accessible. Women reported that they had challenges with getting PPE that fitted them well and was not too heavy. The participants reported that if hospital managers ensured availability of PPE, it would facilitate their utilization of it.

**Table 2**  
The use of different types of PPE among participants and reasons why they would not consistently use this PPE

	Ceiling-suspended screen	Lead apron	Thyroid shield	Lead glasses
<b>Utilization of PPE</b>	<b>N = 108 (%)</b>	<b>N = 108 (%)</b>	<b>N = 108 (%)</b>	<b>N = 108 (%)</b>
Uses PPE >70%	75 (69.4)	106 (98.1)	79 (73.1)	11 (10.2)
Never uses PPE	21 (19.4)	2 (1.9)	8 (7.4)	66 (61.1)
	<b>n = 46 (%)</b>	<b>n = 106 (%)</b>	<b>n = 100 (%)</b>	<b>n = 42 (%)</b>
Reported that the PPE fitted well	n/a	95 (89.6)	87 (87)	32 (76.2)
<b>Years using PPE</b>				
Median	5	10	9	3
IQR	3–10	5–19	4–15	2–6
Range	1–20	1–40	1–35	1–30
<b>Reasons why they would not consistently use PPE (multiple responses possible)</b>	<b>N = 108 (%)</b>	<b>N = 108 (%)</b>	<b>N = 108 (%)</b>	<b>N = 108 (%)</b>
Not available	44 (40.7)	1 (0.9)	1 (0.9)	41 (38.0)
Difficulty performing procedures	16 (14.8)	0	4 (3.7)	16 (14.8)
PPE does not fit well	n/a	0	9 (8.3)	6 (5.6)

PPE, personal protective equipment.

**Table 3**  
Bivariate analysis for the lack of PPE availability and PPE utilization as the dependent variables

	N (%)	$\chi^2$	OR (CI)	p-value
<b>Lack of PPE availability</b>				
<b>Gender</b>		13.2	5.4 (2.07; 13.8)	<b>&lt;0.000</b>
Male	43 (41.9)			
Female	27 (79.4)			
<b>Occupation</b>		18.1		<b>&lt;0.000</b>
Pediatric cardiologists	25 (78.1)	10.9	4.7 (1.79; 12.07)	<b>&lt;0.001</b>
Radiologists and adult cardiologists	33 (43.4)			
Training received	20 (52.6)	0.03	1.1 (0.49; 2.36)	0.869
	<i>t</i> test	Mean difference	CI	p-value
Height	2.8	4.67	1.39; 7.95	<b>0.006</b>
BMI	1.5	1.11	-0.31; 2.53	0.124
Ranked level of exposure	1.5	0.20	-0.61; 0.45	0.134
<b>PPE utilization</b>				
Age	2.6	5.72	0.85; 10.59	<b>0.05</b>
Height	-0.3	-1.05	-7.50; 5.41	0.749
BMI	-0.2	-0.22	-2.95; 2.50	0.871
Ranked level of exposure	-0.8	-0.21	-0.70; 0.29	0.410

PPE, personal protective equipment; OR, odds ratio; CI, confidence interval; BMI, body mass index.

The bold values indicate statistically significant p-values.

**5. Limitations**

The participants who completed the survey were not randomly selected, and this may have introduced selection bias. There may also have been recall bias as PPE utilization and PPE fit were self-reported. The participants selected for the qualitative component were purposively selected to include a diversity of interventionalists, but although the findings are not generalizable, they may though be transferable to similar settings.

**Table 4**  
Logistic regression models for PPE utilization and PPE availability as the dependent variables

Variable	Adjusted OR	CI	p-value	Degrees of freedom
<b>Model 1: logistic regression analysis, PPE utilization as a dependent variable</b>				
Age	0.9	0.83; 1.01	0.068	1
Gender	1.6	0.21; 13.01	0.640	1
BMI	1.0	0.81; 1.25	0.940	1
Ranked exposure	1.7	0.47; 6.41	0.412	1
Occupation			0.948	2
Adult cardiologists	1.3	0.12; 14.84	0.808	1
Pediatric cardiologists	1.4	0.19; 9.77	0.757	1
PPE availability	2.2	0.37; 13.16	0.386	1
Training received	0.6	0.10; 3.91	0.606	1
<b>Model 2: logistic regression analysis, PPE availability as a dependent variable</b>				
Gender	4.3	1.47; 12.82	0.08	1
PPE utilization	0.5	0.10; 3.13	0.430	1
Training received	0.9	0.31; 2.50	0.809	1
Occupation			0.003	2
Adult cardiologists	0.1	0.05; 0.45	0.001	1
Radiologists	0.3	0.08; 1.08	0.065	1

PPE, personal protective equipment; BMI, body mass index; OR, odds ratio; CI, confidence interval.

**6. Discussion**

The use of radiation protection PPE in the cath. lab is a complex matter. It is influenced by factors such as the availability of PPE, the fit of the PPE, and the ease of doing procedures with it [21]. In our study participants indicated that they consistently used ceiling-suspended screens, lead aprons, and thyroid shields more than 70% of the time. One participant remarked that wearing the lead apron was like “wearing a uniform and you did not perform a procedure without it.” The use of lead glasses was very low with a high number of people indicating that they never used it. This finding is consistent with that of interventionalists in a UK study where lead glasses were underutilized compared with other PPE [22]. The use of lead glasses reduces the radiation dose to the eye by 70–98% based on various studies [7,23]. It is, thus, imperative that employers provide appropriately fitting lead glasses for the interventionalists to reduce cataracts [24].

The provision of PPE increases the uptake for using it [25]. In our study, a low number of participants cited a lack of availability of PPE as a reason for not using it. Women were 4.3 times more likely to report that PPE was not available. In a study in the USA, they found that barriers to PPE utilization included that it was time consuming to don, it was burdensome to use, they did not receive training on using it, and availability was an issue [26]. Our qualitative findings similarly indicated that poor compliance for using the PPE was related to the weight of the lead aprons and lead glasses, the cumbersome nature of performing procedures with the lead aprons, and not readily having access to appropriately fitting PPE. This contrasts with the quantitative findings where participants who consistently wore PPE indicated that the fit of the PPE was generally not an issue. It may, however, be for this reason that they were consistent in using the PPE. Those participants who did not consistently wear PPE may well have cited reasons as illustrated in the literature for not using it consistently.

I don't like wearing the lead gowns because they are heavy, and they don't always have the right. (Female, Pediatric cardiologist).

The problem is the size, because we have one pair or two pairs. There's [...] one size for everyone, we not all the same sizes so for some of us it may not fit. (Female, Radiologist).

The lead apron is ok but if you use it and the lead glasses and thyroid shield and lead gloves and skull cap it can be cumbersome. (Cardiologist).

Women have a different body habitus compared with men, and this has to be cogitated in the design and procurement of radiation PPE. PPE currently available on the market for women is ergonomically designed to suit their build, and this should be considered when PPE is purchased. In a study in the USA, it was found that PPE for women existed, but it was not actively marketed to the buyers of PPE, and improving promotion of these products may result in better uptake of the product [27]. This can be assumed to be the case in this study as responses indicated that one of the factors for noncompliance with wearing PPE was a requirement for alternative fitting PPE. Health managers are crucial to facilitate creation of a CRP by ensuring that PPE is readily available. Improving PPE utilization at an individual level has limitations, and it is important that this agenda is driven at a managerial level as well [21]. Participants regarded the role of health managers of paramount importance to facilitate compliance with wearing their PPE.

So, I would imagine it's the hospital's responsibility to provide it (PPE). I mean we're employed by the hospital. The hospital has a

responsibility to all its employees to maintain [their] safety. (Pediatric cardiologist).

It's the hospitals responsibility to provide that [PPE]. It's my responsibility to use it. (Radiologist).

I don't think the CEOs of the hospital take radiation safety seriously and [they] do not listen if there are problems with PPE or equipment. (Cardiologist).

Poor availability of PPE is an important reason for poor compliance of utilization [27]. Our survey data indicated that PPE availability was not ranked highly by participants which contrasted strongly with the qualitative findings where many participants reported a lack of availability as a determining factor for poor utilization. This disjunction suggests that if PPE is available but not being used, there may be other factors that fuel the perception that it is not available. Woman may have this perception because although the PPE might be available, the appropriate sizes and ergonomic fit might not be available.

Ja and it becomes such a hassle to try and get a thyroid shield and to try and get goggles that you just don't. You don't have enough time in a day to try and look for it cause you never goanna find it in any case. So, then you just ignore it and you go with the lead apron only. That's what most of us do. (Radiology registrar).

We don't have the caps. Even the screen that you put in front, that's become difficult for us to use because we feel like it's interfering [with the procedure] and we want to push it out of the way. But we just need to get into the habit that it must be there, and you've got to learn to work around it. That it becomes so engrained that you just do it. Because the lead apron we wear without even thinking. (Radiology registrar).

The appropriate procurement of PPE for women is important because failing to do so nurtures gender disparity in the workplace. The cath. lab is a highly contextualized work space where gender disparities and inequalities may still be present. Deliberately ensuring provision for appropriate PPE for women in the cath. lab aids to create a more equitable workplace. Creating this milieu requires deliberate concerted effort from managerial structures. One participant reflected on making suitable PPE available for women as follows:

It's untrue that there isn't suitable alternatives PPE for women. It is available, but your hospital has to buy this equipment. The PPE is available in your size, that is light weight, from goggles to shields, to the actual lead itself and it's available in different styles. You know if you don't like a single suit you can get your split skirt and top, or whatever. It's available but if nobody [management] thinks that you are that important that you shouldn't get it then you must wear something that's too large and just doesn't protect you. But I think lastly when you know you are the Registrar we also think ag, this will be over in four years [so you don't make a fuss]. (Female, Radiology Registrar).

The universal and consistent use of lead aprons is starkly contrasted with the poor uptake of the lead glasses.

Interventionalists are a highly skilled medical workforce and take a long time to train. It is a costly endeavor that includes human resources and is financially intensive. The demand for more interventionalists has increased as the burden of diseases they can treat has escalated [28]. It is, thus, important that these HCWs are protected in the workplace [29]. The use of radiation equipment and interventional procedures has increased dramatically, and it is important that appropriately skilled radiation workers are available

to operate these machines and perform the complex procedures [30]. The ramifications of not promoting radiation safety may well have dire consequences years later due to increased radiation-induced health effects on patients and radiation HCWs.

This study has important implications for radiation safety policies and practical implementation of PPE control in the radiation workplace, especially in emerging economies. The findings should urge radiation regulatory bodies to evaluate and possibly review policies about PPE utilization. It should motivate departments using radiation to revise their PPE guidelines. It should galvanize radiation protection officers to rethink how to improve compliance of PPE utilization. It should encourage hospital managers to be proactive in ensuring PPE is available and developing a CRP in the cath. lab. Future studies could include other members of the cath. lab to get a holistic understanding of the qualitative and quantitative utilization of PPE. A larger randomized survey sample size would improve the statistical power of the study.

## 7. Conclusion

Availability and proper fitting PPE remain important considerations in the utilization of PPE among radiation HCWs. The responsibility of the individual is important to facilitate this practice, but the role of hospital management is vital to entrench compliance. Developing and promoting a culture that practices good PPE utilization is thus crucial. Creating and nurturing a culture of radiation safety where PPE utilization is a normative and prioritized component is essential to improving compliance. The consistent use of PPE is an essential quality assurance activity to protect radiation HCWs from radiation exposure and promotes patient safety.

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## Authors' contribution

W.R. and A.R. conceptualized the study. AR wrote the first draft of this article. All authors gave input to the article. All authors read and approved the final article.

## Conflict of interest

All authors declare there are no conflicts of interest.

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