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Effect of Aluminium Filtration on Dose and Image Quality in Paediatric Slot-scanning Radiography

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Abstract— **This paper examines the effect that a 1.8 mm aluminium filter has on paediatric patient dose and image quality for linear slot scanning radiography (LSSR). A dynamic dose prediction model for LSSR accurately predicted the dose reduction effects of added aluminium filtration. A cadaver imaging study was carried out to assess the effects of filtration on image quality. With 1.8 mm added aluminium filtration, no visible degradation to image contrast or clarity was found, and in some cases the aluminium filtration improved the image quality as judged by radiologists.**

I. Introduction

Digital imaging techniques have revolutionized the medical imaging field. The ability to manipulate the dose/image brightness relationship has allowed digital radiography to offer a far broader range for balancing dose and image quality than conventional radiography[1]. Digital detectors have been found to produce images equal or superior in quality to those of conventional radiography. These are some of the advantages that have led to digital systems becoming the gold standard in radiography [2].

The risks associated with ionizing radiation are higher in paediatric than in adult radiology [3]. While children are growing, their cells are rapidly dividing, which makes them prone to increased DNA damage from radiation. These effects may predispose to malignant changes in later life, as the sum of damage to biological tissue from radiation increases over a lifetime [4-5]. For these reasons, radiation dose must be kept to an absolute minimum for paediatric patients, provided suitable image quality is maintained [4–6].

We describe the implementation of a model-based filtration technique for the Lodox Statscan (Sandton, South Africa) linear slot-scanning digital X-ray machine, to reduce radiation dose for paediatric patients while preserving diagnostic image quality.

The Statscan is an FDA approved, commercially available digital X-ray imaging system used in trauma centres. The Statscan has been shown to deliver significantly lower radiation dose than conventional X-ray systems for comparable studies without loss of image quality [4]. This is particularly beneficial in paediatric radiology.

At present, the Lodox Statscan applies a 0.1mm copper filter to examinations that deliver over 110kV, with 2mm inherent aluminium filtration. These filters reduce dose and maintain image quality. The lower range of kV settings on the Statscan, and in particular the paediatric settings, have no added filtration. There is scope to implement a filtration technique to reduce radiation dose while maintaining image quality.

We applied a dynamic dose prediction model that allows the user to adjust the scanning parameters of the Statscan system to suit the examination type, and view the effect that the settings have on dose. This model was used to select the most suitable filtration technique for the Statscan paediatric procedures. The model was verified, and image quality evaluation methods were used to examine the effect added aluminium filtration has on image quality.

II. Background

A. Ionizing Radiation Dose

Dose absorbed by air, measured in Gray (Gy), is a measure of the ionization effect an X-ray beam has on the atoms it interacts with in its path [7]. Entrance surface dose is the measure of radiation at the point where the X-ray beam makes contact with the patient. This measure does not take into account the effect of radiation on different organs and tissues, although it does account for backscatter [8]. Entrance surface dose is used as the standard for setting dose levels for common radiographic examinations in adults and children [9]. Effective dose, measured in Sieverts (Sv), is the measure of the amount of radiation to which a whole body is exposed, taking into account different radiosensitivities for difference organs.

B. Filtration and Dose Reduction

Filtration is a well-known technique for altering the spectrum of an X-ray beam. Filtration occurs when a filter material is placed between the X-ray source and the patient, reducing the number of photons reaching the patient. Low-energy photons do not fully penetrate the body and are absorbed in human tissue, and thus increase patient radiation dose without adding to image quality. Some diagnostic systems are equipped with a low-atomic numbered filter

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material to absorb the low-energy photons ("soft X-rays") in the beam [1]. This process is known as "beam hardening".

The image quality to patient exposure ratio can be optimized using replacement or additional filters to the standard aluminium filters installed in some machines [10]. The Statscan makes use of a rotating anode X-ray tube which has 2mm of aluminium filtration included. This will be referred to as inherent filtration. We have previously shown that a 0.1mm copper filter can significantly lower the radiation dose while maintaining diagnostic image quality at high kV exposures [11].

C. *Image Quality Evaluation Techniques*

Evaluating the quality of diagnostic medical images is a complex task, as image interpretation is dependent on the human observer, the image source and the clinical application [12], [13], [14]. The reasons for this complexity are the variations in noise level, resolution contrast and anatomical detail affecting signal detection. The interpretation of the image also depends on the human observer, the image source and the application [12]. There are two primary methods of assessing imaging systems: images of test objects can provide an objective assessment, while assessments of anatomy visualization are subjective to the examiner [14].

Test objects allow for observation of contrast differences and spatial resolution. A benefit of using test objects is that the testing can be performed easily and regularly, allowing for continual monitoring of image quality [14]. Although test objects are useful for determining image quality, the highest level of imaging performance verification is clinical analysis, because test objects lack the anatomical relevance of a patient [2]. Visual grading of images by experienced radiologists is an essential part of the image analysis procedure for comparing diagnostic procedures on different systems. This is because a radiologist will have the anatomical knowledge to identify important structures, and provide a subjective view of image noise, contrast and resolution [13].

Harmer et al [15] suggest a scoring system be used, where experienced radiologists examine comparable images, scoring them according to personal interpretation. This system, originally based on the European Guidelines on Quality Criteria for Diagnostic Radiographic Images [16], was adapted to suit our image quality trial.

III. Dynamic Dose Prediction Model

Irving [17] developed a static dose prediction model for the Statscan, which predicts the skin entrance dose and effective dose for a single anteroposterior scan for one specific setting. This model was adapted to accept a wide range of input settings, and to allow for a choice of filter material and filter material thickness. Figure 1 shows the user interface for the model.

The dynamic model allowed for theoretical experimentation with different filter materials and thicknesses in order to find the optimal filtration technique for the paediatric settings on the Lodox Statcan.

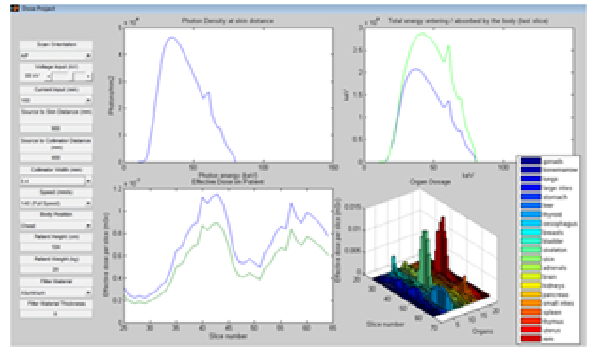

Figure 1. User interface for the dynamic dose prediction model

Figure 2 displays the dynamic model expected dose comparisons for a variety of commonly used filter materials at various thicknesses. Copper and aluminium displayed the best results theoretically, and while aluminium had a significantly more appealing dose vs thickness curve, both were used in a series of image quality assessments.

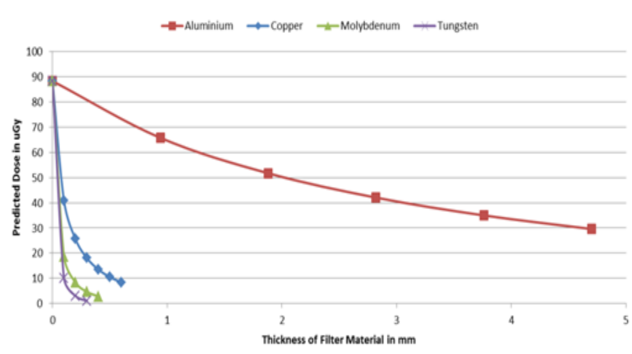

Figure 2. Predicted dose reduction curve for various filter materials

The filter of 0.1 mm copper proved to harden the beam too effectively, so that image contrast was reduced. Aluminium was selected for further testing with the Statscan's paediatric settings. Aluminium is commercially available with the sheeting having a thickness of 0.9 mm. Two sheets were combined to create a filter of 1.8 mm thickness, and a study followed to assess the impact of this filtration technique on patient dose and image quality. A 1.8mm thick aluminium filter appeared to have no adverse effect on image quality during preliminary tests.

IV. Image Quality Study

A. *Phantom Study*

A comparison between two images of the same test object was carried out, each with a different filtration technique applied. All other factors and settings related to the scan were identical.

The PTW Normi 4 FLU^{PLUS} phantom test object was used for the assessment, and the resulting digital images were viewed with the naked eye on diagnostic quality monitors. The test object includes an attenuation plate to simulate a patient in the X-ray beam path.

The threshold contrast percentage is the smallest change in contrast of luminance (or brightness) that can be perceived by the human eye, and is recorded by observing the number of visible contrast discs on the X-ray image compared to the number of contrast disks available. The spatial resolution is recorded in line pairs per millimetre by noting the point on the resolution test pattern (line pair tool) where two distinctly separate lines can no longer be seen.

The South African National Accreditation System (SANAS) minimum requirements for spatial resolution on a linear slot scanner is 1.3 line pairs per millimeter at full scanning speed. SANAS requires a minimum of 2% threshold contrast for linear slot scanning systems operating at 90kV, 64mA and at full scanning speed.

The standard Lodox Statscan paediatric settings were selected: 80kV, 160mA, full scanning speed with the table set to the lowest position. Three test images were scanned of the test object without any filtration, followed by three images with 1.8 mm aluminium applied to the collimator in order to filter the X-ray beam. The resulting images were assessed using the monitor which is supplied with the Lodox Statscan and the threshold contrast and spatial resolution of each image was recorded.

B. *Cadaver study*

Due to the risks inherent with X-ray radiation, a clinical trial with paediatric patients was not warranted, and a cadaver imaging trial was conducted. A benefit of cadavers is that the test subject can be scanned multiple times without any movement, providing ideal conditions for comparing two images with differing filtration settings.

The trial was conducted at the Salt River Forensic Pathology Laboratory in Cape Town during a two month trial period in 2012. Twelve anonymous cadavers, ages 0-1 years were each scanned twice on the Lodox Statscan. Both scans made use of the standard paediatric settings on the machine, with the table at its lowest position.

Air temperature and pressure were recorded to generate the dose correction factor which needs to be applied to the PTW Unidos dose meter readings. The PTW 30 cc ionization chamber (type 23361) was placed between the test subject legs, at the same height as the chest skin entrance in order to get the most accurate entrance dose “free in air”, with the smallest amount of backscatter.

Experienced radiologists reviewed the images. They were tasked with assessing twelve sets of images “blind”, where each set contained two images of the same test subject. The radiologists did not know which image in the set was filtered to reduce dose. The two images in each set were compared against each other in the following four categories: Initial Impression, Contrast, Clarity, and End Impression. The first three categories are assessed without any image editing, while the End Impression was given once the window and level settings on the digital image had been adjusted to enhance the image. Such enhancement is common practice in clinical settings. Each image was compared with its partner image, and scored according to the following levels: Much better/worse, slightly better/worse or equivalent. Each radiologist was also asked to indicate whether they considered the image to be of diagnostic quality.

V. RESULTS

A. *Verification of the Dynamic Dose Prediction Model*

Trauernicht et al [11] achieved accurate results when using the dose prediction model for 0.1 mm copper filtration. With knowledge that the inherent tube filtration is 2mm aluminium, a “free in air” series of dose readings was captured with the 30cc PTW Unidos ionization chamber. For a total filtration of 3.8 mm aluminium, the dose prediction model predicted the dose to be 41.04 µGy, while the measured dose for similar scan conditions was 39.01 µGy, resulting in a difference of 4%.

The model estimated that the added filtration to the Statscan paediatric settings would reduce entrance dose by 36%.

B. *Phantom Study*

A series of images was obtained of the PTW test object at the Forensic Pathology Laboratory. Each data set included three scans of the test object under regular paediatric settings, followed by three scans with the same scan settings and 1.8 mm added aluminium filtration.

The results showed no difference in contrast or spatial resolution between the images. The pre and post filtration images had identical scores for threshold contrast, high and low level contrast, and for spatial resolution.

C. *Cadaver Study Dose Reduction*

Taking into account the correction factor for local air temperature and pressure, the results in Table 1 show the “free in air” doses recorded during the trial. The highest dose reduction was found to be 39%, while the lowest dose reduction was 35%. The average dose reduction over 12 sets of data was 36%.

TABLE I. DOSE READINGS FROM PAEDIATRIC CADAVER TRIAL

Dose Reduction	Unfiltered		Filtered		Result
	Recorded Dose [uGy]	*Corrected Dose [uGy]*	*Recorded Dose [uGy]*	*Corrected Dose [uGy]*	*Dose Reduction [%]* (a)
Maximum	71.91	71.31	44.05	43.68	39%
Minimum	74.71	73.27	48.24	47.31	35%
Average	73.85	72.66	46.94	46.18	36%

a. Percentage dose reduction based on the corrected doses

D. *Cadaver Study Image Quality*

Twelve sets of paediatric cadaver images were considered for examination by four experienced radiologists, who assessed the images from their independent places of practice following the guidelines for the study. Figure 3 shows an example of an image and its filtered version.

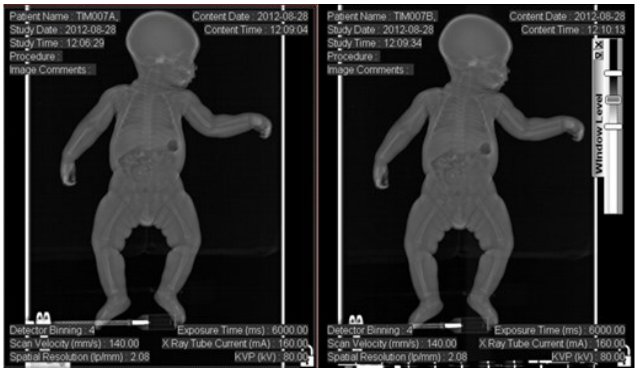

Figure 3. Paediatric cadaver trial images. Filtered image on the right.

They first assessed the image sets without any image manipulation. On average, the radiologists scored the filtered images to be "equivalent" or "slightly better" than the unfiltered image for the initial impression, contrast and clarity assessments.

After manipulating the image contrast settings they unanimously found that all twelve image sets were mutually equivalent, and of diagnostic standard.

VI. Conclusion

A dynamic dose prediction model has been verified in a cadaver study, and the model was successfully used to design a new filtration technique for the Lodox Statscan's paediatric settings. Two millimeters of added aluminium filtration to the standard paediatric settings for the Lodox Statscan showed an average "free in air" entrance dose reduction of 36%, as predicted by the model.

A panel of experienced radiologists found that the added filtration did not affect the image quality, and the cadaver images with filtration added were found to be of diagnostic quality.

This result supports the goal of keeping paediatric patient dose to a minimum while maintaining diagnostic image quality.

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