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GENERAL RADIOLOGY

ORIGINAL ARTICLE

How protective are the lead aprons we use against ionizing radiation?

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PURPOSE
To evaluate, in terms of their protective features, the lead aprons used in areas working with ionizing radiation at a hospital by analyzing qualitative and quantitative aspects using a variety of methods.

MATERIALS AND METHODS
Eighty-five protective lead aprons used in our hospital's clinics to work with ionizing radiation were analyzed in the radiology unit. Each apron was identified by registering the unit from which it had been obtained and by how long it had been used, its storage condition, and its lead thickness. X-ray films of the aprons, controlled according to their appearances, durability and cleanliness, were taken to evaluate their internal structure; their permeability was measured with electronic dosimeters in terms of their absorbent features. All of these data were compared with the results acquired from brand-new, Turkish Standards Institution approved aprons having different lead thicknesses.

RESULTS
Regarding internal structure homogeneity, only 13 (15.3%) of 85 aprons were found to be at normal levels and usable. A total of 14 (16.5%) of the remaining 72 aprons' radiation absorptions were at normal levels, but folds were observed in their protective lead layers. The remaining 58 aprons (68.2%) were found to be defective. All of the aprons were considered to be defective in terms of their radiation permeability.

CONCLUSION
All of the aprons were found insufficient for protection and were more radioparent than the defined limits; it was concluded that they must be replaced by new ones.

Key words: • radiation protection • film dosimetry • radiation injuries

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It is widely known that radiation exposure may cause deterministic and stochastic effects (1). However, it is not always possible to estimate how these stochastic effects will affect an organism (2). It is necessary for medical personnel to take care of their own health first, in order to offer proper health services to their patients. In addition, medical institutions are responsible for providing a safe environment, both for the personnel and the patients, in order to prevent problems. With this purpose, in areas where personnel work with radiation, the regulation and guidelines for radiation safety have been enacted; also, every institution has been asked to take precautions for radiation safety within its own structures. Institutions have been making efforts to maintain job safety and to protect the health of their employees working in radiation areas by establishing Radiation Safety Committees within their structures (3). Thus, the Radiation Safety Committee at our hospital performed a study and analyzed the protective aprons composed of lead (Pb) and lead-equivalent material, used for protecting the personnel working in radiation-related areas and the patients against radiation. Our study was undertaken with close cooperation between the medical personnel and the medical institution; although there have been some similar studies elsewhere in the world, to the best of our knowledge, this is the first such study in Turkey.

Materials and methods

Eighty-five protective lead aprons used in areas within our hospital and the district polyclinics where there is exposure to radiation were collected properly and were brought to the radiology clinic of our hospital to evaluate how protective they were. All of the aprons were identified according to the units from which they had been obtained, the number of years that they had been used, the approximate number of personnel by whom they had been worn, their model, the material of which they were made, and the thickness of the lead inside of the apron. The aprons were registered with numbers placed on their interior surface.

After that step, a physical examination was performed. The durability, wear and cleanliness of the exterior surfaces of the aprons were evaluated; also, the following qualities were analyzed: protection conditions (if the apron had been racked properly or not), periodic cleaning methods, and whether the material used for cleaning was convenient (Fig. 1).

A quantitative assessment was performed after these evaluations. Films of the aprons were taken by a licensed and calibrated X-ray unit. The parameters of 100 kV, 320 mA, and 63 ms were keyed into the console as the exposure dose. First, each apron's X-ray film was taken with phosphor plate storage cassettes with a size of 35×35 cm to evaluate fractures, cracks and holes within the internal structure. During this procedure, the

Figure 1. a, b. A protective apron left on the X-ray table without any care after the film has been taken **(a)**, and the protective apron and other protective garments hung according to the ideal storage conditions **(b).**

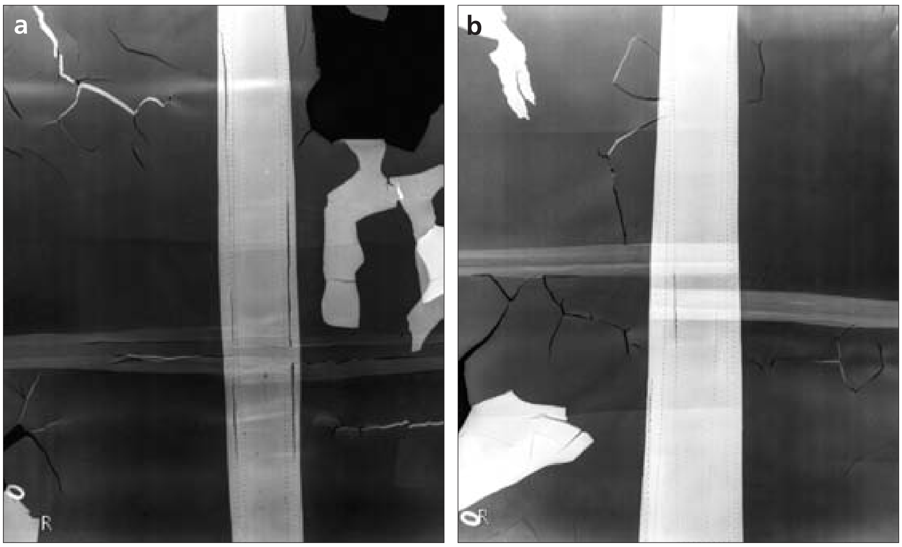

Figure 2. a, b. The rips, cracks, and defects on the aprons are seen on the X-ray films, indicating that the aprons should be discarded.

middle part of the apron was targeted. The X-rays were collimated in a way to expose an area on the lead apron that was 35×35 cm wide. The distance between the tube focus and the lead apron was adjusted to 110 cm. A ruler using a millimeter and centimeter scale, which enabled us to make the closest measurement as possible to the actual size, was placed near the cassette. The images on the plates, exposed in the back side of the apron, were transferred to films. The films were evaluated in terms of scratches, rips, cracks and defects that the lead aprons may have contained in their structures. In terms of the standards created by modifying the methods used in Canada (4), holes greater than 2 mm in diameter and cracks longer than 4 mm were the destruction (i.e., being defective) criteria used by our Quality Unit (Fig. 2).

Next, while the aprons were exposed using the same parameters as those described above, they were subjected to dosimetric testing (Unfors brand) in terms of the ratio of ray absorption. The absorption features were evaluated with two different tests by scattering X-rays on the apron directly and indirectly. With the direct scatterings, the protective aprons were exposed to the X-rays directly, whereas with the indirect scattering method, the aprons were exposed to indirect (secondary) X-rays from a certain distance by being placed vertically with regards to the X-ray direction.

In the direct method, the same exposures were performed with the same technical parameters as defined above by targeting the middle sections of the aprons' front sides. During irradiation, the intensity of the X-rays was measured with digital dose-measuring devices (dosimeters) on the front and back sides of the aprons. The doses measured on the front and back sides of the aprons were compared, and the aprons' ionizing radiation (X-ray) absorptions were determined.

In the indirect measurements, the same parameters were used. The X-rays were reflected on the center of a water phantom consisting of two circles, one on the top of the other, the total height of which was 18 cm, and the radii of which were 18.5 cm and 25 cm. The apron was vertically fastened on the desk's surface, 50 cm away from the water phantom's center. During exposure, the intensities of the rays on the front and back sides of the apron were measured by the detectors and were compared; finally, the X-ray absorption ratio of the apron was determined.

To use as a base for the apron measurements, the radiation permeability of 10 protective lead aprons having different lead thicknesses, the quality and durability of which had been approved by TSI (Turkish Standards Institution) documents and which had never been used before, was measured and evaluated, and these aprons formed the control group. The average values acquired from the aprons in the control group were accepted as the standard by taking a 5% margin into account.

The aprons analyzed were measured separately. The results were compared between two groups. The data were analyzed using Statistical Package for the Social Sciences (SSPS) software (SPSS for Windows, version 16.0, SPSS Inc., Chicago, Illinois, USA). The results with *P* values < 0.05 were accepted as significant. The aprons' internal structure features and the ratio of ray permeability were separately considered as destruction criteria.

Results

In all of the aprons analyzed, lead was the material used for protection from radiation. The Urology Operating Room contributed the highest number (n=17) of protective aprons. The Surgery Operating Room had the highest number of apron users (n=125). In our hospital, double-sided lead aprons, frontal protection lead aprons and skirt-vest lead aprons are used, and the frontal protection apron is the one most used among them. The period during which these aprons had been used varied from 1 to 6 years. In terms of equivalent lead thickness, most of the aprons' lead thickness was 0.5 mm. A general evaluation showing the number of the aprons that had been destroyed is presented in Table 1 based on the following factors: the unit where these protective aprons had been used, the number of aprons, the number of users, the model of the aprons, the lead equivalent thickness, how long the aprons had been used, the defects in the lead layer and the ratio of radiation permeability.

The first step was to evaluate the cleanliness of the aprons, and it was observed that 23 of the aprons (27.1%) were clean, 43 aprons (50.6%) were slightly dirty, and 19 aprons (22.3%) were quite dirty. The cleanest protective aprons in terms of storage conditions and hygiene were the ones used in the Cardiovascular Surgical Unit of our hospital. The relationship between the aprons' cleanliness and the destruction criteria is given in Table 2; no significant relationship was observed between them. Similarly, no significant relationship was found between the clinics where the aprons had been used and the destruction criteria (Table 1). Likewise, no significant relationship was found between the apron cleaning methods and the destruction criteria (Table 3).

Regarding the overall condition of the aprons, it was determined that 45 aprons (52.9%) were in good condition, 26 aprons (30.6%) were slightly worn out, and 14 aprons (16.5%) were extremely worn out. Aprons that had the fabric part ripped or unstitched or had an old belt buckle were classified as slightly worn-out aprons; aprons that had the fabric part greatly torn

Table 1. The classification of the aprons analysed according to the different criteria

			Apron model			The age of the apron (year)						Number of aprons that have to be annihilated		Pb equivalent thickness (mm)		
The unit where the aprons have been used	Number of aprons	Number of users	D	F	S/V	1	2	3	4	5	6	According to radiation absorption	According to internal structure	0.25	0.35	0.50
Newborn Unit	1	15		1		>1						1	1			1
Urology Operating Room	17	124		17		>1						17	16			17
Surgery Operating Room	4	125		4		>1						4	3			4
Neurosurgery Operating Room	5	118		5		>1						5	4			5
CVC Unit	12	12		12		>1						12	6			12
Polyclinic - Radiography	5	12	2	3		>1						5	3			5
Urgent Radiography	2	15		2		>1						2	2			2
Fluoroscopy	2	21	2			>1						2	2			2
Gastroenterology ERCP Unit	5	75	2	3		>1						5	5			5
Basın Sitesi District Polyclinic	1	4		1		>1						1	1			1
Anesthesia Intensive Care	1	15		1			>2					1	1			1
CVS Intensive Care	1	15		1		1						1	1			1
Radiation Oncology	2	21		2		>1						2	2			2
Alsancak District Polyclinic	2	4		2							>6	2	2			2
Second Orthopedics Unit	1	25		1			>2					1	1			1
Urology ESWL Unit	1	2		1			>2					1	1			1
Narlıdere District Polyclinic	1	2		1			>2					1	1			1
Nuclear Medicine	2	17	2			>1						2	0			2
Cardiology Angiography Unit	20	47	1	4	3 pairs	1			4	5		20	7	4	3	15

CVS, cardiovascular surgery; ERCP, endoscopic retrograde cholangio-pancreatography; ESWL, extracorporeal shock wave lithotripsy; D, double sided; F, frontal protection; S/V, skirt/vest; Pb, lead.

and that had defects in their shape due to sags in the protective lead layer, the lead protective layer sticking out from the torn fabric, wide tears and deformations around the armpits, and changes in the color of the fabric part were classified as extremely worn-out aprons. According to this classification, although the radiation permeability of all of the aprons was found to be high, the highest radiation permeability was observed with the extremely worn-out aprons, followed by the apron group in good condition; the slightly worn-out apron group was found to be less permeable than the aprons in good condition and the extremely worn-out aprons.

Fifty-eight aprons in total had been destroyed due to cracks in 26 aprons; holes and tears in 14 aprons; and cracks, holes, and tears in 18 aprons. It was found that all of these aprons' radiation permeability was higher than normal levels. As it was observed that the radiation permeability of the aprons, the internal structure of which was at normal limits, was found in higher than normal levels, there was no significant relationship found between the internal structural features of the protective lead aprons and their radiation permeability.

There were no significant relationships among the time for which the aprons had been used, their total number of users and their radiation permeability (Table 1).

There was a significant relationship between the apron models and destruction criteria (Table 4). According to this relationship, the frontal protection lead apron was the model that had been destroyed most often.

In the analysis performed with the parameters provided in the Materials and Methods section, the exposure dose was determined as 996.1 µGy (micrograys) on average. For the 0.25 mm lead equivalent aprons determined as the control group, this exposure dose was 51.59 µGy on average (95% absorbance), whereas the 0.5 mm lead equivalent aprons demonstrated 9.891 µGy ray permeability on average (99% absorbance). Based on these measurements, a 5% dose range was accepted as a tolerable margin.

In the indirect measurements, the scattered radiation value, measured from a distance of 50 cm, was found to be 2.1 R/h (Roentgens/hour), provided that all of the parameters maentioned were kept the same; the indirect radiation value measured for the 0.25 mm lead equivalent apron was measured as 1.85 µGy, and the indirect radiation value for the 0.50 mm lead equivalent apron was measured as 1 µGy.

There were some sags and folds on the lead protective layers of the aprons. However, between the aprons that had been folded and the ones that had not been folded, no significant differences were found in terms of radiation permeability. While the protected dose was measured as 60.26±22.96 µGy for the 0.5 mm lead equivalent aprons that were not folded, this dose was measured as 50.36±22.96 µGy for the aprons that were folded. While the protected dose was measured as 50.36±22.96 µGy for the 0.25 mm lead equivalent aprons that were not folded, this dose was measured as 46.0±19.05 µGy for the aprons that were folded.

According to the internal structural features seen on the X-ray films, between the aprons that had been destroyed and the ones that had not been destroyed, there was no significant difference in terms of radiation permeability.

All of the 85 aprons evaluated had been destroyed based on their radiation absorption. Only 13 of these aprons (15.3%) were found to be usable at normal levels in terms of their internal structural homogeneity. Although the radiation absorption of 14 (16.5%) of the remaining 72 aprons were measured at normal limits, there had been some folding of their lead layers. The remaining 58 aprons (68.2%) had been destroyed due to their internal structural features.

Table 2. The relationship between the aprons' cleanliness and evidence of their destruction

	Aprons that had been destroyed		
Cleanliness of the apron	Not available (n=27)	Available (n=58)	*P*
Clean	10 (43.5%)	13 (56.5%)	0.330
Slightly dirty	11 (25.6%)	32 (74.4%)	
Quite dirty	6 (31.6%)	13 (68.4%)	

Table 3. The relation between the aprons' cleaning methods and evidence of their destruction

	Aprons that had been destroyed		
Cleaning method	Not available (n=27)	Available (n=58)	*P*
Not cleaned	2 (15.4%)	11 (84.6%)	0.270
With wet nap	-	1 (100.0%)	
With chlor tablet	19 (32.2%)	40 (67.8%)	
With other disinfectants	6 (50.0%)	6 (50.0%)	

Table 4. Availability of destruction criteria according to the apron models

	Apron model				
Destruction criteria	Double sided n (%)	Frontal protection n (%)	Skirt n (%)	Vest n (%)	*P*
Not present	8 (29.6)	14 (51.9)	2 (7.4)	3 (11.1)	0.015
Present	9 (15.5)	46 (79.3)	3 (5.2)	-	

Discussion

The aprons used for protecting the personnel working with ionizing radiation against scattered radiation are usually produced by embedding lead in rubber fabric (mix of lead-rubber or lead-vinyl), and they are defined as having a 0.25 mm or 0.50 mm lead equivalent thickness (5, 6). In terms of cost, these aprons have considerable value and are of great importance, under proper use and storage conditions, for the safety of the personnel against radiation (4). Due to their weight and size, we observe that these aprons are not preserved in good condition most of the time and are folded and left without any care. Also, they are not cleaned with proper solutions; therefore, they lose their protective features before the expected time. As far as we know, this study was the first at our quality-certified hospital and in Turkey to have a control standard that is based on both qualitative evaluations and quantitative measurements for protective lead aprons.

Whether the aprons are made of lead or non-lead material, these types of aprons should be monitored in terms of safety and protection, and periodic control is also required. Thus, both the internal structure and ionizing radiation absorption ratios of the aprons should be tested regularly, starting from the time of purchase, at least once every year (7).

Based on the results that we acquired from the lead protective aprons, the quality and standards of which were documented by TSI, the radiation absorption proportions were determined as 95% (996.1/51.59 µGy) for 0.25 mm lead equivalent thickness and 99% (996.1/9.891 µGy) for 0.50 mm lead equivalent thickness. When a 5% tolerance ratio was added to these reference values, we found 10.39 µGy for the aprons with 0.50 mm lead equivalent thickness and 54.17 µGy for the aprons with 0.25 mm lead equivalent thickness. Figures greater than these values were considered as destruction criteria. It is expected that 0.5 mm lead aprons will absorb more than 90% of the dose at 150 kVp irradiation. The same apron should absorb more than 99% of the dose at 70 kVp (6). In a study conducted according to the 100 kVp voltage criteria we used, the average permeability was determined as 11.4% for aprons with 0.25 mm lead equivalent, 7.1% for aprons with 0.35 mm lead equivalent, and 3.9% for aprons with 0.5 mm lead equivalent (6). The permeability ratio was found to be greater in aprons made of non-lead material with measurements of 4%–5% (8, 9).

Although there was no significant relationship found between the aprons' appearances and their radiation permeability, it was seen that sometimes misleading results might be obtained. To be clearer, the permeability of the extremely worn-out aprons was the highest, but regarding the permeability ranking, the aprons that were slightly worn-out were less permeable than the ones in good condition. It is very thought provoking that 54.5% of the aprons in good condition had actually been destroyed. Therefore, an evaluation based only on appearance is not reliable in terms of the apron's protection. As far as we know, in the international or national area, the relationship between the appearance of an apron and its radiation permeability was not evaluated before.

When the two aprons with 0.50 mm lead equivalent thickness, which were brand new, very clean and in good condition in terms of appearance were analyzed with the radiographic method, it was seen on their internal structure that there were holes and cracks that were so large and long that the aprons had actually been destroyed; we found that their radiation permeability was 12.5 times greater than normal (129.8 µGy). There were no significant relationships among the total number of users, the period during which the aprons were used, and the aprons' radiation permeability.

Considering the use of radiation protection aprons in clinics, we have seen that personnel are not aware of the importance of preservation and storage conditions, and for this reason, they do not heed the rules for using, preserving and cleaning aprons. Even in the radiology clinic of our hospital, it has been observed that the personnel do not pay due attention to the conditions of preservation, periodical cleaning, use and storage. The Cardiovascular Surgery Clinic has been the one place where the rules have been taken into account regarding the conditions of cleaning, storing and using the aprons.

We found that there were three types of protective aprons at our hospital. There were no significant differences among the aprons in terms of radiation permeability. However, it was seen that the frontal protection aprons had been destroyed most often when the X-ray films were used to evaluate the internal structure of the aprons. The model that required this destruction the least often was the vest part of the skirt/vest model. In addition, it was seen that folding, as determined by the X-ray films, might cause a risk of cracks, but folding did not constitute risks in terms of radiation permeability.

Our evaluations revealed that the internal structural features and the measurements performed by means of detectors should be evaluated separately as destruction criteria. In other words, the aprons need to be evaluated using both X-ray films showing the cracks, tears, etc., and the results of radiation measurements. The radiation absorption of aprons having a normal internal structure has been observed as less than normal; internal structural defects, cracks or tear might have been seen on the aprons, the X-ray absorption ratio of which was found to be within normal limits. As a consequence, the qualitative and quantitative results should be evaluated separately. In other words, either a crack or a hole greater than a certain length or with a permeability greater than 5% is sufficient for the apron to be considered defective.

These results demonstrate that the features of ray absorption and protection are not dependent on how new the aprons are or on their appearance but on the fractures, holes, tears, and cracks, and on the ray absorption edges measured numerically. We believe that the most solid evaluation in terms of protection is the radiation absorption measurement.

In studies performed on the absorption ratios of protective aprons, there has been research that the direct or indirect X-ray absorption ratio of the aprons should be measured separately (9, 10). In our study, we tried to do the same. Although the intended use of the aprons was protection against indirect rays, the results acquired from measurements made according to direct irradiation might be more useful in the evaluations, due to the wider spectrum width. As the results acquired from indirect measurements have demonstrated a very restrictive range in terms of the ray absorption evaluations of lead aprons, it has been thought that such types of evaluations require working overtime in practice and are wasteful. Therefore, direct measurements have been accepted in order to present better results from lead aprons' ray absorption evaluations.

In Turkey, laws and regulations have been passed for the use of personal protective equipment in the workplace (11, 12), but there has been no such legislation concerning the features of personal protective equipment. These laws and regulations were prepared based on the Directive of the European Council No. 89/656/EEC of 30 October, 1989 (12). As in 1989, this personal protection equipment was brought up to the agenda by European Union countries, and in 1993, it entered into force in line with the directives of the European Council, using the Ireland Guidelines. Since 1993, however, further international arrangements were made. Today, during the production phase, CE mark and 89/686/EEC code are added onto the products (13). However, no registered documents could be found according to what type of feature this 89/686/EEC code was created for in terms of radiation protection aprons and other protective garments.

Conflict of interest disclosure

The authors declared no conflict of interest.

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