ORIGINAL ARTICLE

Lead Aprons Are a Lead Exposure Hazard

Kevin M. Burns, MD[a], Jamie M. Shoag, MD[b], Sukhraj S. Kahlon, MD[c], Patrick J. Parsons, PhD[d], Polly E. Bijur, PhD[e], Benjamin H. Taragin, MD[a], Morri Markowitz, MD[f]

Abstract

Purpose: To determine whether lead-containing shields have lead dust on the external surface.

Methods: Institutional review board approval was obtained for this descriptive study of a convenience sample of 172 shields. Each shield was tested for external lead dust via a qualitative rapid on-site test and a laboratory-based quantitative dust wipe analysis, flame atomic absorption spectrometry (FAAS). The χ^2 test was used to test the association with age, type of shield, lead sheet thickness, storage method, and visual and radiographic appearance.

Results: Sixty-three percent (95% confidence interval [CI]: 56%-70%) of the shields had detectable surface lead by FAAS and 50% (95% CI: 43%-57%) by the qualitative method. Lead dust by FAAS ranged from undetectable to 998 $\mu g/ft^2$. The quantitative detection of lead was significantly associated with the following: (1) visual appearance of the shield (1 = best, 3 = worst): 88% of shields that scored 3 had detectable dust lead; (2) type of shield: a greater proportion of the pediatric patient, full-body, and thyroid shields were positive than vests and skirts; (3) use of a hanger for storage: 27% of shields on a hanger were positive versus 67% not on hangers. Radiographic determination of shield intactness, thickness of interior lead sheets, and age of shield were unrelated to presence of surface dust lead.

Conclusions: Sixty-three percent of shields had detectable surface lead that was associated with visual appearance, type of shield, and storage method. Lead-containing shields are a newly identified, potentially widespread source of lead exposure in the health industry.

Key Words: Occupational safety, radiation protection, patient safety

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INTRODUCTION

Shields to protect staff and patients from ionizing radiation during diagnostic x-ray and therapeutic fluoroscopic image-guided procedures often contain lead as the protective material. Lead-containing and lead-equivalent shields, usually referred to as "lead aprons" or simply as "lead" in hospital slang, may be worn for several hours each day within the fields of radiology, cardiology, gastroenterology, pain management, urology, vascular surgery, orthopedic surgery, neurosurgery, anesthesia, and dentistry.

The construction method and lead content of aprons varies by manufacturer, but traditionally lead powder with or without other metals is mixed with rubber or polyvinyl chloride to form sheets, which are then sewn on the inside of nylon fabric coated with urethane on the side in contact with the lead [1,2]. Although lead-free shields are available, those containing lead remain the predominant type in use in the United States (D. Cusick, e-mail communication, Lead versus nonlead aprons, February 3, 2016).

With daily use, bending, or improper handling, the lead sheets and covering layers may split and, with growing gaps, lose their effectiveness as protection against scattered ionizing radiation. For these reasons, shields

[a]Department of Radiology, Montefiore Medical Center/Albert Einstein College of Medicine, Bronx, New York.

[b]Department of Pediatrics, New York University Langone Medical Center, New York, New York.

[c]Department of Radiology, University of California, Davis Medical Center, Sacramento, California.

[d]Laboratory of Inorganic and Nuclear Chemistry, Wadsworth Center, New York State Department of Health, Department of Environmental Health Sciences, School of Public Health, The University at Albany, Albany, New York.

[e]Albert Einstein College of Medicine, Bronx, New York.

[f]Department of Pediatrics, Montefiore Medical Center/Albert Einstein College of Medicine, Bronx, New York.

Corresponding author and reprints: Kevin Michael Burns, MD, Department of Radiology, Montefiore Medical Center/Albert Einstein College of Medicine, 111 East 210th St, Bronx, NY 10467; e-mail: kburns@montefiore.org.

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undergo regular radiographic assessment for gaps and cracks and those deemed unacceptable are removed from circulation [3,4].

Although lead is a highly toxic metal, during the entire history of the use of lead aprons no prior study has ever assessed the risk of lead exposure to patients and health care workers from the use of these aprons. This study was designed to assess whether lead aprons, long believed to be nonhazardous, expose wearers to lead particles present in dust on exterior shield surfaces [1]. Secondarily we assessed whether a US Environmental Protection Agency (EPA)-approved qualitative on-site test could be used to identify the presence of lead instead of the more time-consuming and expensive method of flame atomic absorption spectrometry (FAAS).

METHODS

We conducted a descriptive study of a convenience sample of 172 shields actively used within the radiology department at a single health care facility. The research was approved by the institutional review board. Shields were identified using the identification number placed by the Radiation Safety Department for tracking and annual radiographic assessment. The shields were cross-referenced with a list of all shields in use at our hospital obtained from the Radiation Safety Department, which included the following characteristics: manufacturer, model, color, owner of the shield (individual versus department), lead equivalent thickness, manufacture date, and site of use (for example, interventional radiology, fluoroscopy, pediatrics). The manufacturers represented in the sample group are Burlington Medical (Newport News, VA), AADCO Medical (Randolph, VT), Xenolite (Norristown, PA), Bar-ray (Littlestown, PA), Pulse Medical (Blue Ridge, GA), Technoaide (Nashville, TN), Burkart Roentgen International (St. Petersburg, FL), and Infab Corporation (Camarillo, CA). Shields were owned either by the hospital or by individual users.

For shields belonging to an individual, the amount of use was assessed via a questionnaire. The location of each shield and whether it was stored on a separate hanger was recorded when the shields were gathered from the various areas of the radiology department.

A visual assessment was performed on each shield, noting if the fabric surface was intact or broken as well as the location and type of damage (if applicable). An overall visual score was assigned as determined by three of the study authors using a 3-point scoring system, with 1 = best-appearing and 3 = worst-appearing. Radiographic assessment was performed by obtaining a scout CT image in accordance with protocols used by the Radiation Safety Office. Images of each shield were saved to a PACS.

Both surfaces of each shield were tested for the presence of lead-containing dust in the following two ways: (1) a quantitative analysis of dust wipe samples performed by an accredited state reference laboratory; and (2) a commercially available and EPA-approved qualitative on-site test (LeadCheck™; 3M, St Paul, MN).

Quantitative testing was performed on dust samples collected from a 12 × 12-inch area (1 square foot) in the center of each shield. The area was swabbed using lead-free wipes and samples were placed in sterile tubes; for smaller shields, such as thyroid collars, the area to be assessed was measured and then swabbed to determine the degree of lead loading, which is reported in $\mu g/ft^2$. In a subset of five randomly selected shields, four-quadrant qualitative and quantitative tests were performed, wherein four individual quadrants were sampled independently to assess for variation across a surface (four shields were tested on both sides).

Field blanks, including wipes and unused glove samples, were also submitted for analysis to assess for lead contamination during collection. Quantitative samples were also taken at three time points during a single day from the table used as the test surface to ensure no contamination and assess for transfer of lead to and from surfaces in contact with the aprons.

All samples were shipped to the Laboratory of Inorganic and Nuclear Chemistry at the New York State Department of Health's Wadsworth Center, which is under the direction of one of the authors (P.J.P.). The laboratory is fully accredited both by New York State and by the State of Florida under the National Environmental Laboratory Accreditation Program for Lead in Soil or Surface Wipes, and participates successfully in proficiency testing for lead in dust wipe samples. The method for lead in dust wipes follows the EPA's method 7000B [5] and 3050B [6]. In brief, surface wipe samples and quality control samples are extracted with an acid mixture (2:1 of HNO_3/HCl) and hydrogen peroxide on a hot plate. The resultant extract is filtered and analyzed for lead content by FAAS; results are expressed in $\mu g/ft^2$. The minimum detection limit of the method is 5 $\mu g/ft^2$. Internal quality control measures include method blanks, matrix spikes (that must fall within ±3 standard deviations), and duplicates (% relative difference must be within 80%-120%).

To determine whether a rapid qualitative test can accurately predict which surfaces have detectable lead, we investigated the utility of the LeadCheck colorimetric method. Reagents are mixed in a small device that is applied to the test surface; a red color is produced within 5 minutes if lead is present. Under laboratory conditions, the method is sensitive enough to detect 1 μg of lead on solid surfaces [7]. This qualitative test was performed on the upper right corner of each shield near a seam (Fig. 1). Thus, both quantitative and qualitative results were available for each apron tested.

Seven fabric swatches (Xenolite, Norristown, PA) were tested on both sides using the qualitative LeadCheck method to detect lead that may be present in dye used for coloring (14 swabs).

Data Analysis

The characteristics of the shields were described by calculating the frequency distribution, presented as percentages and medians with interquartile range as appropriate. The presence of lead was summarized by the percent of all shields that had detectable lead on one or both sides of the shield by the qualitative method (present or absent on qualitative on-site testing) and quantitative method (lead categorized into absent: <5 μg/ft^2, or present: 5 μg/ft^2 or higher) and the 95% confidence interval (CI). The χ^2 test was used to test the association between characteristics of the shields and the quantitative detection of lead. We assessed the utility of the qualitative measure to substitute for the quantitative method by calculating the sensitivity, specificity, and positive and negative predictive values.

Fig 1. LeadCheck (3M) test performed on the upper right corner of a shield. Red color indicates the presence of surface lead dust. This red color was easily washed off with an enzyme-based cleaning solution.

RESULTS

Characteristics of the shields are shown in Table 1. Most of the shields were skirt, vest, or thyroid and most shields were stored on a wall-mounted peg rack. Burlington Medical and AADCO Medical accounted for 88.6% of the samples from our department. The median age of the shields was 5 years and ages ranged from <1 to 16 years. The interrater reliability of shield condition was moderate: kappa = 0.43.

QUANTITATIVE RESULTS

One hundred and nine shields (63% [95% CI: 56%-70%]) had detectable amounts of lead based on the quantitative reference method (FAAS). Lead in dust wipes by FAAS ranged from undetectable to 998 μg/ft^2; the distribution of surface lead dust values is shown in Figure 2. Eighty-two percent of the shields that had detectable lead on either side of the shield had detectable lead on both sides. None of the 10 samples from shields constructed without interior lead (Burlington Medical Envirolite) had detectable surface lead on either side.

Table 2 shows that the quantitative detection of lead was significantly associated with the following: (1) visual appearance of the shield (1 = best, 3 = worst): 88% of shields that scored 3 had detectable lead dust (P = .02); (2) type of shield: a greater proportion of the pediatric patient, full-body, and thyroid shields were positive than vests and skirts (P = .04); and (3) use of a hanger for storage: 4 of 14 shields on hangers (27%) were positive versus 66 of 105 not on hangers (67%) (P < .01). Manufacturer, radiographic determination of shield intactness, thickness of interior lead sheets, and age of shield were unrelated to presence of surface dust lead.

Qualitative Results

Eighty-six shields (50% [95% CI: 43%-57%]) tested positive for surface lead using the qualitative method on one or both sides. There was agreement on presence and absence of lead between the qualitative and quantitative

Table 1. Characteristics of the shields

	N (%)
Shield type	
Full-body	14 (8.1)
Skirt	50 (29.1)
Vest	55 (32.0)
Thyroid	42 (24.4)
Pediatric patient shield	11 (6.4)
Age of shield (years)	
Median (IQR)	5.0 (1.5, 9.0)
Condition - visual score	
Best = 1	77 (45.0)
Average = 2	70 (40.9)
Worst = 3	24 (14.1)
Manufacturer	
Burlington	82 (47.7)
AADCO Medical	69 (40.1)
Xenolite (leaded models)	16 (9.3)
Other	5 (2.9)
Internal material	
Containing lead	167 (97.1)
No lead	5 (2.9)
Storage	
Hanger	14 (8.1)
Peg	158 (91.9)

Note: IQR = interquartile range.

measurements on 71.5% of the shields. Table 3 shows the comparison of the qualitative and quantitative methods.

Of the subset of aprons tested in four quadrants on each surface, there was detectable lead in all four quadrants in 35 of 36 samples. None of the 14 fabric swatch surfaces (Xenolite) had detectable lead. The amount of surface lead on the table used to test the shields trended up during the day, from undetectable before shield testing to 8 $\mu g/ft^2$ at midday and to 15 $\mu g/ft^2$ at the end of the same day.

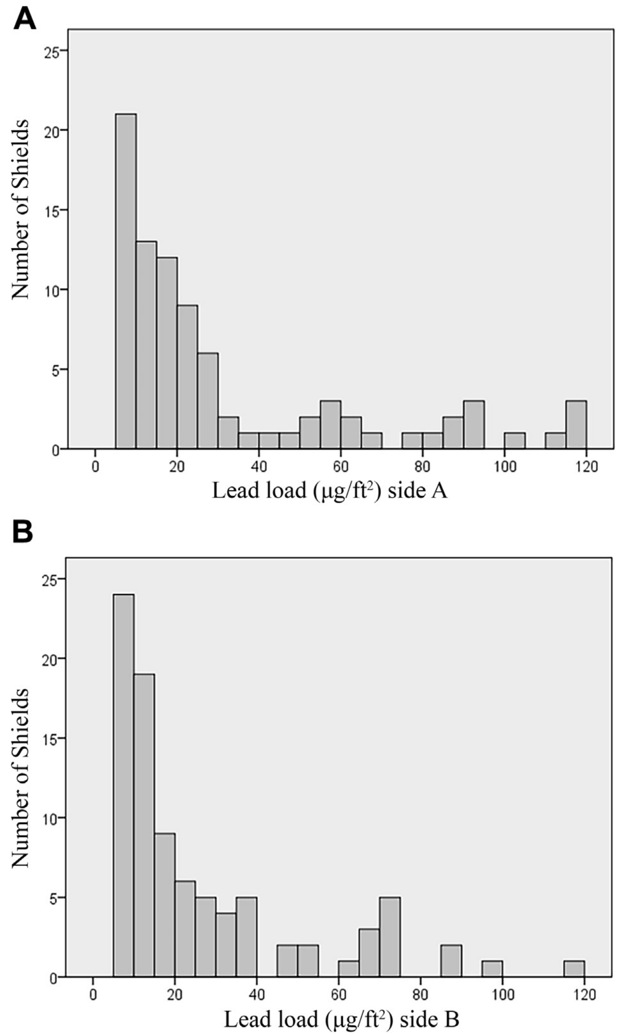

Fig 2. Distribution of detectable surface lead dust from shield side facing the wearer (A, inner) and away from the wearer (B, outer). Distribution truncated at 120. Seven shields had higher lead levels on the inner surface (152, 196, 219, 378, 840, 873, 998 $\mu g/ft^2$) and five shields had higher lead levels on outer surface (125, 159, 230, 347, 703 $\mu g/ft^2$).

DISCUSSION

This study has shown, for the first time, that lead-based radiation shielding contains particulate lead associated with dust on the exterior surfaces. Sixty-three percent of the shields had detectable amounts of lead on the outer surface, which was associated with visual appearance, type of shield, and storage method. This is a potentially troubling finding, as lead-based dust is a well-known source of exposure that can be absorbed into the blood either by inhalation or by inadvertent ingestion, resulting in elevated blood lead levels, and such exposure should be minimized as much as possible. The lead-based dust is in direct contact with patients and with the clothes, hands, and neck of the clinicians that wear aprons during fluoroscopic procedures.

Over 100 industries are known to be associated with occupationally related cases of lead poisoning, including construction, mining, and metal recycling. Therefore, lead exposure assessment is mandated by the federal Occupational Safety and Health Administration for these industries. Airborne lead content monitoring is required because inhalation of lead particles is considered the main pathway into the body for these workers. In contrast, for children, ingestion is the main route leading to lead absorption. Previous studies have shown that children of lead-exposed workers have disproportionately high blood

Table 2. Presence or absence of lead by quantitative flame atomic absorption spectrometry testing: Visual score, shield type, and use of a hanger

	Quantitative Lead Present		
	No	Yes	Total
Visual score ($P = .02$)			
1 – Best	34 (44.2%)	43 (55.8%)	77
2 – Average	25 (35.7%)	45 (64.3%)	70
3 – Worst	3 (12.5%)	21 (87.5%)	24
Total	62 (36.3%)	109 (63.7%)	171*
Shield type ($P = .04$)			
Pediatric patient shield	3 (27.3%)	8 (72.7%)	11
Thyroid	10 (23.8%)	32 (76.2%)	42
Vest	26 (47.3%)	29 (52.7%)	55
Skirt	22 (44.0%)	28 (56.0%)	50
Full body	2 (14.3%)	12 (85.7%)	14
Total	63 (36.6%)	109 (63.4%)	172
Hanger ($P < .01$)			
No	53 (33.5%)	105 (66.5%)	158
Yes	10 (71.4%)	4 (28.6%)	14
Total	63 (36.6%)	109 (63.4%)	172

Note: Shield type and visual score are significantly associated with presence of surface lead.
*One shield had no visual score assigned.

lead levels when compared with age-matched, socioeconomic status–matched, and geographically matched control children of nonlead-exposed workers [8,9]. These outcomes were seen when parents were exposed to lead in the workplace at least 1 hour a week, with no required minimum length of service in this industry [9]. Lead dust on the skin and the clothes of workers can be carried home and is known as "take-home exposure"; it settles on surfaces from where it is then inhaled or ingested by young children with normal mouthing behaviors.

The lead encapsulated inside shields worn by medical workers has long been believed to pose no health risk. In fact, the Health Physics Society states it "cannot imagine that inhaling or swallowing particles from leaded aprons would present a significant source of lead poisoning" [1]. There are currently no regulatory requirements that the risk of exposure from the lead in radiation shields be assessed. Particle seepage from the shields may contaminate clothes and skin. This occupational lead exposure has the potential to present a threat to the health of hospital employees through inhalation and ingestion, and to their families if the lead is transported home on the shoes, clothes, and hands of those employees. As such, occupational biomonitoring for lead exposure among these workers is warranted and is currently under investigation.

This study demonstrated that modifiable factors were associated with surface lead dust, including visual appearance, type of shield, and storage method. Because a poor visual appearance was associated with surface lead irrespective of the integrity of the internal lead sheets, extra care should be taken to handle aprons properly and maintain a good external surface appearance to minimize lead dust exposure to medical personnel, their families, and patients. These data suggest that lead-containing aprons should be kept on a hanger instead of the wall peg systems commonly in use. A wall-mounted or mobile rack providing a longer arm to hang each apron properly may also reduce the amount of surface lead owing to less folding and mishandling.

A larger proportion of one-piece full-body aprons, pediatric patient shields, and thyroid shields had detectable surface lead compared with the skirts and vests. The full-body shields are larger and heavier than a skirt/vest combination, which may lead to more folding, mishandling, and improper storage, potentially damaging the interior and exterior of the shield. Thyroid shields are small, and proper use to prevent ionizing radiation from reaching the thyroid requires curving the strap to fit around the neck. These items are often seen

Table 3. Diagnostic accuracy of qualitative measure of lead to detect presence or absence of quantitative measure of lead

		Quantitative Measure (FAAS)		
		Lead Present	Lead Absent	Total
Qualitative measure (LeadCheck)	Lead present	73	13	86
	Lead absent	36	50	86
	Total	109	63	172
Sensitivity		73/109	67%	(95% CI 58%-76%)
Specificity		50/63	79%	(95% CI 69%-89%)
Positive predictive value		73/86	84%	(95% CI 76%-92%)
Negative predictive value		50/86	58%	(95% CI 48%-68%)

Note: CI = confidence interval; FAAS = flame atomic absorption spectrometry.

folded and bent in half. Thyroid shields are also the only type to directly contact the wearer's skin; skin oils and sweat may lead to deterioration of the exterior shield surfaces.

The stitching around the outside of each shield, which holds the internal and external layers together, creates small defects in the exterior surface and in the internal lead sheets, which is evident during x-ray assessment of the internal shield integrity. This may be another route that allows particulate lead to contaminate the exterior surface. The thyroid shields and pediatric patient shields have more stitches per surface area owing to their small size, which may be an additional reason these types of shields were more likely to have detectable external lead dust.

In the hospital, aprons are tracked by an institution's radiation safety office and are radiographically assessed regularly to ensure that the internal lead is intact. A commonly employed labeling system uses a metal tag that is fixed to each apron by piercing the apron surface and creating a defect. Newer tagging methods exist that are nondestructive and are highly recommended.

As is expected, none of the lead-free aprons in our study had detectable amounts of lead on surfaces. Many studies have evaluated the effectiveness of nonlead materials in blocking ionizing radiation, showing equivalent effectiveness or improvement compared with lead [10]. However, other studies show that manufacturer-reported lead-equivalence protection is not always accurate [2,11-14].

There are other advantages in considering the use of nonlead-containing radiation shields. Because lead aprons contain a toxic material, they must be discarded as hazardous waste [15]. Often these alternatives weigh less, an important feature for staff who must wear the aprons for many hours per day [10].

This study did not test whether cleaning aprons reduces surface lead dust; however, the transferral of lead to the wipes indicates that wet cleaning does remove lead dust. The EPA recommends a combination of vacuuming and wet cleaning to remove lead dust in homes; the use of a wet shop towel alone can reduce lead by 91% [16,17]. Our institution recommends cleaning lead aprons according to manufacturer's guidelines and does not impose a time interval. A policy requiring routine surface cleaning with a manufacturer-approved detergent could reduce lead exposure, but an appropriate time interval is unknown.

Although the quantitative lead dust assessment method is the "gold standard" for determining the amount of lead in a sample, it involves multiple steps and is laborious, time consuming, and costly. A secondary goal of this study was to determine whether a rapid and less expensive qualitative on-site test could accurately predict which surfaces have detectable lead. We found that the LeadCheck swab had an accuracy of 71.5%, a false-negative rate of 33%, and a negative predictive value of only 58% when the positive threshold of the quantitative method was set at 5 $\mu g/ft^2$. Consequently, the LeadCheck swab is not adequate to exclude the presence of lead on shield surfaces.

There were limitations to this study. All of the aprons were from a single health care facility, so its generalizability is unknown, though we have no reason to think that the results are not generalizable. Because this is the first study of its kind, there was no standardized protocol for testing the shields. We chose an area in the right upper quadrant for the qualitative and the middle of the shield for the quantitative method, and these locations may not represent the lead dust content of the entire surface; we did attempt to mitigate this limitation by performing a four-quadrant analysis on a subset of shields, which showed consistent results in all locations. The results of visual scoring were consistent between three independent reviewers. However, this method of assessment will need validation at other centers.

Further research is needed to assess the clinical impact of our findings, because chronic low-level lead exposure, often asymptomatic, is toxic to both adults and children. Monitoring blood lead levels (ie, biomonitoring) could be used to assess internal contamination via transfer of lead into the body, and hand wipes could be used to determine if lead dust is transferred from aprons to the hands of physicians, nurses, and technicians.

TAKE-HOME POINTS

- Sixty-three percent of the aprons had quantifiable amounts of lead-containing dust on the external surface. A larger proportion of the thyroid shields, full-body-style aprons, and small pediatric patient shields had elevated surface lead dust compared with vests and skirts.
- Even radiographically intact lead shields with a poor visual appearance are associated with surface lead dust.
- A rapid on-site negative qualitative swab is not adequate to exclude the presence of lead on shield surfaces; but a positive swab is likely to be confirmed as indicating lead dust on quantitative testing (dust wipe method).

- Chronic lead exposure, often asymptomatic, results in increased morbidity and mortality. Occupational lead dust exposure has repeatedly been reported as a source of lead poisoning in the children of exposed workers as the lead is brought home on clothes.
- Users of lead shields should transition all radiation shielding to lead-free materials to eliminate unnecessary exposure to lead-containing dust.

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