HOW-TO

OPTIMISATION OF PLANAR CHEST PA EXPOSURES USING THE CDRAD CONTRAST DETAIL PHANTOM

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Abstract— **Optimization is a vital process for minimizing the risk of detriment from diagnostic radiation use, while ensuring adequate image quality for diagnosis. It is a legal requirement in most countries worldwide, and there are a number of strategies available. One such technique is the use of quantitative and anthropomorphic phantoms to adjust exposure factors, in combination with dosimetric techniques, to achieve acceptable image quality at a minimum dose. A case study is described, which uses the CDRAD contrast detail phantom and a thorax phantom to optimize exposure factors for chest posterior-anterior (PA) exposures.**

Keywords— **Optimization, image quality, CDRAD, contrast detail phantom**

I. Introduction

Section I discusses the legislative requirements for optimization and strategies for undertaking it. A case study is then presented describing the use of several of these strategies to optimize chest PA exposures, based on image quality and patient dose.

Section II describes the materials and methods used in this case study, with section III, IV and V containing results, discussion and conclusions, respectively.

A. *Legislation and Motivation*

The principle of optimization is enshrined in legislation worldwide, and is defined as the process of ensuring that all radiodiagnostic doses are as low as reasonably achievable, consistent with obtaining adequate information to allow a diagnosis [1].

Optimization is one of the three general principles of radiation protection, along with justification and dose limitation, and is given as Principle 5 in the International Atomic Energy Agency's latest edition of "Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards (BSS), published in July 2014 [2].

Under Requirement 38 of the BSS, the exposure to the patient from a diagnostic procedure must be "the minimum necessary to fulfil the clinical purpose of the radiological procedure, with account taken of relevant norms of acceptable image quality … and of relevant diagnostic reference levels."

According to the BSS, special attention should be paid to optimizing certain types of exposure, including doses to pregnant women or pediatric patients, volunteers, screening programs and exposures giving relatively high doses. Exposures that fall into this last category might include computed tomography (CT), extended image-guided interventional procedures or high activity nuclear medicine administrations.

The dose to a patient from a planar radiographic exposure is comparatively low when set against these "high dose procedures". A 2010 review of the UK population's radiation doses from medical exposures found that conventional radiography accounted for only 19% of the total population dose in man Sv, compared with 68% due to CT scans [3]. The conventional proportion had reduced from 44% in 2007/8, due the increase in CT examinations, a trend mirrored worldwide. However, the number of conventional radiographs performed, 90% of the total in 2008 [4], means that rigorous optimization is still required.

B. *Strategies for Optimization*

A number of different strategies can be used as part of the optimization process. This paper focuses on planar diagnostic radiographs. The same principles apply to modalities such as CT, fluoroscopy, mammography and diagnostic nuclear medicine, but the technical and clinical methods will vary.

It is important to remember that the object of optimization is not just to reduce the dose; the image quality must be of sufficient diagnostic quality to answer the clinical question, or the exposure may have to be repeated.

1. Technological tools

In general, the condition of the equipment used for x-ray imaging has a large impact on the doses to patients and the resultant image quality, and all x-ray equipment should be part of a rigorous quality control system, from acceptance testing and commissioning to routine testing.

One key technological aid to optimization is the automatic exposure control (AEC) device. A table or chest bucky may contain such a device, usually located behind a grid, which terminates the beam when a fixed exposure parameter is met (such as air kerma or detector dose indicator) [5]. This achieves consistency across exposures, ensures the detector receives sufficient dose to form an adequate image, and stops additional exposure above that level. Ensuring that the dose at which the AECs cut off the beam is at the correct level is a vital optimization strategy, and may be done by the manufacturer's engineer, in cooperation with medical physicists or x-ray technicians. The receptor dose may be recommended by the manufacturer, and is lower for more efficient detectors.

Also important is regular testing of AECs, for reproducibility, consistency between different AEC chambers, and repeatability for multiple exposures.

Advancements in x-ray imaging technology should aid optimization by reducing doses for a fixed level of image quality, or, conversely, improving diagnostic information for a particular dose. Improvements may be in the form of superior image processing or imaging plate design, such as increased detective quantum efficiency (DQE) or spatial resolution. It is important to have good communication between the equipment manufacturer, installer and local users, so that the best use of the equipment can be made, for example in using and setting up optimized protocols at commissioning.

2. Positioning and Orientation

Patient dose can be altered by choosing a particular projection and positioning the patient accordingly. For example, a recent study compared the effective doses to patients from lumbar spine exposures in eight different projections and found variations of up to 60% [6]. This is due to the varying radiation dose to organs of different radiosensitivities; there may be no difference in the dose-area produce (DAP) recorded. The position of overlying organs will also need to be considered.

3. Diagnostic Reference Levels

Diagnostic reference levels (DRLs) are a means of monitoring typical imaging doses and indicating the need for a review or investigation. Established DRLs are published, for example by governments or national bodies, based on large data surveys and can be used as a comparison with local doses for a particular procedure.

DRLs may be set locally, but should not normally exceed national levels. Typical calculation methods involve finding the median of a distribution of DAPs for a room and procedure and for patients of mean mass within a certain range, while national DRLs may be the third quartile of mean doses from local centers [5]. Periodically, local doses should be assessed and compared against published DRLs, both for exceeding it and falling significantly below, the latter of which may indicate poor image quality. The distribution of doses, often in the form of DAPs, provides a useful indication of variation. For an individual patient, there may be a valid reason for exceeding a DRL; for example, a patient may have a substantially larger than average body mass. However, the process of assessing local doses against local and national DRLs should indicate the need for an investigation and initiate a cycle of the optimization process.

4. Exposure Factors

The choice of radiation quality, determined by kVp and filtration, for a particular exposure will depend on the anatomy, detector type, acceptable noise and receptor dose needed. Different detectors will have particular energy dependences and peak sensitivities. In general, detector sensitivity increases at lower kVp and image contrast improves, but patient dose increases as more x-ray photons are absorbed in the body [5]. Filtration, in the form of sheets of metal such as aluminium or copper, are used to remove photons of such low energy that they will contribute to patient dose without adding to the image. Recommended exposure factors are published, for example by the European Commission [7]; these provide good references but may not be maximally optimized for particular exposures on local equipment.

Increases in tube current and time (mAs) will increase the patient dose. When AECs are in use, the mAs is not selected, and the AECs provide assurance that the detector receives an adequate but not unnecessarily large dose. However, the choice of beam quality still affects the patient dose when AECs are in use.

The choice of anti-scatter grid, and whether to use one, also influences patient dose and image quality. Grids may be parallel or focused (the latter requiring a fixed distance from the beam focal spot), and eliminate scattered photons, which degrade the image. The grid ratio, which is the height of radiopaque strips divided by the thickness of the inter-strip spaces, controls how much scattered radiation is transmitted. However, the primary beam is also attenuated, , so patient dose increases for a given

receptor dose. This may be justified if the level of scatter without a grid is unlikely to give adequate image quality for diagnosis.

5. Phantom Measurements

Phantoms can be exposed using the settings for a particular clinical examination, allowing the operator to adjust exposure factors, successively altering the dose and assessing the resulting image quality.

This can be done quantitatively, using a phantom with contrast and resolution details of known dimensions, and qualitatively, using a phantom as close as possible to the clinical reality so that the image quality achieved by the optimization process is mirrored in real patient images subsequently produced using the final choice of parameters.

C. *Case Study: Chest PA exposures, radiographic room*

The case study described here uses a combination of several of the techniques described above to optimize chest posterior-anterior (PA) exposures at a large radiology department, the Churchill Hospital, part of the Oxford University Hospitals NHS Foundation Trust (OUH). It focuses on methods that can be employed by a local medical physics team, rather than improvements to imaging equipment design or changes to clinical positioning.

Chest radiographs may be requested for a range of clinical questions, and must have adequate image quality for small lung field details, possibly obscured by mediastinum and ribs. The current UK national DRL for chest PA examinations is 10 cGycm^2 [8]. However, the OUH local DRLs were 8 cGycm^2 for computed radiography (CR) systems and 7 cGycm^2 for direct radiography (DR) systems, reflecting local equipment and DR's superior DQE.

II. Materials and Methods

The first step in this optimization process was analysis of the patient doses for a range of clinical examinations and x-ray rooms across the hospital Trust. Data was taken in the form of DAPs from the RIS system, and inevitably contained some spurious data due to incorrect recording or unit errors, some of which were revealed on investigation of outliers. The distribution for chest PA for the room featured in this case study is given in Figure 1 below:

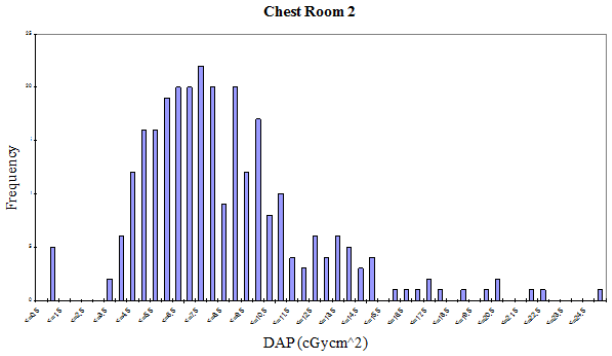

Fig.1 Distribution of doses for chest radiography room

Distributions for different rooms were then compared, highlighting areas where there was particularly high variation or a large number of outliers. The room means were then compared with each other and with national and local DRLs, as shown in Figure 2.

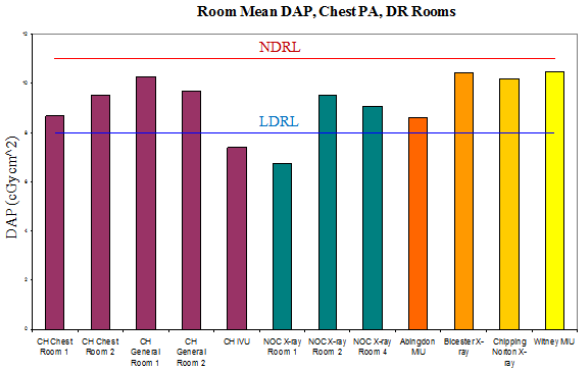

Fig.2 Doses for different radiography rooms

Although none of the room means here exceed the national DRL, many were exceeding the local DRL based on previous data across several hospitals. The variation also prompted an investigation and an effort to optimize doses. In some cases the variation could be explained, for example where certain rooms are used for imaging inpatients. The exposure factors for different rooms were compared, including whether there were protocols built in for each examination type or selected with reference to a chart, and whether AECs were used and at what exposure termination level.

Thought was also given as to whether images from these systems were always of acceptable diagnostic quality. This can be addressed by discussion with radiologists and radiographers, and analysis of rejected images.

In this optimization process, one room was chosen for initial further optimization work, on the basis that its doses were on the higher end of the distribution, and because the equipment was typical of that used across the Trust for chest PA exposures. The room in question had a GE Definium 8000 DR x-ray system, and was used with

clinical exposure parameters of 120 kV and no additional filtration, with left and right AECs, an anti-scatter grid and a focus to detector distance of 180 cm. The AEC performance had been previously optimized according to local protocol. However, its inherently poorer energy response at high kV settings (greater than 100 kV) could not be mitigated against, resulting in higher terminating exposures at these beam energies.

Having ascertained the normal clinical parameters and that these were used for all chest PA exposures except in extraordinary circumstances, the next step was to decide what factors to vary to test the effect on dose and image quality. In general, it is better to not vary too many parameters at once, or to move too far away from the current clinical practice. At this stage, it is also important to be aware of recommendations given by the manufacturer, professional bodies and national guidelines, as well as to find out if the results of similar optimization work is available.

The parameter chosen for testing was beam quality in the form of kVp and filtration. In addition to the current clinical exposure parameters (120 kVp, no filtration), we considered 90, 100 and 110 kVp, and 0.1 and 0.2 mm copper (Cu). This gave twelve combinations in total.

A. *CDRAD Contrast Detail Phantom*

Image quality was assessed quantitatively using a CDRAD contrast detail phantom, which has dimensions of 26.4 by 26.4 cm, with thickness 0.76 cm, and incorporates a 15 by 15 grid of squares, each containing two cylindrical holes. These vary in depth and diameter from 0.3 to 8 mm, in 15 exponential steps, and test a system's detection of objects as they become smaller and of lower contrast [9].

The phantom was positioned between 5 cm thicknesses of Perspex as a scattering medium. The field size was set to cover the whole phantom, and five exposures were taken for each set of parameters.

"Unprocessed" images were used for this analysis and the images were automatically scored using the Artinis CD Analyser program [10], which gives an inverse image quality figure, IQFinv, for each set of images:

$$IQFinv = 100/\Sigma(C.D) \quad (1)$$

Where C and D are the threshold detection contrasts and diameters, respectively, for each set of images of the CDRAD phantom. Increased detectability, i.e. the ability to detect smaller and less contrasted objects, gives a higher IQFinv.

B. *Chest Phantom Images*

Having chosen sets of parameters which gave an improvement in image quality as measured using a CDRAD phantom, it was important to assess the effect on image quality for more realistic clinical images. An anatomical chest phantom was positioned by a radiographer as if for a chest PA exposure, and images acquired at the settings tested above, to be reviewed by a radiologist to confirm that a change in parameters would still give adequate image quality.

C. *Effective Doses*

Effective doses for each combination of kVp and filtration were calculated using Monte Carlo simulation and the PCXMC v. 2.0 software package. Organ and effective doses were calculated using ICRP 103 weighting factors, the same field size set as for clinical chest PA examinations, and knowledge of the inherent half-value layer and filtration of the x-ray unit, with each combination of varying kVp and additional filtration.

III. Results

A. *IQFinv and Effective Doses*

A sample contrast detail score diagram (for 110 kV and 0.1 mm Cu) is given in Figure 3, with the contrast detail curve for all twelve combinations in Figure 4.

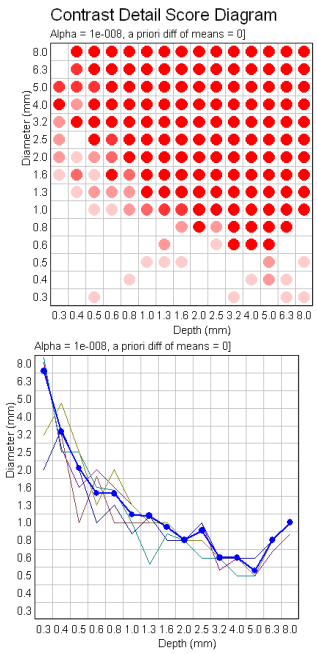

Fig.3 Contrast Detail Score Diagram and Curve for 110 kV and 0.1 mm Cu (five exposures)

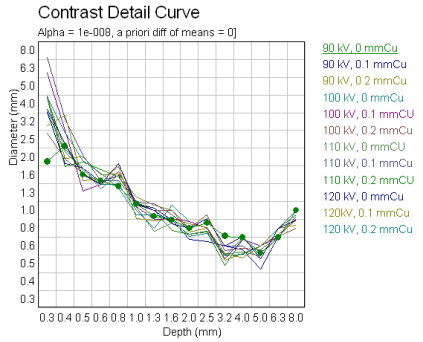

Fig.4 Contrast Detail Score Curve for all twelve combinations

Inverse image quality figures and effective doses for each of the combinations of kVp and filtration are given in Table 1 below, and in graphical format in Figure 5.

Table 1 Effective doses and IQFinv

Exposure Parameters	Effective Dose (µSv)	IQFinv
90 kV, 0 mm Cu	9.3	3.13
90 kV, 0.1 mm Cu	8.1	3.09
90 kV, 0.2 mm Cu	7.6	3.20
100 kV, 0 mm Cu	9.4	3.22
100 kV, 0.1 mm Cu	8.0	3.07
100 kV, 0.2 mm Cu	7.5	3.28
110 kV, 0 mm Cu	9.7	3.29
110 kV, 0.1 mm Cu	8.5	2.89
110 kV, 0.2 mm Cu	7.8	3.11
120 kV, 0 mm Cu	10.1	3.34
120 kV, 0.1 mm Cu	8.8	3.16
120 kV, 0.2 mm Cu	8.2	3.20

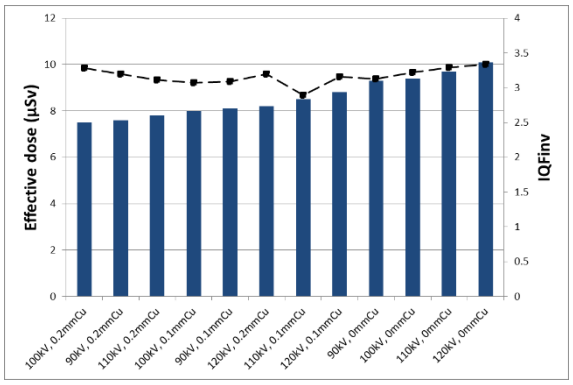

Fig.5 Effective doses and IQFinv

There is not a great change in detectability, as indicated by the IQFinv values and the contrast detail curve, between the twelve combinations (13% between the least and most detectable). However, the increase in effective dose from the lowest (100 kV, 0.2 mm Cu, 7.5 µSv) to the highest (120 kV, 0 mm Cu, 10.1 µSv) is 26%. There can be some confidence, therefore, that choosing one of these other combinations will reduce effective dose without significant loss in image quality.

B. *Phantom images*

The highest effective dose comes from the current clinical parameters, 120 kV and 0 mm Cu. Changing to the lowest dose parameters, 100 kV and 0.2 mm Cu, reduces the effective dose by 26% for a change in IQFinv of 1.8%.

The phantom images for these two combinations of kV and filtration are shown in Figure 6.

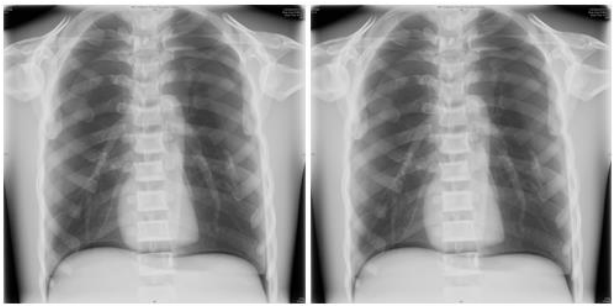

Fig.6 Left: 120 kV, 0 mm Cu (10.1 µSv, IQFinv 3.34; Right: 100 kV, 0.2 mm Cu (7.5 µSv, IQFinv 3.28)

The two images were judged to be of equivalent diagnostic image quality. We therefore chose to implement these new settings for future chest PA exposures using this equipment.

IV. Discussion

A. *Implementation and extension*

The reduction in effective dose expected from changing the beam quality is a reduction in average risk to a population. However, it is reasonable to assume a reduced risk to an individual patient, consistent with the principle of keeping doses as low as reasonably practicable while achieving images of diagnostic quality.

It is important to work in cooperation with all users of the equipment when making changes, especially radiographers and radiologists. Radiographers and other operators must be clear about any changes to equipment settings or clinical procedures, and radiologists must approve the expected image quality post-changes, and

feed back any problems as soon as possible after a change.

For these reasons it is sensible not to make too many changes at once, and to only make small adjustments, so that there are no undiagnostic or repeated images.

The effect on the room dose mean and distribution should be monitored and compared with local and national DRLs.

Ideally, each type of exposure should be optimized for every piece of x-ray equipment. However, it may be better to have the same parameters for a set of similar equipment or in the same department. This will depend on the variation in optimum parameters between equipment, and whether each unit has built in exposure factors or if they are selected from an exposure chart.

Having a clear system for inputting doses and exposure factors into RIS after exposures allows greater confidence when examining room dose distributions and comparing with DRLs. The implementation of dose management systems which record these automatically may improve this process.

The variation in dose and image quality for different clinical examinations and equipment may influence the decision on subsequent choices of equipment.

B. *Limitations of this method*

This method is time-consuming to complete for all examinations and x-ray units. The greatest benefit may be achieved by investigating units with the highest and most variable doses or which record many repeated exposures.

CDRAD images and IQFinv values are not direct measures of image quality. It may be difficult to find phantoms which adequately reflect the range of clinical questions requiring diagnosis. Similarly, it is difficult to optimize for a range of patient sizes. In particular, larger patients may have poor image quality due to increased scattered radiation, and are usually excluded from data used to produce DRLs. If they form the majority of patients in a particular center, a local DRL may be formulated specially. If they form a minority or are outliers for a number of units, it may be appropriate to form adjusted reference levels and exposure parameters for these patients.

V. Conclusions

A number of strategies are available to optimize diagnostic radiographs for individual x-ray units and across hospitals. The case study presented here used qualitative and quantitative assessment of image quality using exposures of phantoms, and calculations of effective dose, to choose exposure parameters for future chest PA examinations. This is part of an iterative process of optimization across many x-ray units and clinical examinations, with the aim of reducing the risk of detriment from radiation and achieving adequate diagnostic image quality.

Acknowledgment

I would like to thank the radiography and medical physics staff at Oxford University Hospitals NHS Foundation Trust.

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