Dose Reduction and Image Preservation After the Introduction of a 0.1 mm Cu Filter into the LODOX Statscan unit above 110 kVp

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Abstract:

Introduction: The LODOX Statscan unit is a low-dose whole-body X-ray scanner that utilizes a narrow fan-beam of X-rays to generate diagnostic quality images. Statscan uses a rotating anode X-ray tube (1 mm of aluminium equivalent inherent filtration and 1 mm added aluminium filtration) mounted on a C-arm. A collimated fan-beam of X-rays is emitted with an adjustable collimator width of 0.4 mm or 1.0 mm. Fixed to the other end of the C-arm is the detector unit, which consists of scintillator arrays optically linked to charge-coupled devices. The imaging technique factors have been selected by LODOX Systems with the intention of optimising image quality and dose. Preliminary calculations suggested that a further dose reduction could be achieved by introducing a 0.1 mm copper filter for energies above 110 kVp while maintaining image quality.

Method: Entrance dose 'free-in-air' was measured using a PTW-UNIDOS dosemeter and a 30 cm^3 cylindrical ionization chamber (type 23361) for a range of examinations and views. Measured doses were corrected for ambient temperature and pressure, as well as kV sensitivity of the ionization chamber and focus-to-skin distance. The effective doses were obtained from the measured entrance doses using the PCXMC (Version 2.0) Monte Carlo code.

The image quality was assessed using the NORMI 4 FLU ^{PLUS} phantom, which has a resolution test pattern as well as a number of contrast and detail inserts.

Results: It was found that the insertion of the 0.1 mm copper filter at energies above 110 kV resulted in a significant effective dose reduction of at least 20.6 %, while image quality was maintained at these energies.

Conclusion: The filter is now standard on all new LODOX Statscan units.

Keywords: Linear slit scanning, dose reduction

1) Introduction

Ionizing radiation has a detrimental effect on the human body, which makes it important to monitor the radiation doses from radiographic examinations [1] and to minimize these as far as reasonably achievable. In minimizing radiation dose it is important to weigh up the risk versus the benefit of the examination [2]. A useful indicator of the probability of stochastic effects occurring due to radiation is the effective dose as defined by the ICRP [3]. In its 1990 recommendations, the ICRP defined the quantity effective dose as the sum of the equivalent doses in the principal tissues and organs, each weighted by a tissue weighting factor. The tissue weighting factor reflects each organ's relative radiosensitivity.

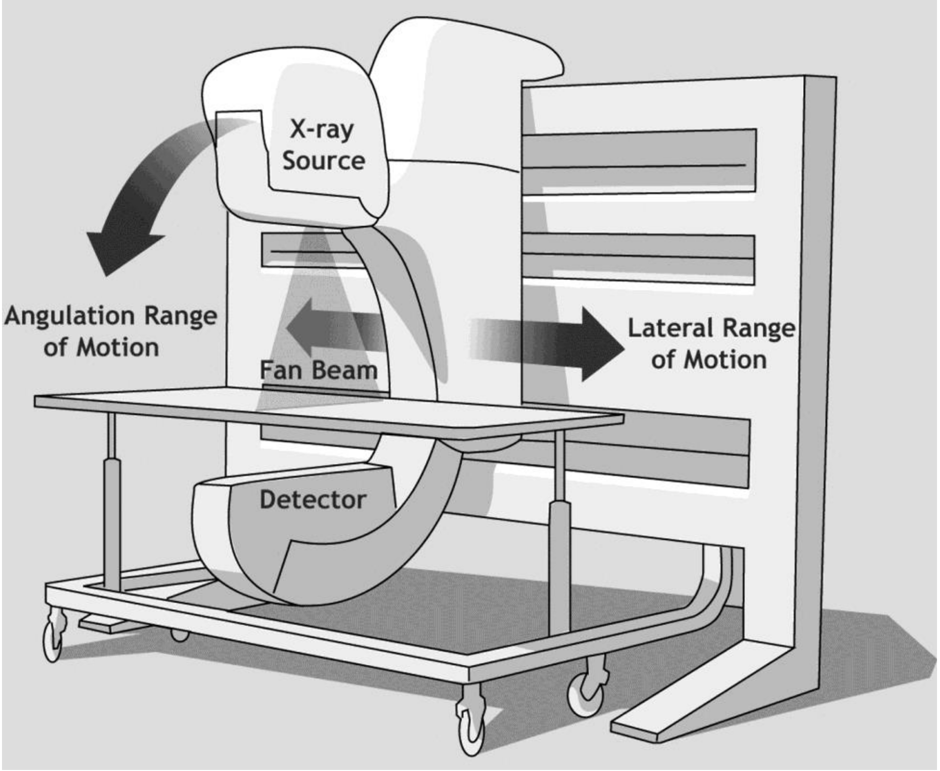
This study looked at the dose reduction after the insertion of a 0.1 mm copper filter into the linear slit-scanning beam of a LODOX Statscan unit. This is a low-dose trauma digital X-ray scanner with full-body scanning capabilities. The entrance doses (free-in-air) were measured using a dosemeter and an ionization chamber for a number of common examinations and converted to effective dose using a Monte Carlo program, namely PCXMC Version 2.0. An image quality phantom was used to assess the images before and after the insertion of the 0.1 mm Cu filter in terms of spatial resolution and the visibility of contrast-detail inserts in the phantom.

2) Materials and Method

The Lodox Statscan unit

The Statscan unit (Figure 1) is a linear slit scanner and has been approved by the United States Food and Drug Administration (FDA). The unit makes use of a rotating anode X-ray tube (1 mm aluminium equivalent inherent filtration and 1 mm added aluminium filtration) mounted on one end of a C-arm. A collimated fan beam of X-rays is emitted via an adjustable collimator of width 0.4 mm or 1.0 mm. Fixed to the other end of the C-arm is the detector unit, which consists of scintillator arrays optically linked to charge-coupled devices. The fundamental pixel size of the detectors is 60 μm and the maximum image size is 12283 x 8000 pixels. The collimated fan beam travels along the patient at speeds of 35 mm/s, 70 mm/s or 140 mm/s, allowing a full-body scan to be performed in less than 13 s. The C-arm is able to rotate around the patient up to 100° in order to allow for different scan angles. The user interface of the Statscan unit allows the size of the patient and the type of scan to be chosen, and the appropriate technique factors are then automatically selected for the scan. The technique factors have been chosen to optimize image quality while keeping the dose low.

Figure 1: The LODOX Statscan linear slit-scanning radiography unit



The PCXMC Version 2.0 Monte Carlo simulator

The PCXMC Version 2.0 Monte Carlo simulator (STUK, Radiation and Nuclear Safety Authority, Helsinki, Finland) is commercially available software and was used to convert the measured free-in-air entrance doses to effective dose. The phantoms used in PCXMC version 2.0 are computational hermaphrodite phantoms representing human beings of various ages (new-born, 1, 5, 10, 15-year-old and adult). These phantoms have been specified by Cristy and Eckerman [4], but a few modifications have been made in PCXMC. It has been reported [5] that comparisons between PCXMC and the Monte Carlo simulator MCNP showed good correlation when calculating effective dose; also, there was a fairly good correlation when the effective dose was calculated by PCXMC, the NRPB-R279 conversion factors and the Organ Dose Software (ODS) [6].

The PTW NORMI 4 FLU PLUS Phantom

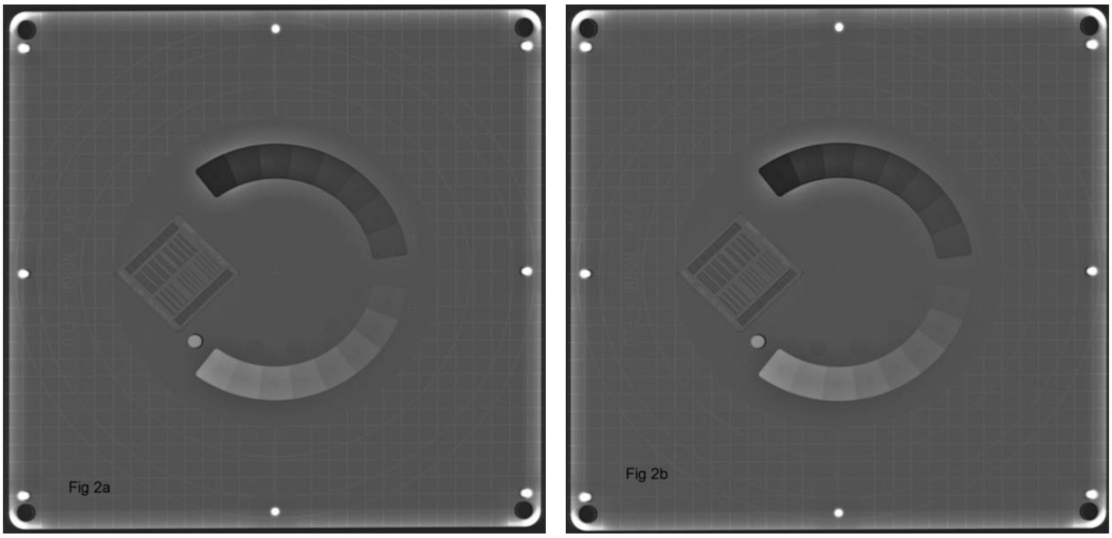
The PTW NORMI 4 FLU PLUS phantom is a test object for constancy tests of analogue and digital fluoroscopic X-ray installations. Included in the object is a copper step wedge for the determination of the dynamic range. There are 17 copper steps with a thickness from 0.00 mm to 3.48 mm, the copper steps 1-8 are embedded into a recess in the PMMA plate with a depth of 13 mm, the copper steps 10-17 into a recess with a depth of 5 mm. There is a resolution test pattern for the determination of the line pair resolution with a range up to 5 lp/mm. There are eight circular contrast-detail test elements with a diameter of 10 mm and depths of 0.4 mm to 4.0 mm. There are also sixteen circular contrast-detail test elements for assessment of the contrast resolution within each step of the copper wedge. These elements have a diameter of 4 mm and depths of 2.5 mm within each step of the copper wedge.

Preliminary calculations suggested that for high kVp (> 110 kVp) exposures an additional 0.1 mm copper filter could be inserted to reduce the dose while maintaining image quality. The entrance doses were measured with a PTW-UNIDOS dose meter and a 30 cm^3 cylindrical PTW type 23361 ionization chamber for a number of examinations available on the Statscan unit. Two measurements were taken for each scan and averaged. Measured doses were corrected for ambient temperature and pressure, as well as kV sensitivity of the ionization chamber and focus-to-skin distance. Large and extra large patients were mostly selected on the Statscan unit, in line with high kVp exposures. Like in [7], the height and weight of a large and extra large patient were assumed to be 188 cm and 100 kg, and 200 cm and 130 kg respectively for the PCXMC mathematical phantom. The field sizes were determined like in [8], where the dimensions of the mathematical phantoms, as well as various organs indicated on the phantoms, served as landmarks to determine the field sizes of various patient sizes. The field size, entrance dose, technique factors and source-to-skin distance were entered into PCXMC for each scan. The Monte Carlo simulation was run to obtain the effective dose. The additional 0.1 mm Cu filter was either added or removed to change the spectrum of the X-ray beam as needed.

3) Results

Table 1 shows a summary of a number of different protocols for large and extra-large patients. For each procedure the imaging parameters (tube voltage and current, slit width, focal spot size, scan speed) are shown, as well as the focus-to-skin distance, the field size on the patient, the reference point on the body of the patient (used for effective dose calculation), the corrected free-in-air entrance doses with and without the filter, the corresponding effective doses with tissue weighting factors from ICRP 103, the percentage dose reduction and the image quality parameters. The image quality parameters are subdivided into line pairs visible, number of copper step wedges visible, number of 10 mm diameter contrast-detail inserts visible and number of 4 mm contrast-detail inserts visible, each with and without the addition of the 0.1 mm copper filter. Figure 2 (a&b) shows a comparison of the images of the NORMI 4 FLU PLUS phantom without and with the additional filter in the beam. The images were taken with the Full Body (Abdomen) AP protocol for a large patient (120 kV, 160 mA).

Figure 2a & b: Images of the NORMI 4 FLU PLUS phantom (Large Full Body (Abdomen) AP – 120 kV and 160 mA) without (a) and with (b) the 0.1 mm Cu filter in the beam



4) Discussion and Conclusion

Doses from linear slit scanning radiography are on average much lower than conventional radiography, in part due to the low scatter-to-primary ratio, the use of a digital detector, the geometry of the setup (dose decreases linearly with increasing distance) and the use of higher than usual tube voltages [7].

A dose reduction in the effective dose of at least 20.6 % is achieved when the thin copper filter is in the beam. This means that an additional significant dose reduction has been achieved on top of the already low doses. Doses for extra-large patients are greater than doses for large patients, due to higher kV and mA settings for the penetration of the larger patients.

As far as the image quality is concerned, there is one case where the spatial resolution is increased when the filter is in the beam and one case where one less copper wedge step and one less 4 mm contrast-detail insert is visible on the image with the copper filter in the beam.

In this study, entrance doses were measured and effective doses were calculated for the Statscan linear slit-scanning radiography unit. Image quality was assessed with the PTW NORMI 4 FLU ^{PLUS} phantom. An additional 0.1 mm copper filter for exposures above 110 kVp reduced the entrance and effective dose significantly, but image quality was maintained.

Table 1: Statscan Doses for Large and Extra-Large Patients for a Number of Examinations

The three contrast columns refer to: 1) Number of copper steps visible 2) Number of 10 mm diameter contrast-detail inserts visible 3) Number of 4 mm diameter contrast-detail inserts visible

Procedure Name and Patient Size	Tube Voltage [kV]	Slit Width [mm]	Focal Spot	Tube Current [mA]	Scan Speed [mm/s]	FSD [cm]	Field Size		Reference Point – Z [cm]	Entrance Dose without 0.1 mm Cu Filter [mGy]	Entrance Dose with 0.1 mm Cu Filter [mGy]	Effective Dose without 0.1 mm Cu Filter [mSv] ICRP 103	Effective Dose with 0.1 mm Cu Filter [mSv] ICRP 103	Percentage Dose Reduction [%]	Image Quality without 0.1 mm Cu Filter				Image Quality with 0.1 mm Cu Filter			
							Beam Width [cm]	Beam Height [cm]							Line Pairs	Contrast			Line Pairs	Contrast		
Chest (lung) AP - XL	140	0.4	S	160	70	99.3	39.5	38.5	60.50	0.315	0.200	0.114	0.084	26.7	2.2	17	5	15	2.2	17	5	15
Full Body (Abdomen) AP - Large	120	0.4	S	160	140	98.0	41.5	188.0	7.03	0.131	0.078	0.106	0.077	27.5	2.0	17	5	16	2.0	17	5	16
Full Body (Abdomen) AP - XL	145	0.4	L	200	140	98.0	45.5	200.0	7.48	0.222	0.147	0.190	0.147	22.7	1.6	17	4	15	1.6	17	4	15
Abdomen AP - XL	120	1.0	L	200	70	98.0	42.0	42.5	19.80	0.891	0.548	0.228	0.176	23.2	2.2	14	5	11	2.2	14	5	11
Pelvis AP – XL	120	1.0	L	200	70	98.0	45.0	32.5	13.80	0.913	0.544	0.159	0.118	25.7	2.2	14	5	11	2.2	14	4	11
Skull AP – XL	120	0.4	S	200	70	93.5	19.6	22.2	96.00	0.329	0.190	0.008	0.006	29.0	2.8	17	5	16	2.8	17	5	16
Chest (lung) Lat – Large	130	0.4	S	160	70	72.4	21.0	32.5	58.00	0.381	0.234	0.042	0.031	26.0	1.2	17	6	15	1.2	17	6	15
Chest (lung) Lat – XL	140	1.0	L	125	70	72.4	23.0	34.5	62.00	0.969	0.627	0.101	0.078	23.2	1.0	13	6	11	1.0	13	6	11
Pelvis / Hip Lat - Large	120	1.0	L	200	70	72.4	19.0	29.0	13.20	1.243	0.744	0.055	0.043	22.5	1.2	13	6	11	1.2	12	6	10
Pelvis / Hip Lat - XL	130	1.0	L	200	70	72.4	20.0	30.0	14.00	1.399	0.876	0.055	0.044	20.6	1.0	11	7	9	1.2	11	7	9

5) Acknowledgements

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