Clinical Evaluation of Protective Garments with Respect to Garment Characteristics and Manufacturer Label Information

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ABSTRACT

Purpose: To test operator exposures inside radiation protection garments in a simulated clinical setup, examining trends related to multiple characteristics.

Materials and Methods: Sixteen garment models containing lead or nonlead materials and a suspended device (Zero-Gravity) were tested for operator exposure from X rays scattered from an acrylic patient phantom. Weight and surface area were determined. The operator phantom was a wooden frame containing a dosimeter in its cavity. Garments were draped over the frame, and the setup was placed in a typical working position.

Results: There was substantial variability in exposures for all garments, ranging from 0.52 to 13.8 μSv/h (mean, 5.39 μSv/h ± 3.82), with a 12-fold difference for garments labeled 0.5 mm Pb equivalent. Most of the especially poor protectors were nonlead, even when not lightweight. Nonlead models were not more protective per weight overall. For closed-back garments labeled 0.5 mm Pb equivalent, mean exposures were lower for lead than for nonlead materials (mean, 1.48 μSv/h ± 0.434 vs 6.26 μSv/h ± 5.13, respectively). Density per exposure^{-1} was lower for lead than nonlead materials in the 0.5-mm Pb equivalent group, counter to advertised claims. Open-back configurations were lighter than closed (3.3 kg vs 6.0 kg, respectively), with similar mean exposures (5.30 μSv/h vs 5.39 μSv/h, respectively). The lowest exposure was 0.52 μSv/h (9.8% of the mean of all garments) for the suspended device.

Conclusions: Operator exposure in a realistic interventional setup is highly variable for similarly labeled protective garments, highlighting the necessity of internal validation when considering nonlead and lightweight models.

ABBREVIATION

IEC = International Electrotechnical Commission

Inadequacies of regulations, testing standards, and labeling for radiation-protective clothing are well reported, with lead equivalences often substantially counter to labels, placing operators at unforeseen risks of excessive exposure (1–11). Previous studies (3,5,7) investigated direct-beam transmission through samples of fabric or portions of functioning aprons composed of different lead or nonlead materials, showing that attenuation correlates mostly with the mass of the fabric, and that lightweight fabrics have reduced attenuation properties. Discrepancies from manufacturers' claims and labels are mainly related to the permitted use of testing and labeling methods that do not provide accurate or useful information about the protective qualities of the products, particularly those not containing lead, along with ambiguous labeling of products with overlapping front flaps for skirt and vest configurations (3).

The attenuation of nonlead materials relative to lead may vary widely across the clinically relevant energy range of scattered radiation (approximately 50–110 kVp), yet labels may report at only one beam quality, which may be the only one at which the stated lead equivalence is satisfied (1,3–9,11). In addition, nonlead materials with

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C.R. receives personal fees from Interventco (Dallas, Texas) and received royalties from a relevant patent. None of the other authors have identified a conflict of interest.

J Vasc Interv Radiol 2017; 28:148–155

http://dx.doi.org/10.1016/j.jvir.2016.08.006

medium atomic numbers often emit secondary fluorescent radiation that is not detected with the use of narrow-beam geometry testing methods but may result in operator exposures substantially greater than expected based on the label (2,8). This is of less concern with lead, which excites no fluorescent radiation at less than approximately 80 keV (8). These deficiencies may be unknown to the operator, apron salesperson, or even manufacturer.

For the operator, it is the transmission of radiation through garments that is important when evaluating protection, more so than the attenuation (7). The present study investigates these issues in a simulated clinical setup that more closely depicts actual operator exposures and examines the effects of apron weight, configuration while being worn on the operator, and material composition.

MATERIALS AND METHODS

Sixteen garments containing lead composite (n = 6) or nonlead composite (n = 10), and a suspended radiation protection system (Zero-Gravity; CFI Medical Solutions, Fenton, Michigan), were tested for operator exposure. Apron styles were open-back (n = 6; traditional one-piece apron without attenuating material in the back) or closed-back (n = 10; skirt and vest combination wrapping around the back) configurations from three major manufacturers. Herein, the terms "garments" and "aprons" will refer to open- and closed-back garments alone, and not the suspended radiation protection system. For the *Results* and *Discussion*, it is explicitly stated if the suspended system is included in the comparison.

Garments were chosen based on their current availability within the interventional radiology department. Aprons in the department undergo a yearly quality assessment check by the radiology department staff, and defective aprons are promptly removed from service. New aprons are also checked before being put into service by radiology department staff. When not in use, aprons are hung in a wrinkle-free manner to prevent defects. To ensure no defective aprons were included in the study, they were first examined under fluoroscopy for holes, tears, or cracks in the attenuating material. Labeled front Pb equivalence was noted. It was determined whether the manufacturer-labeled "front" Pb equivalence corresponded to a single layer of the front panel (ie, overlapped area would be twice the Pb equivalence as labeled) versus two layers of the front panel (ie, each front panel is actually only half of the labeled Pb equivalence, and full labeled value requires doubling, or overlap of panels). This was done with fluoroscopic evaluation of the adjacent front and back panels in all overlapping vests to look for the presence or absence of transitions in attenuation, which can be correlated with labeled front and back Pb equivalences, as seen in Figure 1. Such frontal overlap may occur only over a limited area, leaving a large part of the anterolateral and lateral body exposed at higher than expected rates.

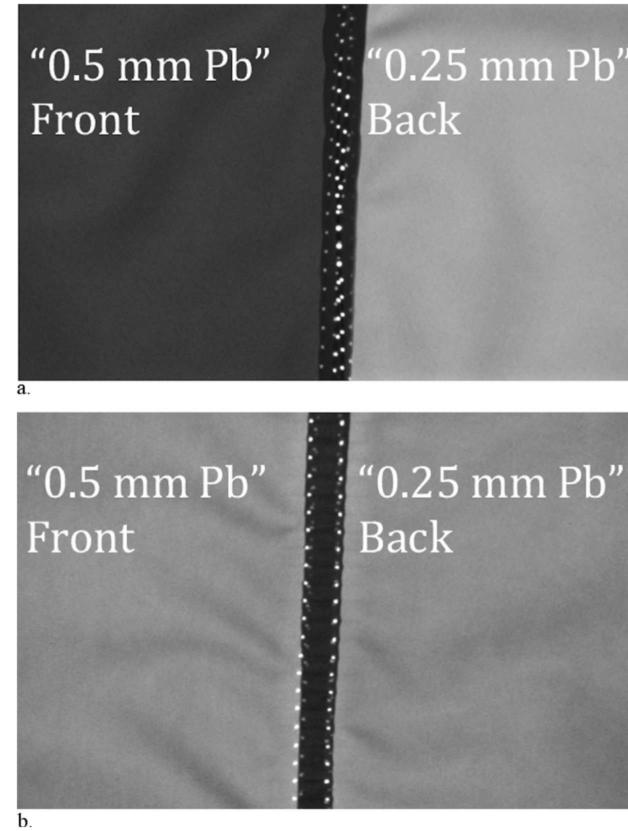

Figure 1. Determination of required overlap. **(a)** Apron does not assume overlap to meet labeled front lead equivalence. Front panel (left) is labeled "0.5 mm Pb," and its attenuation is visibly higher than that of the back panel (right), labeled "0.25 mm Pb." **(b)** Apron assumes overlap to meet labeled lead equivalence even though this is not stated on the label. Front panel is labeled "0.5 mm Pb" (left), but has similar attenuation as the back panel labeled "0.25 mm Pb" (right).

All garments were weighed individually by using a hanging digital scale calibrated by the radiation physicist with a 20-pound weight standard. The radiation protection system is suspended from the ceiling and is therefore weightless to the user, and could not be weighed without detachment by the manufacturer. Skirt and vest combinations were weighed separately, and the sum was used when appropriate. Area density was calculated from frontal surface areas by using overhead photographs (Fig 2a) and ImageJ software (National Institutes of Health, Bethesda, Maryland).

Test setup was intended to simulate a transfemoral angiographic procedure of the abdomen or chest. Scattered radiation was produced from a patient phantom composed of a stack of acrylic slabs in an Allura FD-20 fixed C-arm (Philips, Andover, Massachusetts) in the interventional radiology department. The phantom operator consisted of a wooden frame with a calibrated pressurized 230-cm^3 ion chamber radiation survey meter (451P; Fluke Biomedical, Everett, Washington) placed within the phantom torso (Fig 2b). Garments were