ORIGINAL ARTICLE

Lead Apron Inspection Using Infrared Light: A Model Validation Study

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Abstract

Purpose: To evaluate defect detection in radiation protective apparel, typically called lead aprons, using infrared (IR) thermal imaging. The use of IR lighting eliminates the need for access to x-ray–emitting equipment and radiation dose to the inspector.

Materials and Methods: The performance of radiation workers was prospectively assessed using both a tactile inspection and the IR inspection with a lead apron phantom over a 2-month period. The phantom was a modified lead apron with a series of nine holes of increasing diameter ranging from 2 to 35 mm in accordance with typical rejection criteria. Using the tactile method, a radiation worker would feel for the defects in the lead apron. For the IR inspection, a 250-W IR light source was used to illuminate the lead apron phantom; an IR camera detected the transmitted radiation. The radiation workers evaluated two stills from the IR camera.

Results: From the 31 participants inspecting the lead apron phantom with the tactile method, only 2 participants (6%) correctly discovered all 9 holes and 1 participant reported a defect that was not there; 10 of the 20 participants (50%) correctly identified all 9 holes using the IR method. Using a weighted average, 5.4 defects were detected with the tactile method and 7.5 defects were detected with the IR method.

Conclusion: IR light can penetrate an apron's protective outer fabric and illuminate defects below the current standard rejection size criteria. The IR method improves defect detectability as compared with the tactile method.

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INTRODUCTION

The regular use of radiation-emitting imaging equipment within a medical institute has expanded beyond the radiology department to areas ranging from the operating room to the dental clinic. To ensure that the radiation dose to staff, patients, and the public is as low as reasonably achievable, radiation protective apparel, which includes lead aprons and gonadal shields, are found throughout a medical institute [1,2]. To be in compliance with regulating bodies such as the Joint Commission, the aprons must be tested regularly to determine if the radiation shielding remains intact [1,3]. Conventional apron inspection has been performed by a combination of visual and tactile inspection as well as fluoroscopic, radiographic, or tomographic evaluation [4-7]. Most institutions appear to do so at least annually [8].

In addition to time constraints, fluoroscopic testing of aprons may expose the inspector to scattered radiation. There are several methods to mitigate the radiation dose delivered to the inspector. Migrating from fluoroscopy-based to CT protocols [9] is effective, but CT scanners have limited availability and require a certified technologist to operate them. This method may be more costly and time-consuming. Alternatively, it is possible to distribute the inspection duty among multiple individuals, but this method potentially increases the inspection performance variability.

A combination of a visual-tactile inspection methodology has recently become more broadly adopted, particularly as the size of the institution increases [10]. However, it is possible that a defect such as a hole or tear can be missed due to (1) the large surface area that must be inspected, (2) the interference of the outer fabric enclosing the shielding, or (3) a lack of familiarity with the technique.

We have developed a third method to evaluate lead aprons using a combination of infrared (IR) thermal

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imaging equipment in conjunction with IR lighting. The use of IR lighting eliminates the need for any ionizing radiation exposure to the inspector. This inspection can also be performed in areas without access to x-ray imaging equipment. The current study presents the validation of this method using a "lead apron phantom" in which we evaluate the performance variability of a cohort of radiation workers asked to use both the tactile inspection and the IR inspection methods.

MATERIALS AND METHODS

A Lead Apron Phantom

To assess the defect detection performance, a lead apron phantom was created. A series of nine holes with increasing diameter were drilled in lead-equivalent apron material from a discarded lead apron (5-mm lead equivalent at 85 kVp, West Medical Inc; see Fig. 1a). Upon removing the enclosing apron fabric from the discarded apron, it was discovered that the lead-equivalent material consists of two sheets to form a bilayer, rather than a single sheet (see Appendix 1). Both sheets of the bilayer were used for the phantom.

For our lead apron phantom, the rejection criteria for aggregate hole areas in a lead apron were converted into equivalent circular hole diameters (Table 1) [1,2]. The center of each hole was equally spaced within a 9 × 9 grid pattern.

The shielding layer was then enclosed with apron fabric to simulate typical lead apron apparel. To simulate the optimal conditions for tactile inspection [11], the material was stretched and stapled to a wooden frame and a sheet of drywall was placed under the frame to allow the edges of the holes to be detected (see Fig 1b).

The defects of the lead apron phantom were first imaged and measured from a computed radiography (CR) radiograph obtained with an abdomen technique (73 kVp and 1.3 mAs) at a source-to-image distance (SID) of 100 cm using a radiography or fluoroscopy system (EasyDiagnost Eleva, Philips Medical Systems, Hamburg, Germany). The image had a pixel spacing of 0.144 mm × 0.144 mm. The diameters were measured in both the transverse and longitudinal direction. The measured diameters are larger than the bit size (Table 1) due to the process of drilling the holes.

IR Illumination and Detection

The equipment used for illuminating defects included an IR light source with a 250-W Incandescent R40 Red Heat Lamp Light Bulb (Philips, Model # 415836). The IR light was detected with a smartphone-compatible IR imaging camera. The IR camera (FLIR ONE-IOS, http://www.flir-direct.com, Global Test Supply, Wilmington, North Carolina) created a 160 × 120-pixel video with a temperature range of −20°C to +120°C (Fig. 2).

The IR thermal camera simultaneously captures a reflected light picture with one camera and an IR picture with a second (onboard) camera. The two channels are registered and displayed as a single image (Fig. 2). To reduce bias from the visual light channel, the lens of the visible light camera was covered with four layers of Post-it notes paper (3M Company; Cynthiana, Kentucky). Thus the resulting video only displayed the IR image without a visible light overlay.

Fig 1. Construction of the detection lead apron phantom for tactile and infrared inspection. (a) Lead apron open exposing 0.5 mm lead-equivalent material (gray) and the backing of the outer apron fabric (purple). A grid is drawn on the material with the drill bit size layout. (b) The shielding material is sandwiched between the apron's original protective fabric and stapled to a frame. A piece of drywall that is thicker that the frame is placed under the frames cut out to put tension on the fabric and create an "ideal" tactile sensory environment for defect discovery. (c) Radiograph of lead apron phantom.