Quantification of lead equivalence using radiographic imaging

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Introduction

Despite minimum lead equivalence for medical radiation protection garments being stipulated in both legislation and international standards (such as those from IEC or ASTM), it is essential for the end user to confirm the lead equivalence provided before garments enter clinical use. It has been reported that garments purchased by some health services may not provide the lead equivalence claimed. This can be due to a variety of reasons, ranging from inconsistent energy dependence in lead equivalent materials, to errors in manufacturing and production [1].

As modern radiation protective garment manufacturers increasingly utilise lead free core compounds to lighten products, attenuating radiation via multiple k-edges of elements with atomic numbers lower than lead, assessment of lead equivalence becomes more difficult. A number of methodologies for experimental determination of lead equivalence exist and all require both exact specifications (such as kVp, HVL, total filtration and beam geometry) and access to a sensitive radiation dosimeter, within current calibration. The ability to perform tests such as this may be available to multi-centre networks or large tertiary hospitals in the form of medical physicists, smaller and more regional locations which also use ionising radiation may not have similar access.

Aim

To develop a new measurement method for fast assessment of the lead equivalence of radiation protective garments, using plain radiographic imaging.

Method

High purity lead foils, comprising a range of thicknesses between 0.125 mm and 0.625 mm, 10 cm x 10 cm images were obtained using a Shimadzu™ modular radiographic unit and a Siemens™ YSIO radiographic system, at 100 cm Focus-Surface-Distance (FSD), with Automatic Exposure Control (AEC) disabled. The experimental setup is shown below in figure 1. Imaging was performed at 100 kVp, using best available image processing with a processed sub-region cropped out to minimise heel effect non-uniformities. After the full range of lead foil exposures were completed, a single commercially available protective garment was imaged with identical settings on panels claiming 0.25 and 0.5 mm lead equivalence at 100 kVp, with all measurements performed three times to better average apparatus output fluctuations.

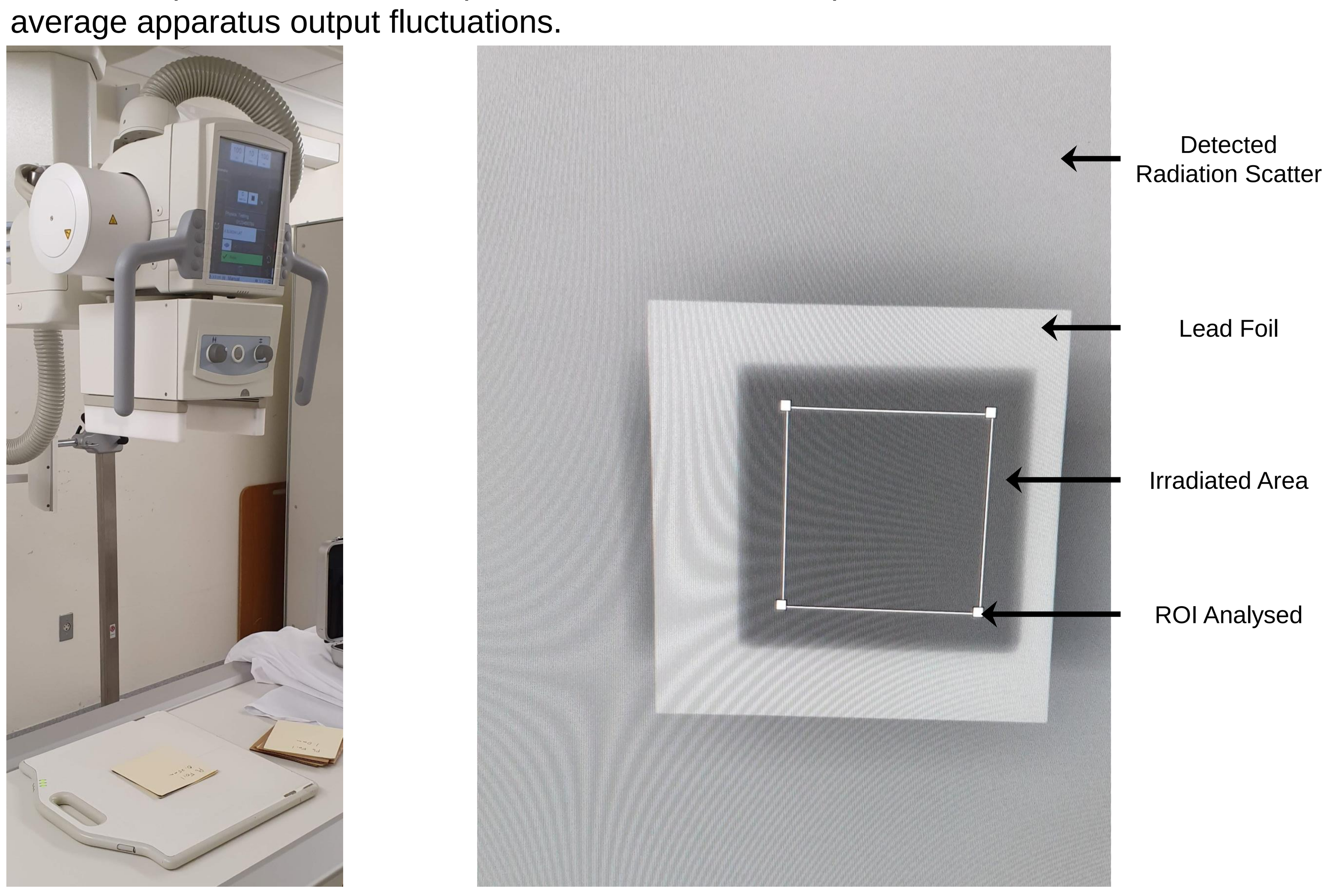

Fig 1: Photograph of experimental setup (left) and radiographic image obtained (right)

For each lead filter image, a minimum 50 square pixel Region of Interest (ROI) was used to obtain five Mean Pixel Value (MPV) measurements with free image analysis software [2] as shown in figure 2. The mean of these 15 MPV measurements was plotted against physical lead thickness, with a linear fit added. This function was then used for calculation of lead equivalence of both the front and back panels of the commercial garment.

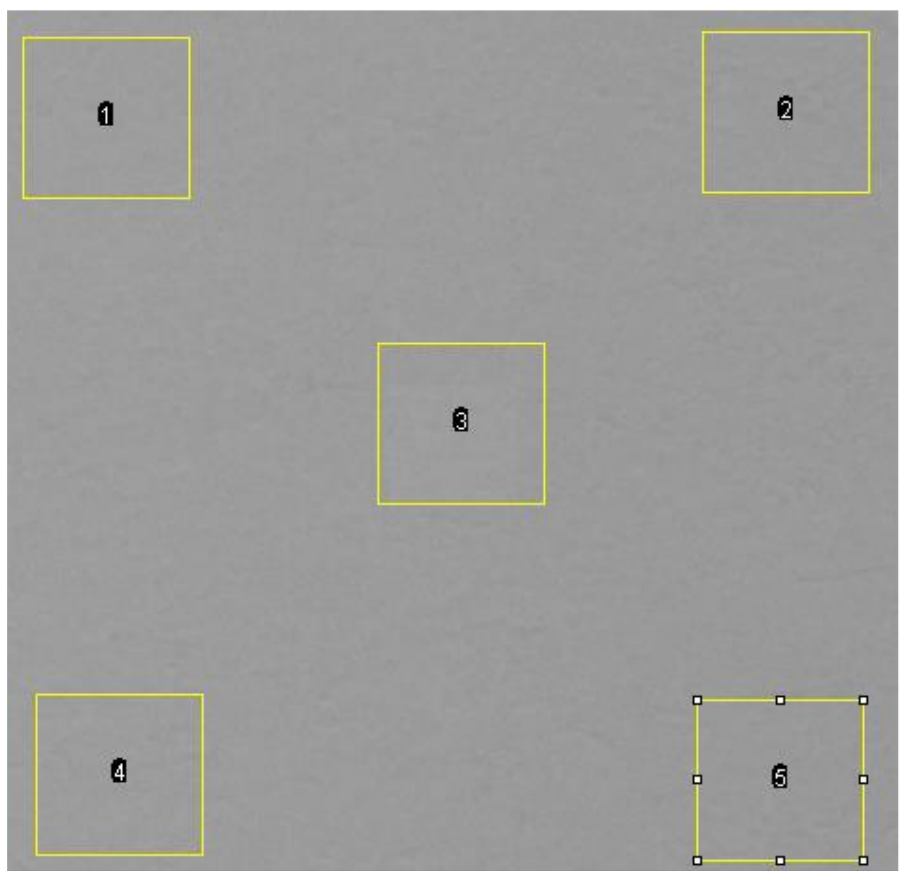

Fig 2: MPV ROI examples on DICOM image of 0.5 mm lead filter

Results

Figure 3 shows the relation of average pixel values and physical lead thickness for the Siemens™ apparatus.

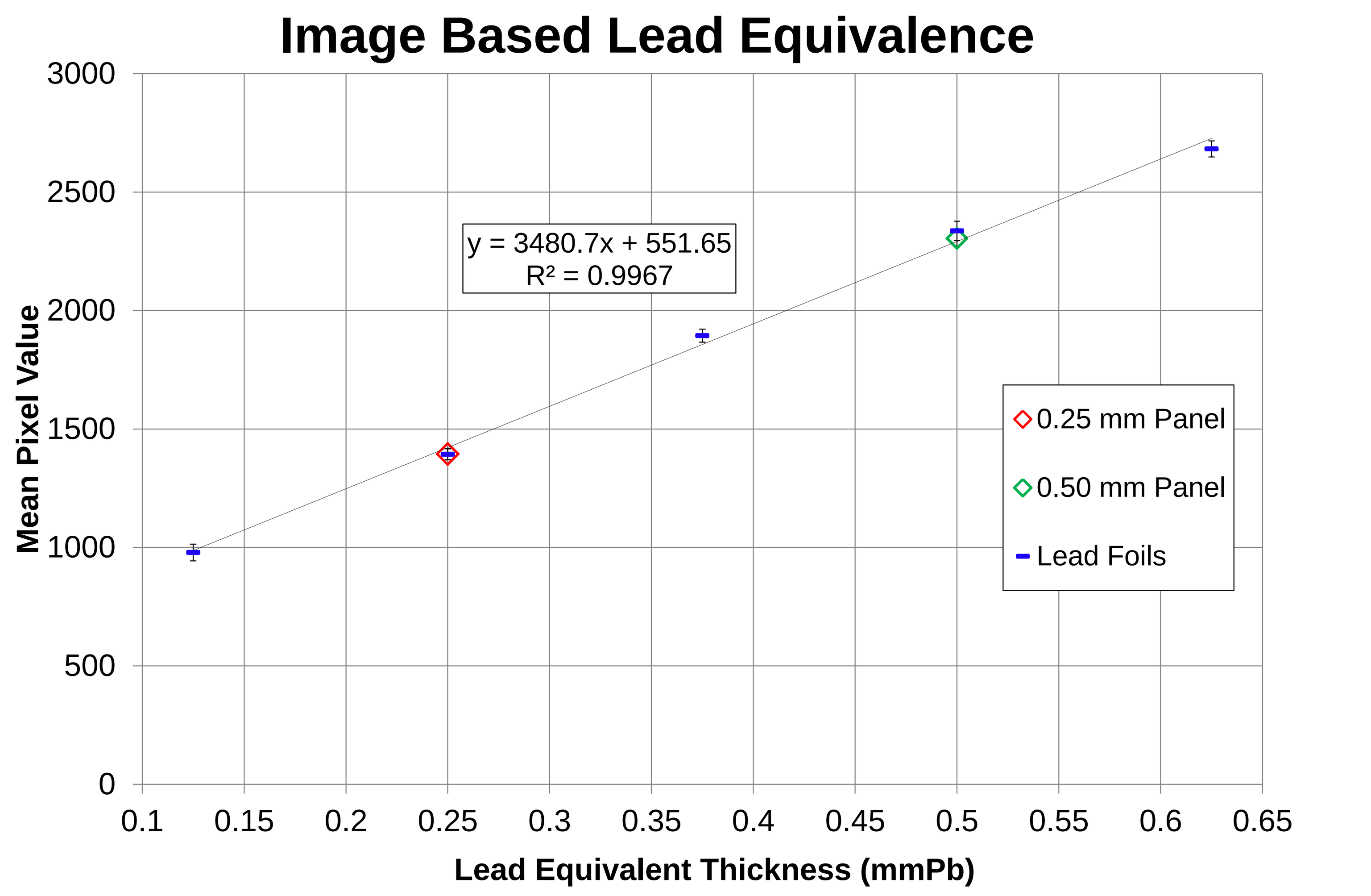

Fig 3: Siemens™ MPV with increasing lead filter thickness and calculated commercial apron thickness, including error bars representing three standard deviations.

Discussion

Due to non-linear post processing and a limited detector response range, measurements could not be completed with the Shimadzu™ unit. The methodology discussed here requires a predictable relation between detector exposure and MPV, across the full detector area. This is not clinically useful and as such uncommon for modern digital radiographic units, since post processing is often based on protocol selection and an assumed anatomy. No such image processing function could be found on the Shimadzu™ unit, resulting in variable MPV with lead thickness and placement on the digital detector. The range of detector exposure values produced during testing also exceeded the range supported by the detector, with high output values exceeding maximum detector exposure limits when using thin lead foils, saturating MPV's but providing useful MPVs with thicker foils. Conversely, if low output values were used, results obtained using thin foils were consistent, but insufficient detector exposure was produced with thicker foils. This indicates image based lead equivalence measurements require high performance imaging hardware and linearised image processing software, and may not be suitable for all sites.

The results obtained with the Siemens™ apparatus does however, demonstrate the potential of image based lead equivalence. A linear relation, with strong agreement across the range of lead thicknesses typically employed for radiation protection of personnel, shows the potential clinical relevance of this approach. The relatively intuitive methodology used here should help with departmental support during implementation and assist staff in performing the required measurements correctly

Although the characterisation of each apparatus may require similar measurements to that of apron evaluation, such measurements could be easily added to apparatus acceptance testing, which often requires use of a dosimetry system and technically experienced staff to complete. Once the relationship between MPV and lead equivalence at given kVp values are characterised, with make/model specific image processing settings determined, on-site radiographic staff could image protective garments and provide resulting DICOM files to a medical physicist located elsewhere for image analysis. Confirming stability of radiation output and detector performance through routine QC would improve result accuracy and reliability over time without requiring recalibration using lead foils. If implemented and supported, this process saves on couriering of radiation protective garments which maintains cost efficiencies without compromising rural/remote equipment standards. In addition to supporting low resource centres, this approach may be useful in the event of inconsistent or locally poor attenuation being discovered during routine fluoroscopic garment screening programs, allowing a holistic assessment of lead equivalence to be performed more simply than conventional dosimeter methods.

Conclusion

Lead equivalence of radiation protective garments can be assessed quickly, using plain radiographic imaging, however care must be taken to ensure correct exposure and image processing settings are used for both calibration and testing.

References

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2. Rasband, W.S. (1997-2018) *ImageJ*, U. S. National Institutes of Health, Bethesda, Maryland, USA, https://imagej.nih.gov/ij/.

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