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Quality of radiation protection aprons and quality control routines at different diagnostic imaging modalities

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Abstract

Introduction: The purpose of this project was to assess the quality of lead aprons at different departments at two hospitals and to investigate whether there was a connection between routines for controlling lead aprons and the actual condition of the lead aprons.

Methods: Lead aprons were tested in several diagnostic modalities in two hospitals. The lead aprons were inspected visually and by palpation. Furthermore, the lead aprons were scanned with a fluoroscopy unit and the size of the defect was recorded. The radiation dose was measured behind defects exceeding 0,4 cm in length. Radiation protection officers at the two hospitals were contacted for a review of the procedures.

Results: Defects were detected in 19% of the tested aprons. Most findings were discovered in emergency room 1, where 62,5% of the lead aprons had one or more defects. The measured radiation doses behind the defects ranged from 3.996 nGy to 83.370 nGy. No defects were detected on nuclear medicine 1, emergency room 2, CT 2 and intervention 2. Both hospitals' routines were based on the Norwegian Radiation Protection Regulations. Hospital 2 controlled most of the lead aprons one month prior to this project.

Conclusion: A possible connection between the hospitals' routines and the quality of the lead aprons is indicated by the fact that the hospital with the most defective lead aprons also had the least follow-up of the routines.

Introduction

Health professionals who stand beside the patient during the imaging procedure are exposed to scattered radiation caused by the Compton effect which occurs when radiation interact with tissues in the patient. Lead aprons are a key radiation protection tool against scattered radiation (1).

Protective aprons come in different thickness and shapes and they attenuate 90% or more of the incident scattered radiation (1). The composition of protective aprons worn by health personnel varies. They can be composed of lead alone, composite materials together with lead or they can be totally lead-free and their lead equivalence varies between 0,25mm and 0,50mm (2). The aprons' protection capability depends on its lead equivalence and the energy of the X-rays because the probability of Compton effect occurrence and thus the amount of scattered radiation increases with the energy of the primary radiation. Body aprons should be available with a protective equivalent of not less than 0.25 mm lead for X-rays up to 100 kV and not less than 0.35 mm lead for X-rays over 100 kV (3, 4). The weight of the apron is proportional with its lead equivalent, and back injuries due to weight were reported in personnel who wear aprons over long periods of time (5), and a solution might be the use of two-piece aprons that distribute weight or newer lead-free aprons which are lighter (3). Lead-free aprons might weigh up to 25% less (6). However, the measured lead equivalent of lead-free aprons might be lower than expected according to some studies (2, 7-9), fact disproved by other studies (6, 10).

Folding or dropping the aprons on the floor, contact with sharp objects or otherwise misusing, might cause sharp bends. The deterioration of the lead-impregnated vinyl is manifested as cracks, holes and tears in the shielding (2, 11). Such defects might result in decreasing shielding capability. All personnel should therefore be aware of the correct use and maintenance of protective aprons, especially storing them appropriately when not in use. Periodical inspections of lead aprons are required by both Norwegian and international guidelines and the inspection is to be performed by palpation, visual assessment and fluoroscopy (3, 4). Infrared thermal imaging was also proposed as a scanning method (12). However, there are no regulatory standards establishing rejection criteria for protective aprons and no consensus in the scientific literature in the field. Some use criteria based on the length of the defect, the area of the defect or the radiation increase measured under the defect (11, 13). As a consequence, individual medical facilities establish they own rejection criteria, if they have any clear criteria at all (11). Studies analyzing the quality of protective aprons show different results. A Turkish study found that the quality was unsatisfactory in 68.2% of their aprons when using a defect size over 2cm as rejection criterium (14). Similar results were found in Nigeria with 70% defective aprons (15). Results from Ireland show defects in 5 of the 43 scanned aprons but none of them was assessed as unsatisfactory when using a 15mm^2 defect area as a rejection criteria (2). Not surprisingly, the mentioned studies also showed suboptimal quality assurance routines.

The aim of the project was to assess the quality of protective aprons at different departments in two Norwegian hospitals and analyze eventual connections between the routines for quality control of protective aprons and the integrity of the aprons.

Methods

Hospital and apron selection

In order to examine a wide range of protective aprons, the investigation was carried out at two different hospitals of different sizes, where Hospital 1 was larger than Hospital 2. At these

hospitals, several different departments and X-ray laboratories were selected (laboratory is further referred to as lab). In order to have variation in the selection of examined aprons the investigation covered both labs, with different apron use frequency and different professional groups using the aprons (radiographers, radiologists and other professions outside radiology departments). The included labs were fluoroscopy, angio-intervention, CT, nuclear medicine, emergency, and outpatient surgical services.

The project took place during the hospitals' opening hours and it was therefore necessary to have aprons available to the employees when needed so it was decided to check only half of the aprons on every lab.

Apron assessment

The inspection of the aprons was performed by palpation and visual assessment followed by scanning of all aprons (even those without any palpable defects) using a fluoroscopic unit and radiation dose measurements behind defects were performed using a Mult-O-Meter (Unfors Instruments AB, Billdal, Sweden). Aprons with visible residue of contrast agents and blood were washed with warm water and disinfectant before scanning. The aprons were spread flat (with no folds or overlap) on the examination table and scanned with a focus-object distance of 110 cm, 73-77kVp and 0.3mA. All defects found were measured and marked with lead markers.

Dose measurements were performed behind all identified defects except for those located at the edges of the aprons. Scattered radiation was generated by irradiating an anthropomorphic pelvis phantom placed on the examination table which was set at the usual height used when examining patients. A didactic model skeleton wearing an apron (to mimic a radiologist at work) was placed 40 cm from the table and the phantom was irradiated

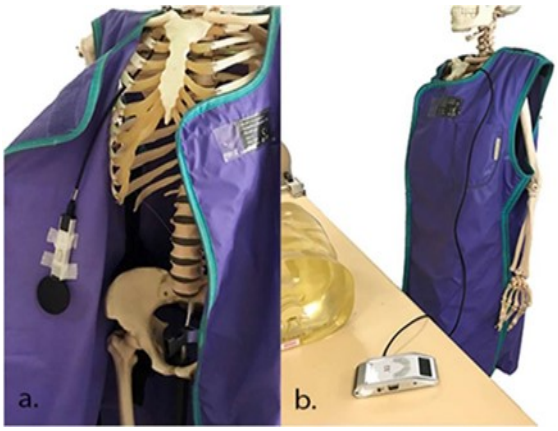

Figure 1. The measuring probe taped behind the defect (a). Lead apron hung over the skeleton at approximately working distance from the phantom.

Figure 2. The apron was divided into four quadrants.

with 90-97kVp, 0,5-0,6mA, 10 seconds, 2 pulse/s. Scatter radiation was measured using a probe placed behind the defect (figure 1) . Reference scatter dose measurements were performed in four quadrants (figure 2) behind two aprons (0,25 and 0,35 lead equivalent). In addition, the routines for quality control of protective aprons at the different departments/lab were investigated.

Data analysis

Descriptive statistical analysis was performed using SPSS. The exposure times and pulse rates used in angiographic interventional procedures are 4-34 min and 7,5 pulse/s (16, 17) which is different from the parameters used in this experiment (for practical reasons) and that required calculation of an estimated dose. The measured doses were used to calculate estimated doses for 7,5 pulse/s and exposure times of 2, 5 and 10 minutes by using the following equation:

$$\text{Estimated dose} = \frac{measured\ dose * new\ pulse\ rate * new\ exposure\ time}{original\ pulse\ rate * original\ exposure\ time}$$

Ethical considerations

Ethical approval was not required. However, the hospitals were anonymized.

Results

Apron assessment

A total of 63 aprons were fluoroscopically examined and one or more defects were found in 19% of them (table 1).

Table 1. Distribution of the defect aprons among the labs.

	Lab	Number of defect aprons	Percent
Hospital 1	Angio-intervention	4	25
	Nuclear medicine	0	0
	Emergency	5	62,5
	Fluoroscopy	1	20
Hospital 2	CT	0	0
	Outpatient surgical services	1	25
	Angio-intervention	1	8,33
	Emergency	0	0
Total		12	19

The highest percent aprons with defects (62,5) was found in the emergency room at Hospital 1. There were not found any defects in the aprons used at the emergency room of the other

hospital. However, one of the aprons presented some irregularities in the material which might be a sign that the apron has been folded (figure 3). Half of the defects were located at the upper quadrants (table 2).

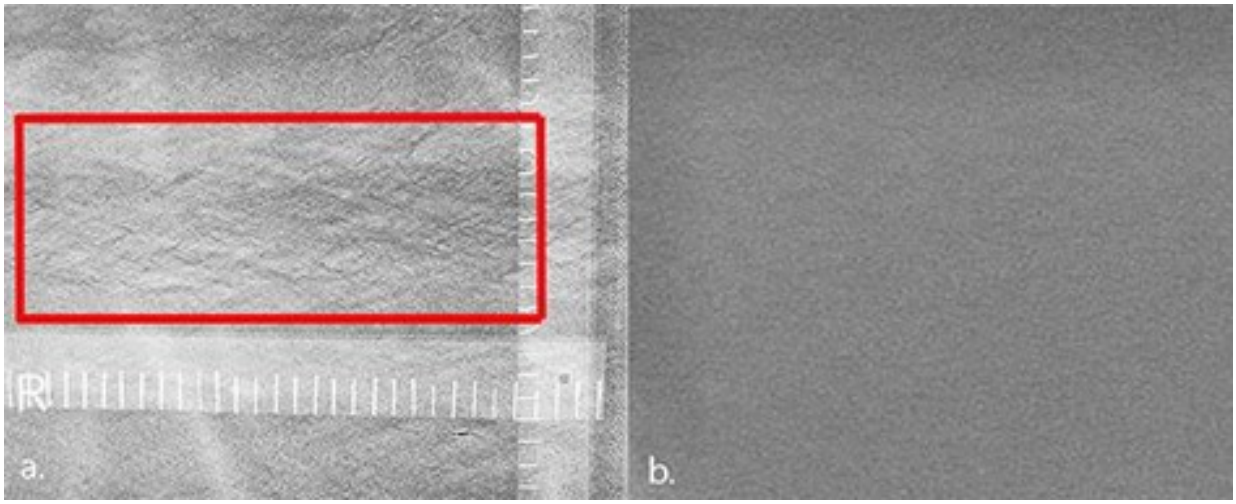

Figure 3. Defective apron (a) and impact apron (b)

Table 2. Defect location

Defect location	Nr	Percent
Right upper quadrant	3	25
Left upper quadrant	3	25
Right lower quadrant	3	25
Left lower quadrant	1	8,3
In the middle	1	8,3
At the edge	1	8,3
	12	100

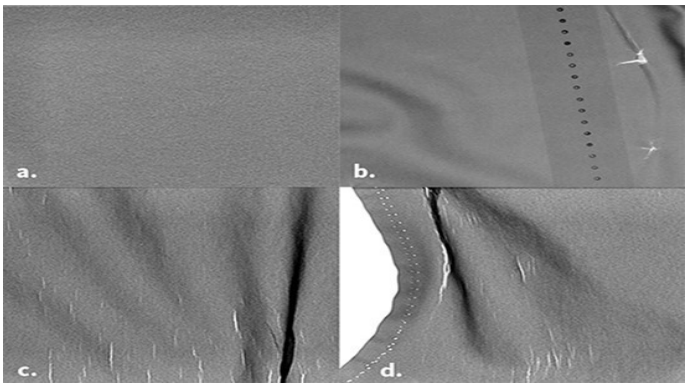

Figure 4. Intact apron (a) Rifts (b) Small cracks spread over a large area (c) Apron with a 8 cm crack (d)

The size of the defects was between 1 and 8cm with only two aprons having cracks or tears larger than 2cm. Some aprons had a worn-out appearance with rifts at the edges around the neck and armpits. All three possible lead equivalent values were registered (table 3)

Table 3. Distribution of different types of aprons

	Lab	Lead equivalent		
		0.25	0.35	0.5
Hospital 1	Angio-intervention	11	3	2
	Nuclear medicine	5	2	0
	Emergency	0	8	0
	Fluoroscopy	1	4	0
Hospital 2	CT	0	3	0
	Outpatient surgery	0	4	0
	Angio-intervention	8	3	0
	Emergency	6	2	0
Total		31	29	2

Table 4. Reference dose measurements in two aprons

Quadrant	Dose (nGy)	
	0.25 lead eq.	0,35 lead eq.
Upper right	14.47	12.17
Upper left	12.89	16.02
Lower right	37	8.55
Lower left	12.12	16.43

Radiation doses

The reference measurements performed in two intact aprons showed radiation dose differences between the four quadrants (table 4).

Measured background radiation was 0,032nGy in 10 seconds.

There was registered great variation in radiation dose measured behind the defects (figure 5 and table 5). The differences between doses measured under the defects and under intact apron is shown in figure 6 and 7)

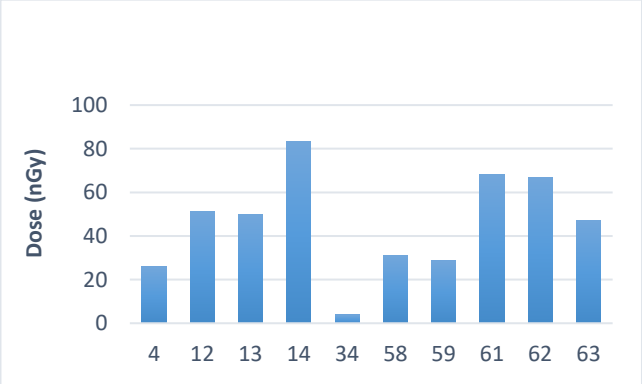

Figure 5. Measured dose behind defects in different aprons

Table 5. Radiation doses

Exposure parameters	Radiation dose (nGy)	
	Min.	Max.
10 s, 2 pulse/s	3,996	83,370
2 min, 7.5 pulse/s	359,64	7503,3
5 min, 7.5 pulse/s	899,1	18757,5
10 min, 7.5 pulse/s	1798,2	37515

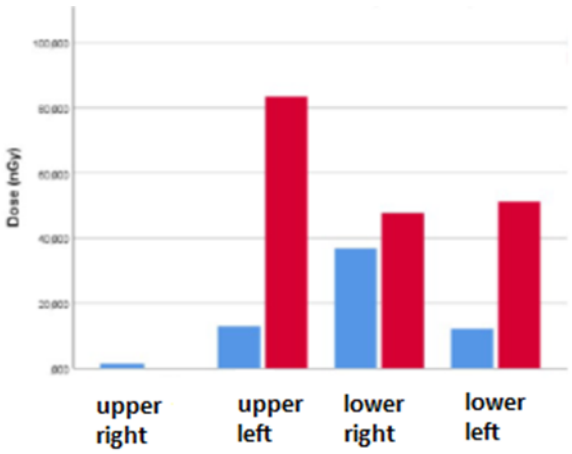

Figure 6. Highest measured dose behind the defects in the four quadrants of a 0,25 mm lead equivalent apron compared with the reference dose behind an intact apron

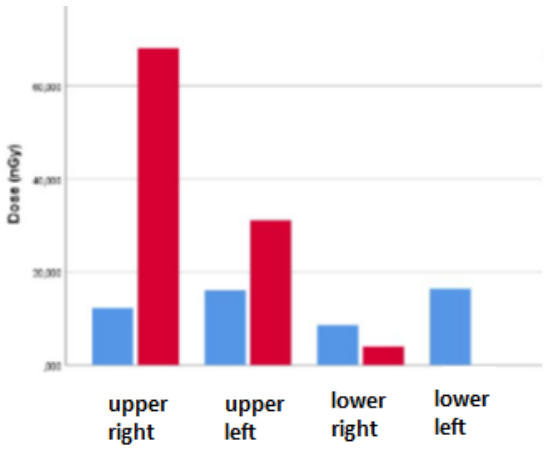

Figure 7. Highest measured dose behind the defects in the four quadrants of a 0,35 mm lead equivalent apron compared with the reference dose behind an intact apron

The average dose behind the defects was 45.42nGy at 10 seconds exposure with 2 pulse/s, which gives an estimate dose of 8,628mGy at only 10 minutes daily exposure with 7,5 pulse/s five days a week in a year. Radiation dose behind tears and cracks located right at the edges of the lead aprons was not possible to measure.

Routines for control and maintenance

Both Hospital 1 and Hospital 2 had written procedures for quality control and maintenance of personal protective equipment. Both procedures were based on the national radiation protection regulations. Both procedures included requirement of annual inspection of all protective equipment.

This should initially be done visually and by palpation. In case of suspicion of injury, the equipment should be fluoroscopically scanned, and a separate description of the scanning procedure was included. The procedure at Hospital 1 also contained information on handling of the lead aprons to avoid damaging the material, and a separate section with information on washing the aprons. The control was to be performed by the lab's senior radiographer and reported to the hospital's radiation protection officer. At Hospital 2 the procedure additionally included a requirement of control of all new acquired equipment to ensure that the aprons have the stated lead equivalent and to detect eventual damage that could have occurred during transportation. This was the responsibility of the local radiation protection officer who should also inform the department about eventual equipment pieces that do not meet the quality criteria.

The findings show variation in quality control frequency and at some of the labs nobody had information about the date of the last control (table 6).

Table 6. Quality control frequency

	Lab	Defect aprons (%)	Time since last control
Hospital 1	Angio-intervention	25	unknown
	Nuclear medicine	0	18 months
	Emergency	62,5	unknown
	Fluoroscopy	20	unknown
Hospital 2	CT	0	1 month
	Outpatient surcical services	25	15 months
	Angio-intervention	8,3	1 month
	Emergency	0	2 month

There were found rests of blood or/and contrast media on some of the aprons at both hospitals. The routines at Hospital 1 required washing of all aprons once a week or when needed. Angio-intervention and emergency labs had an agreement with the janitors who came and washed the aprons at the end of the week. The routines at Hospital 2 implied washing of the aprons only when needed.

Discussion

Of the total of 12 defective aprons that were detected in this project, 10 were found at Hospital 1, and most of them belonged to the emergency lab where 62.5% of the examined aprons had detectable defects. This may be related to the fact that several professions worked together at a high pace in this department. It is also likely that not all professions using those aprons have been instructed in how to handle and store them. However, none of the aprons from the emergency lab at Hospital 2 had any defects. An explanation might be

that they were newer and quite recently checked and eventual defective aprons might have already been replaced. A high percent defective aprons was also found at angio-intervention lab at Hospital 1, where 4 of 16 lead aprons were defective despite the fact that the employees had personal aprons that were in use almost every day and they were assumed to have knowledge about handling and maintenance, and it was expected that they hang them up properly after use. It looks like the hospital which controlled the aprons more recently had a lower percent defective aprons at all labs.

The total percent of defective aprons in this study (19%) was a little higher than in a similar study performed in Ireland which detected 12% (2) and much lower than the ones found in other studies - 68% in Turkey (14) and 70% in Nigeria (15). One possible explanation might be higher apron replacing rate in Europe due to quite high prices- lead apron prices range from $400 to over $700 (11). The high percent defective aprons in the two mentioned studies might also be a consequence of improper use and storage of the aprons which was observed in these studies (14, 15).

Most of the defects were detected on the aprons' right side. An equal number of defects were represented in the upper right and upper left quadrants, but in the lower quadrants most of the defects were on the right side. A probable explanation is that most users were right-handed and thus would stand with the right side against the X-ray table and this can contribute to wear and damage of the material in the lead apron.

The highest radiation dose was measured behind a 1 cm long defect located in the upper left quadrant of a lead apron with a lead equivalent of 0.25 mm. The radiation dose was 83.37 nGy, which is more than six times higher than the dose behind a corresponding area on the reference lead apron (12.89 nGy) and exceeds the recommended limit of 5% increase in radiation (18) and this might have unforseen consequences if the user's breast tissue is exposed to the increased radiation dose. However, employees who are aware of such defects would avoid choosing that particular apron (13).

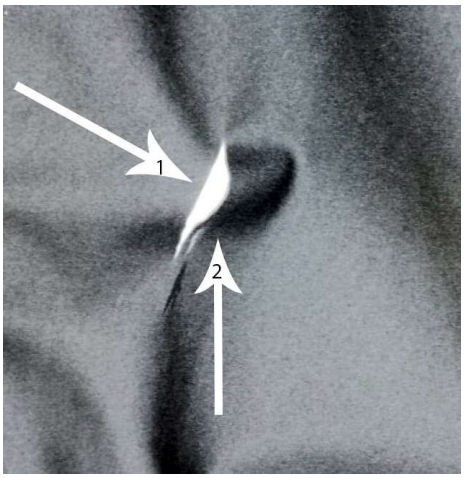

Figure 7. Photons hitting the crack with an angle (arrow 1) and photons hitting the crack from the front.

The second highest dose recorded was 68.0 nGy measured behind a crack of 8 cm in a lead apron with a lead equivalence of 0.35 mm. A possible explanation for the lower dose behind this crack which is 7 cm longer than the defect with the highest measured dose may be the angle at which the photons hit the defect. A long and narrow crack can let in photons that hit the lead apron at an angle, while it will stop most frontal hits. In this way, fewer photons hitting the defect from the front will be able to pass through the crack (figure 7).

The Norwegian Radiation Protection Authority (4) recommends 0.25 mm lead equivalent when working on X-ray and fluoroscopy labs and 0.35 mm lead equivalent when working close to the patient during angiography / interventional procedures and CT biopsies. Lead aprons with 0.5 mm lead equivalent will provide much better protection, but it puts a greater strain on the user (5). Of the 16 lead aprons tested at intervention Lab 1 at Hospital 1, only three had a lead equivalent of the recommended 0.35 mm. One of them, a set of vests and skirts, had a lead equivalent of 0.5 mm, while the remaining 12 had a lead equivalent of 0.25 mm. One reason for this is that lead aprons with a lead equivalent of 0.25 mm that overlap on the front can be used as an alternative to lead aprons with a lead equivalent of 0.35 mm. However, these will only provide extra protection at the front of the lead apron, while the back and the lateral sides will be protected with a lead equivalent of 0.25 mm while is recommended to use at least 0.35 mm lead equivalent when using 100 kV (4). For example one of the frequently used procedures, biliary drainage uses an average kV of 92 with a standard deviation of 11.8 (17) However, since the tube voltage (kV) will change depending on the size of the patient and since overweight rate is increasing, one can therefore imagine that kV will often exceed 100. Based on this, it would be wise to replace the 0.25 mm lead aprons with 0.35 mm lead equivalent to protect the user from the increased scattered radiation in high kV procedures.

It may seem that a connection can be made between routines for checking the aprons and the proportion of defects at both Hospital 1 and Hospital 2. Neither the responsible radiographer at intervention 1, the responsible radiographer at fluoroscopy 1 nor the coordinator at emergency department 1 had information about when the last inspection of the lead aprons took place. At the same time, these posts had the highest proportion of defective lead aprons (20%, 25% defective 62.5% defective lead aprons respectively). The responsible radiographer at nuclear medicine 1 estimated that the lead aprons had not been tested in 1-2 years. Although these lead aprons had not been inspected for some time, no damage to the lead aprons was detected. One of the reasons may be that the patient examinations on nuclear medicine are performed at a slower pace and in a more controlled environment than the examinations that are performed, for example, in the emergency department. In nuclear medicine, the examinations are also performed by radiographers and bioengineers who have higher radiation protection competence than the other professional groups. When comparing the two hospitals, the larger one had a higher percent defective aprons, one explanation for that might be the higher number of examined patients, higher tempo, and higher number of employees using the aprons. The variable compliance with the routines for quality control of protection equipment found in this study is consistent with results from similar studies (2, 14, 15, 17).

The study has some limitations. Only half of the aprons at each lab were tested and that might have influenced the findings. Further, the results may be affected by how the lead aprons were selected. The lead aprons that were visibly worn and looked older were chosen over those that had less visible wear and that might have led to an overestimation of the frequency

of defect detection. In addition, it could have been appropriate to investigate also the connection between defects and material type in the lead aprons.

Conclusion

The aim of the project was to assess the quality of protective aprons at different departments in two Norwegian hospitals and analyze eventual connections between the routines for quality control of protective aprons and the integrity of the aprons. The findings showed variation in quality of lead aprons both between hospitals, between different departments of the same hospitals along with variation in quality control frequency and compliance with relevant guidelines. However only two of the analyzed aprons had defects that required replacement of the apron. A possible connection between the hospitals' routines and the quality of the lead aprons is indicated by the fact that the hospital with the most defective lead aprons also had the least follow-op of the routines.

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