Report

Surveying dose levels for computed radiography in the UK

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Project details

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KCARE

KCARE is an X-ray equipment evaluation centre, which has provided the NHS with advice on the selection and purchasing of radiological equipment since 1979. It is part of the independent evaluation programme funded by the Centre for Evidence-based Purchasing (CEP).

The KCARE mission statement

Expert Advice for Imaging in Healthcare

The KCARE team of evaluators have many years of technical and clinical experience in the assessment of imaging equipment and the provision of purchase guidance to the NHS.

KCARE has produced a wide variety of reports; from Technical Evaluations and Buyers' Guides to Evidence Reviews and Cost-effectiveness analyses for a variety of topics including X-ray equipment and ultrasound. Consultancy and advice services are provided to NHS Trusts and other bodies. In addition, KCARE provides project management and quality management services.

Introduction

Computed radiography (CR) was the first digital technology employed in radiology for planar imaging and is a cassette based system that can be used for all general radiography diagnostic applications. CR provides a cost-effective and easily implemented transition from traditional film to digital radiography by using existing X-ray equipment. It is suited both to centralised environments, serving multiple X-ray rooms (whereby cassettes are brought to a shared reader), or in-room solutions with dedicated readers.

A CR system includes:

- A plate reader
- A range of image plates and cassettes
- A review workstation
- An ID terminal

The image plate is contained in a cassette, which after exposure is inserted into the reader where the it is scanned by a laser beam. The reader then digitises the signal to form an image, links the data to the patient details and sends the image to an associated review workstation. Both single and multi-plate readers are available.

CR image plates have a different chemical composition to X-ray film intensifying screens and consequently have a different energy response. Therefore, it is necessary to have the kVp compensation curve for the automatic exposure control (AEC) of the X-ray system tailored to the CR system rather than using the existing film/screen curves.

Many departments have kept the AEC settings previously used for film/screen systems. The Medical Devices Directive [1] recommends that sufficient information should be provided with a CR system to allow safe operation with the associated X-ray unit. MHRA keynote notice, ‘Radiation Dose Issues with Digital Radiography Systems’ [2] is more specific and states that a supplier should provide the information on the kVp compensation curves or set-up methods for AEC and the recommended receptor dose for optimised images.

Literature review

The risks from radiation exposures have been studied over many years and the latest review of the data is in ICRP103 report [3]. Medical exposures represent one of the largest sources of radiation exposure [4] and therefore, in the interest of reducing the radiation dose burden on the population, it is important to monitor the doses and ensure that all the exposures are optimal. In general radiography, the risk to the patient is for long term harm due to the stochastic risk of inducing cancer rather than from skin doses which are substantially below the level to produce erythema. Therefore, in comparing doses from different systems, effective dose is used as it compares the risk even when the beam quality is very different.

Radiation doses from medical diagnostic exposures have been measured by many different authors. Huda et al [5] reviewed the doses for the United States and showed a decrease over the last 50 years of between 50% to 70%. In the UK the NRPB (now incorporated into the Health Protection Agency [HPA]) has undertaken a number of dose audits since 1986 [6]. Their reports indicate that the doses delivered to patients in English hospitals undergoing routine X-ray examinations can vary by up to a factor of 10.

A recent report authored by KCARE (CEP08040) showed that there is a large variation in patient doses for the same examinations even for systems with the same detector.

Compagnon et al [7] compared doses between CR, film/screen and direct digital radiography (DDR). They showed that DDR systems had the lowest dose, which is consistent with the detector being more sensitive. Moreover, they showed that the doses for CR were between a few percent and 50% higher than film/screen. In particular, CR gives a 28% and 41% higher effective dose for chest AP and abdomen PA respectively than film/screen.

Neofotistou et al [8] reviewed current data and summarised that CR generally required higher doses than film/screen. This is due to the loss of sensitivity at higher tube potentials and the susceptibility to scattered radiation.

The literature indicates that patients imaged using CR receive more radiation dose than those imaged with film/screen systems. However, CR has a wider dynamic range than film/screen and this means that the imaging is more forgiving of variation of dose and so can mean less repeated images. There is some evidence that CR has less repeats than film/screen [9,10].

One advantage of digital imaging systems is the separation between the acquisition and display of the image so that irrespective of the dose received by the digital detector the image will be displayed optimally. Therefore there is scope to vary the dose rather than to use a set dose which gives the correct

blackening on a film. There are no definitive methodologies for setting the dose level and the calibration of the kilovoltage compensation. Essentially this should be a clinical decision on the lowest dose to allow the image reader to see the clinical detail required. There has been some work undertaken to set generic kilovoltage correction curves based on physics measurements. However, none of these are directly related to clinical image quality. A methodology for constant detector dose indicator (DDI) was shown by Doyle and Martin (2006) [11].

Method

The aim of this project was to investigate the dose range for CR imaging across the UK by undertaking a survey of radiological practice in radiology departments, and to measure the variation in patient dose and how this variation was related to the exposure factors used. The report focuses on two frequently performed examinations; Chest PA (posterior-anterior) and Abdomen AP (anterior-posterior).

Integrated CR systems were excluded from the survey.

The project was a combination of results of system tests undertaken by KCARE and data collated from questionnaires sent to radiology departments. KCARE discussed the project with colleagues from both radiology and medical physics and enlisted the help of various interested parties. Some key contacts were the IPEM diagnostic radiology special interest group (DRSIG) and the diagnostic radiology users group (DRUG). KCARE undertook this work in conjunction with an MSc student from King's College London to increase the value of the project.

Dose and image quality measurements

Dose measurements and limited image quality measurements were performed by KCARE on a number of different CR systems. KCARE also produced a protocol for other medical physics departments to undertake the dose measurements on their systems, these are also included in the report.

The standard operating protocols (SOP) used with the CR system were first established for a single Chest PA and Abdomen AP procedure.

A number of exposures were made to determine the DDI, contrast to noise ratio (CNR) and mAs achieved by the SOP. A 9 cm PMMA phantom was used for the Chest PA and an 18 cm PMMA phantom for the Abdomen AP, with a contrast disc placed in front of the phantom. The CR plate was then processed using a manufacturer specific flat field protocol.

Entrance surface dose (ESD) and detector doses were measured using the SOP. A 60 cc ionisation chamber was placed at least 20 cm in front of the phantom and the measured air kerma was recorded. For the abdomen procedure the kVp was varied from 70 to 120 KVp in 10 kVp increments with dose measurements repeated at each kVp.

To test the AEC response, the receptor dose was measured by repeating all previous exposures with the CR cassette replaced with a semi-conductor detector (Unfors Mult-o-meter) in a special holder cassette. The receptor dose was corrected using the ratios of the measured ESDs.

Effective doses were calculated from the measured air kermas, half value layer and distances used in the standard operating protocols using the PCXMC software package.

Questionnaire

In addition to collecting dose data, a questionnaire was sent to radiology and medical physics departments to determine the local AEC set up, protocols used, model and age of the CR systems, etc.

A copy of the questionnaire is included in appendix 1.

Results

Data collected

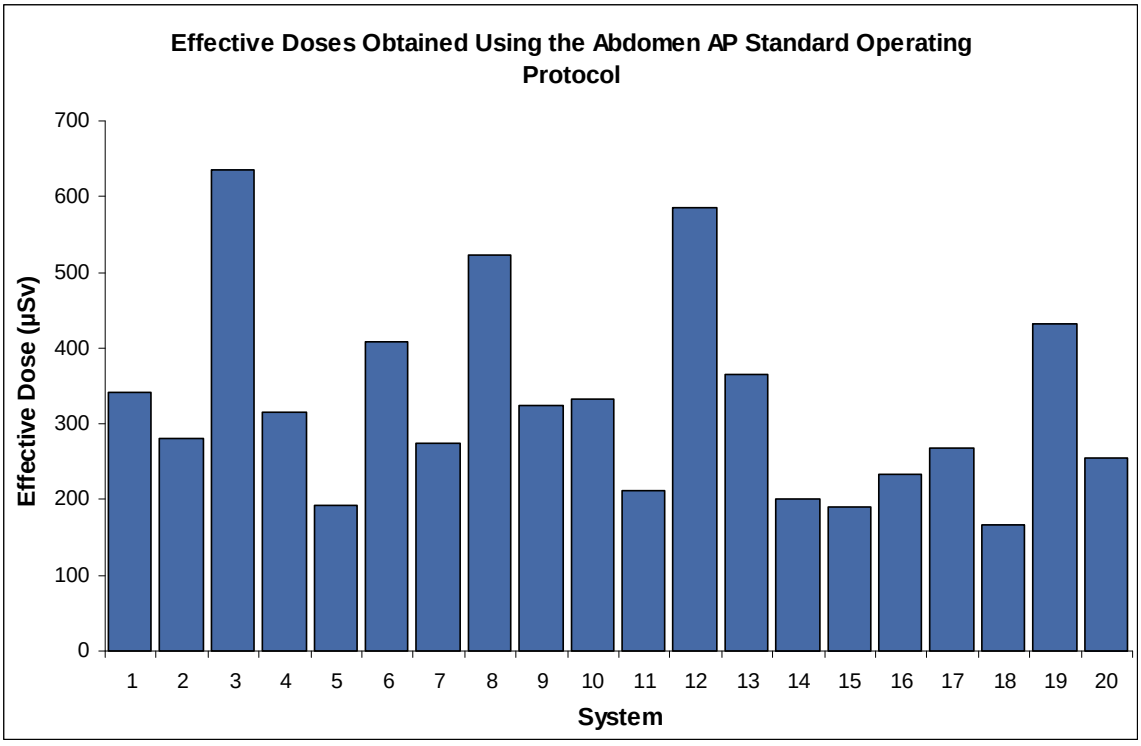
KCARE collected data from nine systems for chest exposures, and twelve systems for abdomen exposures. A further six sets of chest results and eight sets of abdomen results were returned by external medical physics groups. These external groups used a range of phantoms, some of which were slightly different to the KCARE standard set. As a result, the uncertainty in these results is slightly larger than in the KCARE-only collected dataset.

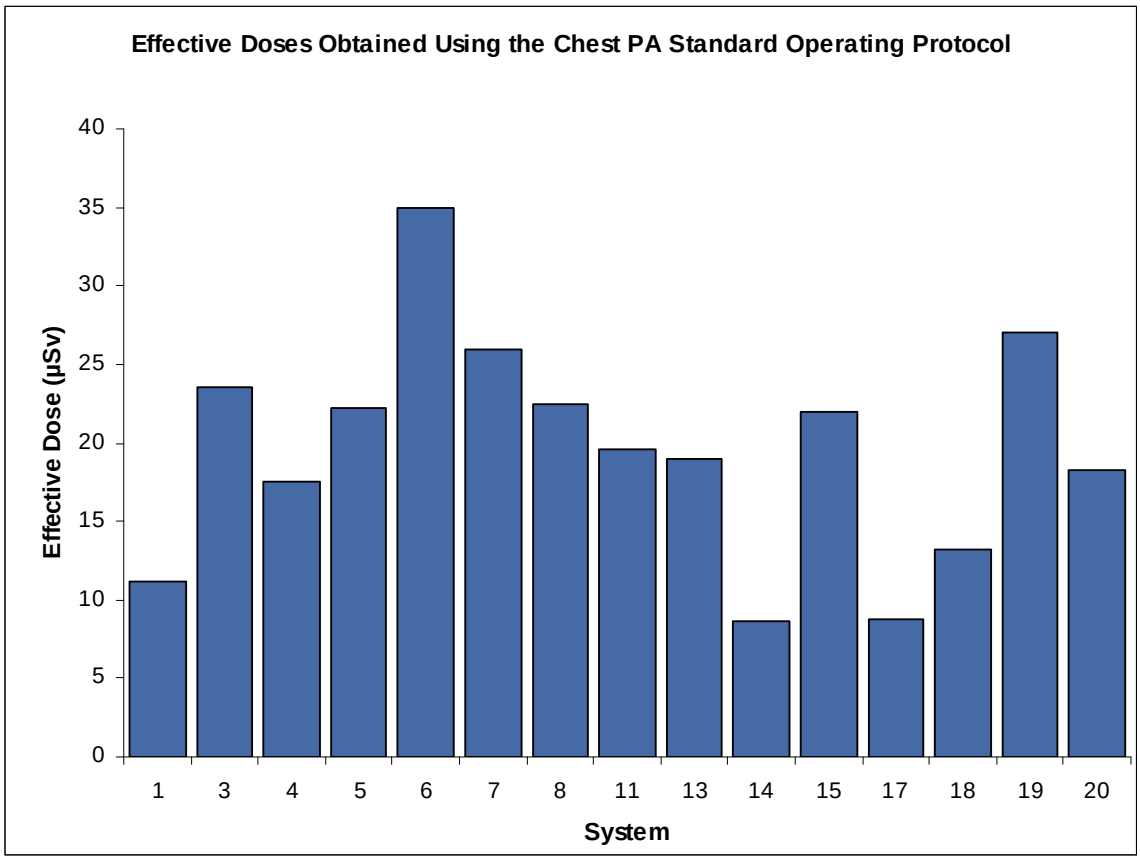
Detector air kerma (DAK)

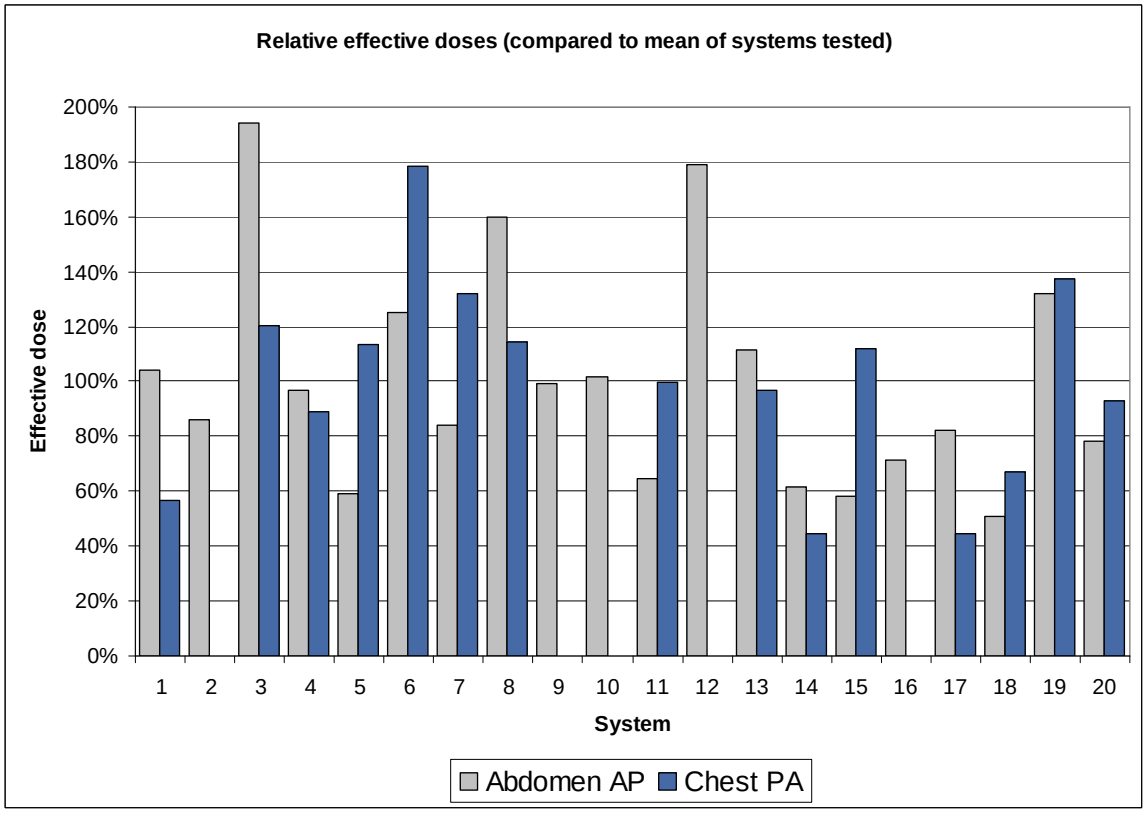
Detector air kerma (DAK) values were found to vary by a factor of more than three for abdomen examinations (2.4 µGy to 7.8 µGy) and DAKs for chest examinations varied by a factor of more than four (4.6 to 19.0 µGy). The kV compensation curves were found to exhibit a range of trends, with both increasing DAK with kVp and decreasing DAK with kVp.

Effective dose

A wide range of effective doses was found. Effective doses from abdomen procedures were found to vary by a factor of four, from 170 to 640 µSv (factor of 3.5, 170 to 590 µSv KCARE only data). Effective doses from chest examinations were found to vary by a factor of nearly four, 9 to 35 µSv (factor of 3, 9 to 27 µSv KCARE only data).




Effective Doses Obtained Using the Chest PA Standard Operating Protocol
Effective Dose (µSv)
40
35
30
25
20
15
10
5
0
1
3
4
5
6
7
8
11
13
14
15
17
18
19
20
System


Relative effective doses (compared to mean of systems tested)
Effective dose
200%
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
System
Abdomen AP
Chest PA

Variation with kVp

The chest effective dose data was divided into two groups (a 125 kVp group and a 81 to 94 kVp group, two entries were excluded at 65 and 102 kVp). These datasets were compared for both KCARE collected data and all data. No significant difference in effective dose was found between the two kVp groups ($p>0.05$).

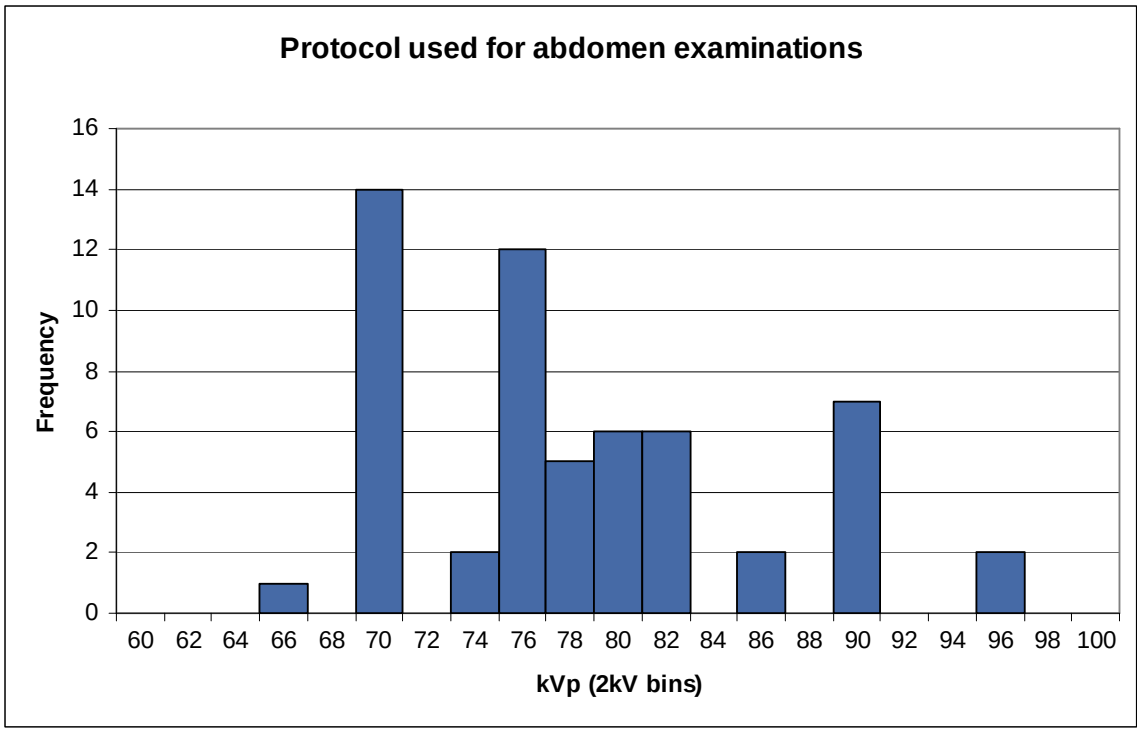
No correlation was observed between kVp and effective dose for abdomen examinations. No identifiable groups were observed in the data, which included a range of kVp values from 65 to 96.

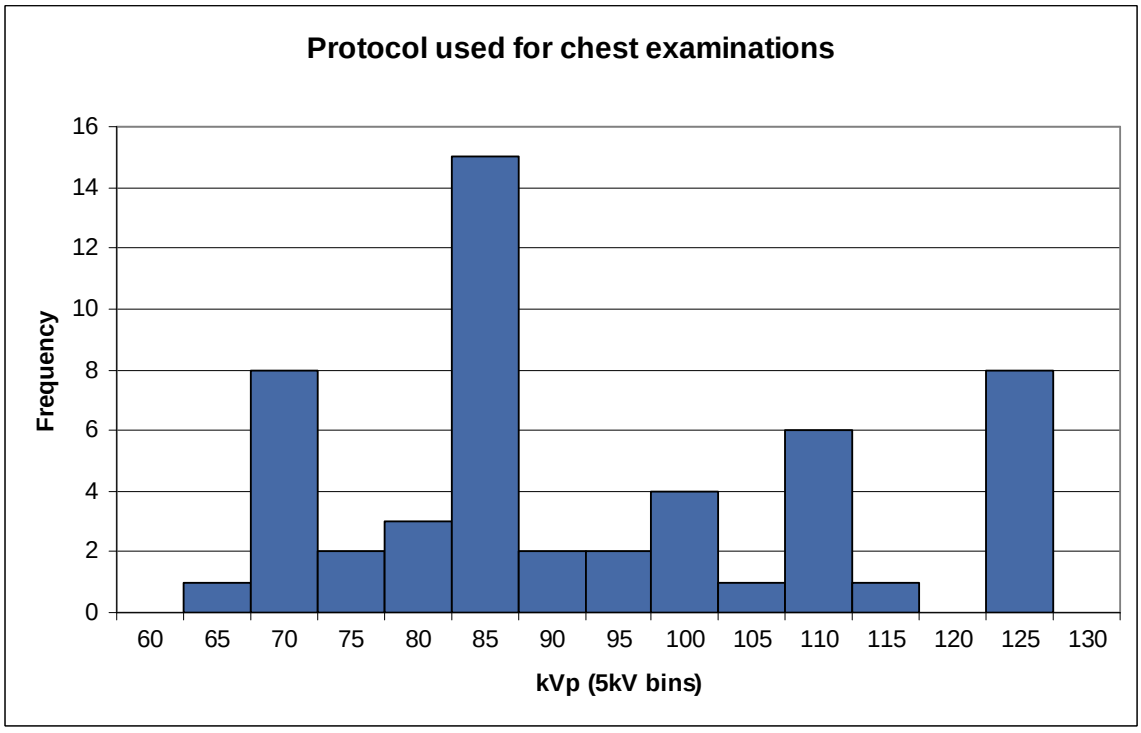
Variation between suppliers

The effective dose data was divided into groups by the supplier of the CR system. No significant difference between suppliers was found ($p>0.05$) for data collected by KCARE for either abdomen or chest examinations. While the data provided by external physics departments added some additional information, the possible selection bias and variation in phantoms used prevents any firm conclusions based on this data.

Standard operating protocols

CR users were asked to complete a survey of CR systems and standard operating protocols used for chest and abdomen examinations. KCARE received 53 responses for chest examinations and 57 responses for abdomen examinations. These responses were from over 35 locations and included CR equipment from five suppliers. All standard operating protocols for abdomen examinations used an anti-scatter grid. Three locations (five responses) used a grid for chest examinations, the remainder used no grid. Most chest protocols made use of a fixed mAs.


Protocol used for abdomen examinations
Frequency
0
2
4
6
8
10
12
14
16
60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 100
kVp (2kV bins)


Protocol used for chest examinations
Frequency
0
2
4
6
8
10
12
14
16
60 65 70 75 80 85 90 95 100 105 110 115 120 125 130
kVp (5kV bins)

Conclusions

A wide range of effective doses and detector air kerma values were found for two frequently performed X-ray examinations (chest PA and abdomen AP). No significant difference was found in dose between CR suppliers or technique (kVp) used. Detector air kerma was also found to vary considerably.

A survey of sites across the UK found a wide range of different techniques in use for both abdomen and chest examinations. Some small clusters were observed around 70 kVp and 76 to 82 kVp for abdomen examinations and 70, 85 and 125 kVp for chest examinations.

The variation in doses observed suggests that many systems may not be optimised, or may be optimised to substantially different standards. The wide variety of techniques in use may indicate that some users are continuing to use film/screen protocols, rather than protocols optimised for their CR system.

Recommendations and further work

- Further data could be collected to attempt to isolate differences between CR suppliers.
- A more reproducible protocol using a more standardised and common test object (e.g. copper) could be produced, to allow the use of data from a wider number of sites.
- Discussion could be initiated at a national level, including stakeholder groups such as the Society of Radiographers and IPEM.

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Lewisham Hospital NHS Trust
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Meriden Hospital, BMI Healthcare
Morecambe Bay Hospitals NHS Trust
Mount Vernon Hospital, West Hertfordshire Hospitals NHS Trust
North Wales NHS Trust
Northwick Park, North West London Hospitals NHS Trust
Oxford Radcliffe Hospitals NHS Trust
Plymouth Hospitals NHS Trust
Poole Hospital NHS Foundation Trust
Royal Bolton Hospital NHS Foundation Trust
Royal Devon and Exeter Foundation Trust
Royal Free Hampstead NHS Trust
Royal Leamington Spa Rehabilitation Hospital General Information
Sandwell General Hospital, Sandwell and West Birmingham Hospitals NHS Trust
Sheffield Teaching Hospitals NHS Foundation Trust
South Devon Healthcare Foundation Trust
St George's Healthcare NHS Trust
Stockport NHS Foundation Trust
Tameside NHS Foundation Trust
The Princess Alexandra Hospital NHS Trust
Whittington Hospital NHS Trust

References

1 Council of the European Union. Medical Devices Directive. 93/42/EEC. (1993)

2 MHRA, Radiation Dose Issues with Digital Radiography Systems, MHRA notice Medicines and Healthcare products Regulatory Agency, (Sep 2006) www.mhra.gov.uk/Safetyinformation/Generalsafetyinformationandadvice/Technicalinformation/Radiationdoseissuesindigitalradiographysystems/CON019628 [Last accessed 29/5/09]

3 The 2007 Recommendations of the International Commission on Radiological Protection. Annals of ICRP, ICRP publication 103. Elsevier. (2007)

4 Watson SJ, Jones AL, Oatway WB *et al*. Ionising radiation exposure of the UK population: 2005 review. HPA-RPD-001. HPA. (2005) http://www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1194947389360 [Last accessed 12/5/09]

5 Huda W, Nickoloff EL, Boone JM. Overview of patient dosimetry in diagnostic radiology in the USA for the past 50 years. Med Phys. **35**: 5713-5728 (2008)

6 Shrimpton PC, Wall B.F., Jones DG *et al*. A national survey of doses to patients undergoing a selection of routine X-ray examinations in english hospitals. NRPB-R200. NRPB. (1986)

7 Compagnone G, Baleni MC, Pagan L *et al*. Comparison of radiation doses to patients undergoing standard radiographic examinations with conventional screen-film radiography, computed radiography and direct digital radiography. Br. J Radiol. **79**: 899-904 (2006)

8 Neofotistou V, Tsapaki V, Kottou S *et al*. Does digital imaging decrease patient dose? A pilot study and review of the literature. Radiat. Prot. Dosimetry. **117**: 204-210 (2005)

9 Weatherburn GC, Bryan S, West M. A comparison of image reject rates when using film, hard copy computed radiography and soft copy images on picture archiving and communication systems (PACS) workstations. Br. J. Radiol. **72**: 653-660 (1999)

10 Strotzer M, Gmeinwieser J, Spahn M *et al*. Amorphous silicon, flat-panel, x-ray detector versus screen-film radiography: effect of dose reduction on the detectability of cortical bone defects and fractures. Invest Radiol. **33**: 33-38 (1998)

11 Doyle P, Martin CJ. Calibrating automatic exposure control devices for digital radiography. Phys Med Biol **51**: 5475-5485 (2006)

Appendix 1

This survey is part of a project to survey CR doses which KCARE has been commissioned to conduct by the Department of Health.

Any information provided which is used in the published report will be anonymous.

You can submit your response via email by clicking the button at the end of the form. Alternatively you can print the form, fill it in and post it to:

CR Dose Project
KCARE
King's College Hospital
Denmark Hill
London
SE5 9RS

If you have any questions, please contact us at crdose@kcare.co.uk. Further contact details are available from the KCARE website (www.kcare.co.uk).

Section 1. Your details

Name

Profession ☐ Physicist ☐ Radiographer ☐ Other

Trust name

Contact email

Section 2. CR system details

Type of CR system

☐ Agfa ☐ Carestream ☐ Fuji
☐ Konica ☐ Philips
☐ Other
Give details

CR Model

Age of CR System (years)

Software version

How were your AECs set up?

☐ Following manufacturer protocol
☐ Not following manufacturer protocol
☐ Don't know

Give details

Section 3. Standard protocols

Please give the standard operating protocol for:

	KV	mAs (if fixed)	Chambers (if AEC)	Grid in	Grid out	DDI	Distance (cm)
Chest							
Abdomen							

Click here to submit completed form.