PhD Thesis Title: The development of new anti-scatter grids for improving x-ray image diagnostic quality and reducing patient radiation exposure

Author: Abel Zhou
Email: abel.zhou@canberra.edu.au
Institution: The University of Canberra, Canberra, Australia
Supervisor: Prof. Rob Davidson and Dr. Stuart Semple
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ABSTRACT:

Medical imaging is commonly used to provide clinicians with a diagnosis for their patients, or to follow up on a patient's treatment. Medical imaging incorporates the use of x-rays, ionising radiation, and non-ionising radiation. One of the major challenges in x-ray imaging is to substantially remove scatter radiation reaching the image receptor without increasing a patient's exposure to ionising radiation, and without compromising image diagnostic quality.

X-ray image diagnostic quality is established by the differentiation attenuations of primary radiation in imaging anatomy. Differentiation attenuations emanate from interactions between primary radiation and the matter of the imaging anatomy. These interactions may scatter primary radiation and produce scatter radiation, some of which moves towards the image receptor. Attenuated primary radiation and scatter radiation reaching the image receptor form the image. The intensities of the scatter radiation deform the differentiation attenuations in the attenuated primary radiation. Consequently, the image diagnostic quality is reduced. A common solution for removing scatter radiation reaching the image receptor is to use an anti-scatter grid technique. This technique, however, increases patient exposure to ionising radiation.

This project investigated how a grid technique can be used in mammography and general radiography without this increase in radiation dose, and without sacrificing image diagnostic quality. The project addressed the transmission of primary radiation (Tp) and the transmission of scatter radiation (Ts) in grid materials. In addition, it presented a quantitative relationship between these transmissions and the stochastic effects of ionising radiation. This relationship suggests a strategy for the reduction of these effects, an essential element for patient radiation protection outlined in the ALARA (as low as reasonably achievable) principle. This project emanates from the scholarly literature with regard to two areas:

1) Using grids fails to minimise radiation exposure delivered to patients because of the compensation for the reduction of primary radiation in grid materials.

2) Using grids lacks adequate optimisation of image diagnostic quality because of the remaining scatter radiation in the image.

In this project, a series of actions to investigate grids were performed in three distinct phases. The first phase examined quantitative methodologies determining Tp and Ts. Moreover, this phase developed a new Monte Carlo simulation code system. In addition, this phase proposed a novel criterion for the

determination of strip optimal thicknesses by using the first differential of the quantum signal-to-noise ratio (SNR) improvement factor (K_{SNR}). Furthermore, this phase also established a new method to determine radiation transmissions in grid materials, overcoming limitations in current radiation transmission methods.

The second phase of this project developed a new grid design method that can be used to design grids to overcome the reduction of primary radiation in grid strips. This phase first analysed the relationships between transmitting primary radiation and reducing scatter radiation. Factors associated with these relationships were then revealed and issues for grid design were examined. Finally, the criteria for designing new grids were evaluated by analysing the relationships between these factors.

The third phase of this project determined a solution for reducing scatter radiation reaching the image receptor. This solution neither increases patient exposure to radiation nor sacrifices image diagnostic quality. In this phase, many new mammographic grids and general grids were designed using the criteria identified in the second phase of the project. The strip optimal thickness of these new grids was determined using the strip optimal thickness criterion proposed in the first phase. The designs of these new grids were evaluated using the Monte Carlo simulation code system developed and validated in the first phase. The results of these new grids were presented in terms of Tp, Ts, and K_{SNR}.

The results for these new grid designs showed that it is possible to have Tp approximately equal to the Tp of a perfect grid (Tp = 1). The Ts of these new designs depends on their grid ratio: the higher the grid ratio, the smaller the Ts. Compared to contemporary grids in the literature, new general grid designs and new mammographic grid designs have 39% and 28% greater Tp, respectively, and all of them have smaller Ts. Furthermore, the K_{SNR} of these new designs showed that new grids could have a benefit of improved image diagnostic quality, regardless of anatomical thicknesses, either in mammography or general radiography. It was found that current mammographic grids have improved image diagnostic quality only for thick breasts (greater than approximately 5 cm). The new mammographic grid designs, however, will have improved image diagnostic quality for all breasts, no matter whether they are thin or thick.

In conclusion, the new grid designs proposed in this project substantially remove scatter radiation reaching the image receptor, do not increase radiation exposure to patients, and do not compromise image diagnostic quality. Using new grids that use these new designs will not increase the stochastic effects of ionising radiation in either mammography or general radiography. Using such new grids to replace current contemporary grids will not only result in less scatter radiation reaching the x-ray image receptor, but the stochastic effects will also be reduced by more than approximately 39% in general radiography and 28% in mammography. Furthermore, scatter radiation reaching the x-ray image receptor can be further reduced by using such new grids with a high grid ratio and without increasing stochastic effects.

Using grids built with these new designs, an effective ionising radiation reduction management strategy in the implementation of the ALARA principle can be achieved. This means that the lowest radiation exposure can be achieved using such new grids to produce x-ray images without compromising image diagnostic quality.

References to author publications that relate specifically to the dissertation:

1. **Zhou, Abel**, Yuming Yin, Graeme L. White, and Rob Davidson. 2016. "A new method for radiation transmission of anti-scatter grids." *Biomedical Physics & Engineering Express* 2 (5):055011. doi: https://doi.org/10.1088/2057-1976/2/5/055011.
2. **Zhou, Abel**, Graeme L. White, and Rob Davidson. 2018. "Validation of a Monte Carlo code system for grid evaluation with interference effect on Rayleigh scattering." *Physics in Medicine & Biology* 63 (3). doi: https://doi.org/10.1088/1361-6560/aaa44b.