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Comparison of film, hard copy computed radiography (CR) and soft copy picture archiving and communication (PACS) systems using a contrast detail test object

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Abstract. This paper describes two experiments where a widely available test object (FAXIL TO20) was used to compare film, hard copy computed radiography (CR) and soft copy picture archiving and communication systems (PACS) images. Baseline images were produced with a fixed mAs. All images were scored by four experienced medical physicists. Contrast detail curves for the three types of images were almost identical. A second series of images was produced with the mAs varying from 1 mAs to 250 mAs. The contrast detail curves were plotted for each mAs value and the wider exposure latitude of CR compared with film was demonstrated. Use of PACS provided no further increase in exposure latitude. The density of the film images increased with mAs but the density of the CR hard copy images remained constant. It is of concern that the wider latitude of the CR images extends to exposures that are much higher than those used for film with no noticeable change in CR image density but with better images at higher exposures, because the potential exists for patient doses to increase. Hard copy CR images provide information about the exposure index which relates to the input dose to the plate and hence approximately to the dose to the patient. However, since such information is currently not available on default soft copy images, the authors suggest that all manufacturers of PACS should provide an indication of dose as a mandatory default setting.

Computed radiography (CR) systems have been shown to have a wider latitude than film [1, 2] and to be advantageous by reducing the number of images that need to be repeated as a result of selecting incorrect exposure factors [3], thus producing resource savings in terms of staff time and consumables such as the cost of films and chemicals [4]. In addition, there are benefits to the patient in terms of reduction of risks associated with repeat examinations, namely: the additional radiation dose, the potential hazard caused by lifting and positioning for the repeat examination, and the additional time before a diagnosis can be made and a decision taken about the clinical management of the patient. The use of CR for imaging patients in intensive care units (ICU) and intensive therapy units (ITU) is particularly beneficial [5]. When CR imaging forms part of a picture archiving and communication system (PACS) there are additional potential benefits because the soft copy PACS images can be manipulated on screen. Changes can be made to the grey scale, contrast, density (including complete reversal of the image to produce "blackbone" images) and to magnify and rotate the images, thus providing additional information which may potentially be used for correct diagnosis from the images.

This paper describes one part of an evaluation of a small scale PACS installed at Glan Clwyd Hospital in North Wales. The hospital is a district general hospital with approximately 550 beds serving a resident population of 175 000 with an additional summer influx of tourists. A Kodak CR Model 3110 system links the Radiology Department and the ITU, which has a maximum of eight beds, via an Ethernet network (IEEE 10 Base 5, ISO 88027). In the ITU, the clinicians viewed soft copy PACS images from which they made decisions about the management of the patients. They were able to use all the facilities that were available on the workstation to manipulate the images. The radiologists in the Radiology Department chose to use hard copy CR images when making reports on the examinations. Throughout the rest of the hospital, a

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Kodak conventional film system was used and if the PACS was not working, conventional film images were used in the ITU.

The aim of this study was to undertake tests to compare soft copy images produced by the PACS, CR hard copy images and conventional film images. Simple tests were used which could be conducted by radiographers and physicists using equipment that could be readily available to the staff and could thus form part of an ongoing quality assurance programme. There were no test objects designed specifically to test PACS and none was available from the manufacturers of the equipment; thus, a protocol using FAXIL test objects designed for other purposes was devised. This paper describes two of these comparative tests.

Methods

Comparative measurements have been made to compare the images produced using the conventional film–screen system used in the hospital (Kodak TML RA film with Kodak Lanex Regular screens, speed class 400) and 35 cm × 43 cm General Purpose GP-25 phosphor plate KESPR (Kodak Ektascan Storage Phosphor Reader) images. The hard copy (CR) images are used by the radiologists to make their diagnosis and produce the radiology report, and PACS soft copy images are used by the anaesthetists in the ITU when deciding how to proceed with the management of patients. Thus, the comparison was of film, hard copy images and soft copy images. All images were produced by the senior radiographer who was in charge of, and most knowledgable about, the PACS and all images were produced on the same day.

The test object

Test object TO20 [6] was used which assesses the minimum contrast required to visualize objects of different sizes above the noise threshold. The test object includes 12 groups of detail sizes ranging from 0.25 mm to 11 mm, and in each group the contrast values range from 0.1% to 91.6% [6].

Baseline comparison of images

Choice of exposure factors

It has been shown that the response of CR plates to incident radiation is not independent of the kilovoltage used [7]. Since the examinations undertaken in the ITU are almost all of the chest, the kilovoltage selected for comparison of contrast detail was that used in the hospital for mobile chest radiography, *i.e.* around 80 kV. The mAs was selected to produce a density reading on the film images of about 1.5, measured from an area outside the test object using a Melico/Photolag transmission densitometer (model TDX).

Experimental set-up for baseline images

The test object was placed directly on the image recording device which was placed on 0.70 mm lead equivalent material to reduce backscatter. An additional beam filtration of 1 mm copper was added to the output of the X-ray tube. The mobile X-ray machine routinely used in the ITU (Picker Explorer PX301V, 3 phase 12 pulse generator battery unit with a single focus focal spot size 0.75 mm) was used to produce all baseline images. Exposures were made using both film and KESPR plates with exposure factors of 81 kVp and 1.0 mAs at 100 cm focus-to-film/plate distance. The collimators of the light beam diaphragm were opened to cover the KESPR plate completely and the collimation remained unchanged for the film exposures.

As far as could be controlled, all images were produced under the same conditions and repeated twice so that three images were obtained for each of film, CR and PACS. The exposure indexes [8] associated with the KESPR images, which give an approximate indication of the dose to the plate, were noted. These are similar to the exposure indexes produced by equipment from other manufacturers such as Fuji that use a sensitivity number, *S*, for the same purpose [9, 10].

Comparison of images produced with a change in mAs

Further exposures were undertaken to demonstrate the effect of change in mAs on each type of image. It has previously been demonstrated that the exposure latitude of hard copy CR images exceeds that of film [11]; this test aimed to determine whether the additional manipulation features of the PACS increased (or decreased) the latitude of CR hard copy images.

To obtain as wide a range of mAs values as possible without overexposing the film or plate, a higher output static X-ray unit was used (Phillips Medio 65CP generator and the broad, 1.3 mm focal spot of the Rotalix Super tube SRO 33 100) and the focus-to-film/plate distance was increased to 180 cm. The kilovoltage was reduced to 75 kV and 1 mm copper filtration was attached to the output of the X-ray tube. The mAs was then increased from the minimum value which could be obtained from the unit, 1 mAs, to a maximum of 250 mAs with all other exposure conditions and processing remaining constant. The associated exposure indexes were noted for all CR images and the density of the film and hard copy CR images was measured at a point outside the test object at a distance 6 cm below the beginning of the "Faxil" sign in the image.

Processing of images

The processing conditions of the films and laser printed images employed were those used for clinical images and were checked for consistency at the start and end of each session, using sensitometry curves and D_{max} readings, with no changes being found. All KESPR plates were processed at a standard time interval of 5 min after exposure since the time delay between exposure and processing is known to affect the resultant image [12]. The plates were all processed using the "pattern" algorithm that is provided for processing non-clinical examinations. The CR images were produced at default window settings (4095W, 2048L) and were printed on transparency film by the laser printer (Kodak Ektascan LP2180 attached to a Kodak X-OMAT LP180 processor) currently used in the Radiology Department to produce the CR hard copy images for reporting by the radiologists. The films were processed in a Kodak X-OMAT RA 480 daylight processor with 45 s processing using RA/30 developer and LO RP fixer.

Viewing and scoring of images

The CR and film images were mounted into individual numbered envelopes in which windows had been cut so that the images could be viewed, but all textual information on the images was hidden from the viewer. All images were viewed using a conventional X-ray illuminator under a protocol agreed by the viewers that reflected the advice given by FAXIL for a standard protocol [13]. The soft copy images of the test objects could not be viewed in the ITU because the workstation was situated in the middle of the clinical area in which very sick patients were cared for. Instead they were viewed in the Radiology Department on the same type of monitors (Kodak M24PMAX, 1660×1280) as in the ITU and from which images would be reported if soft copy reporting was in operation. The viewing conditions in the room in which these monitors were located were better than in the ITU; the room had no windows thus minimizing aberrant light and the viewing conditions were chosen by each of the viewers to give them their own optimum viewing conditions. The viewers were allowed to use all the tools that were available to the ITU clinicians for manipulation of the soft copy images, for example, windowing, magnification and image reversal to produce "blackbone" images, to produce the images that they considered provided the most information. For viewing all images, viewers were provided with card masks and they had the option of using a lens eyepiece if this was their normal practice. No limit was set on the viewing/scoring times or on the viewing distance.

All images were viewed and scored independently by four medical physicists, two from the Medical Physics Department serving Glan Clwyd Hospital, and two from the Medical Physics Department in Oxford. All four viewers were experienced in viewing and scoring the test object images and were familiar with the information that should be present and observable in an image containing all information within the test object. However, the observers were not told the conditions under which the images were produced. In addition, the two local medical physicists re-scored one image for each test on three occasions, with an interval of at least 1 week between each set of scores.

Analysis and graphical display of data

For each image, the 12 sets of detail sizes were each scored by all four viewers. For the baseline test there were three images for each system, *i.e.* film, CR hard copy and CR soft copy (PACS). In addition, for one image of each type there were two scores that had been undertaken on each of two subsequent reading sessions. Thus, for each type of image there were 16 readings. The mean, maximum and minimum values of the scores for each set of 16 readings were found and the results used to plot second order polynomial contrast detail curves using Fig P software [14]. This software also produced statistics concerning the F-distribution [15] relating to the fit of the data on each curve.

The relative displacement of the curves from the bottom left-hand corner gives an indication of the relative merits of the images of the test object. The curve with greatest displacement from the bottom left-hand corner towards the top right-hand corner indicates the best image in terms of visualization of the detail within the test object. The upper left of the curve represents the ability to detect large detail, low contrast objects whilst the bottom right represents fine detail, high contrast objects. The curves for the film, CR and PACS images that were produced when film and phosphor plates were exposed under the same conditions were plotted on the same axes to allow visual comparisons to be made.

Results

Baseline images

The mean exposure index for the CR images was 2033. The contrast detail curves are shown in Figure 1. This figure shows that under these exposure conditions, the curves are almost identical for film, CR hard copy and PACS soft copy images and the F-distributions showed that all curves had good fit for the data.

Images with change in mAs

The contrast detail curves that were produced with variation in mAs are shown in Figures 2 to 9. The densities of the film and hard copy CR images and the exposure indexes associated with the KESPR images for each mAs are shown in Table 1 and presented in Figure 10.

For all three image types, the displacement of the curves from the large detail/high contrast part of the axes increased with increase in exposure from 1 mAs to 4 mAs. At 8 mAs the CR hard copy and PACS soft copy images improved compared with film, which showed little change. Between 16 mAs and 250 mAs the CR hard copy and PACS images improved very noticeably compared with film images, which became too dense for any information to be identified. For film, the error bars on the curve obtained at 32 mAs extend down to the *x*-axis indicating that some readers could identify none of the details within the test object whereas for both CR hard copy and soft copy images more information was seen than in images produced at lower mAs values. In the curves for higher mAs values, both hard copy CR and PACS images improved as the mAs increased and were still found to be improving at 250 mAs. The contrast detail curves show the maximum exposure latitude for film to range from 1 mAs to 32 mAs and that for

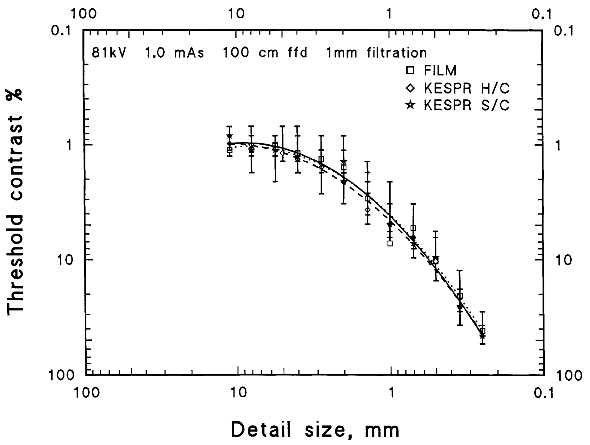

Figure 1. Contrast detail curve for Leeds test object TO20, Glan Clwyd Hospital, December 1996.

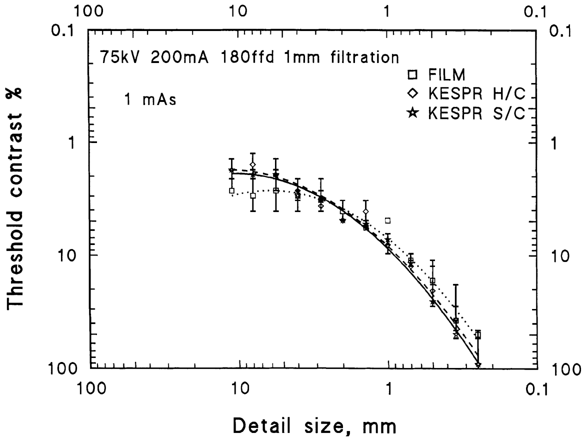

Figure 2. Contrast detail curve for Leeds test object TO20 at 1 mAs.

CR hard copy and PACS to range from 1 mAs to at least 250 mAs.

The response of the conventional film to increase in mAs was an increase in density from 0.37 at 1 mAs to 3.11 at 32 mAs. Further increase in mAs produced densities that were too high to be read, and too high for any of the image to be identified, even with a bright light. The density of the CR hard copy image remained almost constant when the mAs increased from 1 mAs to 250 mAs (mean 0.62, range 0.60–0.65).

The value of the exposure index indicated on the hard copy CR films increased as the mAs increased. CR images produced at both 1 mAs and 2 mAs had a very mottled appearance due to underexposure of the plate and the associated exposure indices were 1470 and 1730.

Discussion

Baseline images

Contrast detail curves for the three types of images compared were virtually identical when they were exposed at the kilovoltage normally

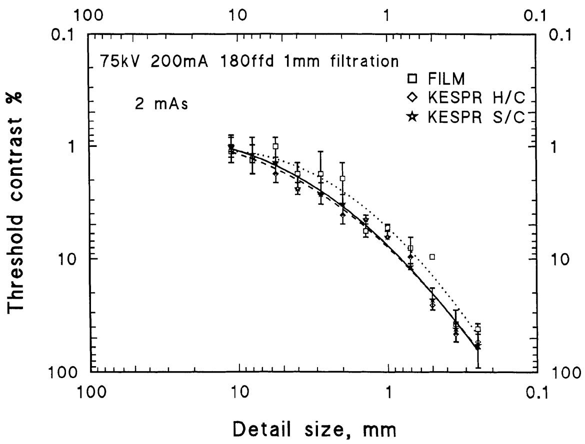

Figure 3. Contrast detail curve for Leeds test object TO20 at 2 mAs.

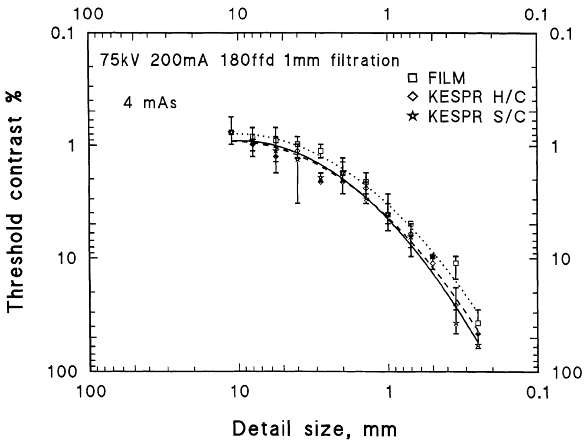

Figure 4. Contrast detail curve for Leeds test object TO20 at 4 mAs.

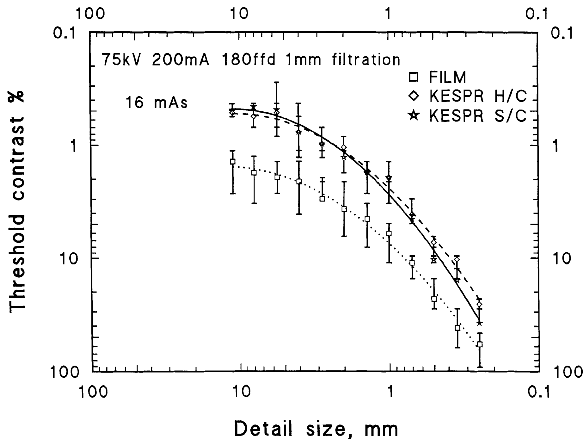

Figure 6. Contrast detail curve for Leeds test object TO20 at 16 mAs.

used for mobile chest examinations (81 kV) in the ITU and with 1.0 mAs and 100 cm focus-to-film/plate distance. This is the result that was expected because all three types of image may be utilized in the Unit and the KESPR system was set up to produce images similar to film images. Thus, the use of this test object to produce contrast detail curves appears to be a valid method for comparison of the three types of images and to form a baseline for subsequent comparisons and could be incorporated in a routine quality assurance programme.

Comparison with other studies

Exposure latitude

The results of the study of images with change in mAs were similar to those found by Broderick et al [11] who, using chest and pelvis images of anaesthetized rabbits, compared film–screen images with hard copy CR images. They found that the exposure latitude for film related to a range of 1.1 mAs and for CR hard copy related to a range of 255.6 mAs. The results of the study described here confirmed the expected wider latitude of the CR hard copy images compared with film images. In addition, this study showed that although soft copy manipulation facilities were available on the PACS workstations and were used by the viewers, little additional information was obtained compared with hard copy CR images. However, the increased latitude of CR and PACS systems occurred at exposure values above the optimum film exposure value rather than below it, and additionally, improved CR and PACS images were obtained with increased exposures. This is of concern because there is the danger that exposure factors that are higher than necessary will be used in order to improve images.

Indication of image/patient dose

When film images are used the density of the image increases with mAs and when the film has received a dose of radiation that is too high, the corresponding film density can be seen to be too high. Conversely, underexposed films have densities which are too low. The radiographer is thus able to see overexposure or underexposure of a

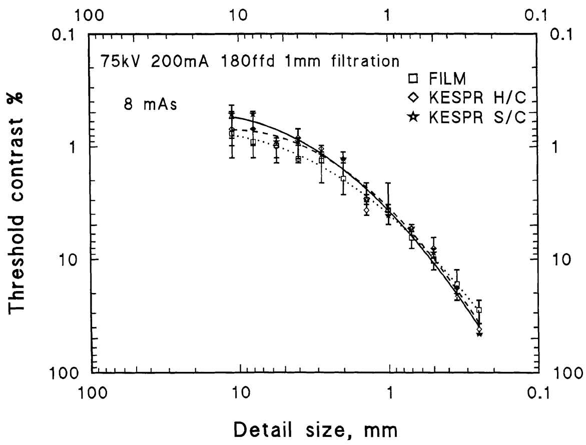

Figure 5. Contrast detail curve for Leeds test object TO20 at 8 mAs.

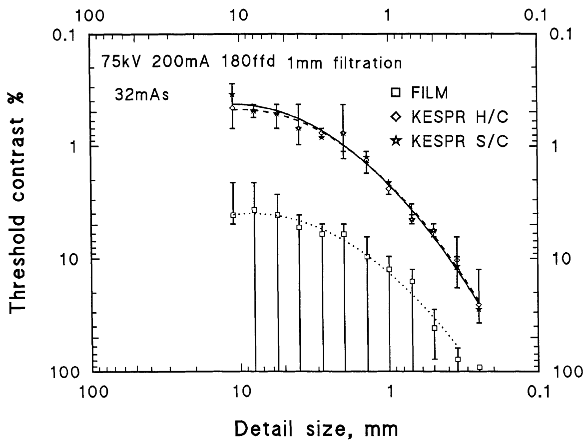

Figure 7. Contrast detail curve for Leeds test object TO20 at 32 mAs.

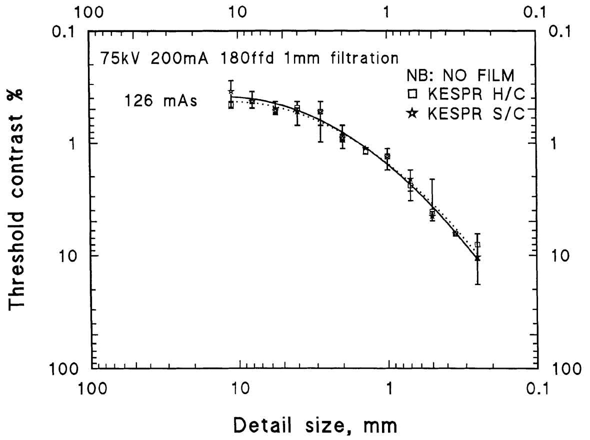

Figure 8. Contrast detail curve for Leeds test object TO20 at 126 mAs.

film (and hence the patient), by visual inspection of the film image. Images produced by CR techniques do not have similar, observable indications of overexposure or underexposure. For some years [16] and at the time of this study, the hard copy CR images provided information about the exposure in the form of the exposure index, which is an approximate indication of plate/patient dose, an increase in exposure index indicating an increase in dose. There was no such indication of patient radiation dose on the soft copy image. Since the completion of this study and the circulation of a draft report, Kodak has adapted the system so that the exposure index can now be obtained for soft copy images. However, this information is not available on the default image. If a user wishes to know the value of the exposure index associated with a soft copy image, it can be obtained by opening a window, clicking on a menu bar and opening an information box, but it must be noted that this is not part of the default information on the soft copy image.

When a radiographer undertakes an examination of a patient who has already been examined

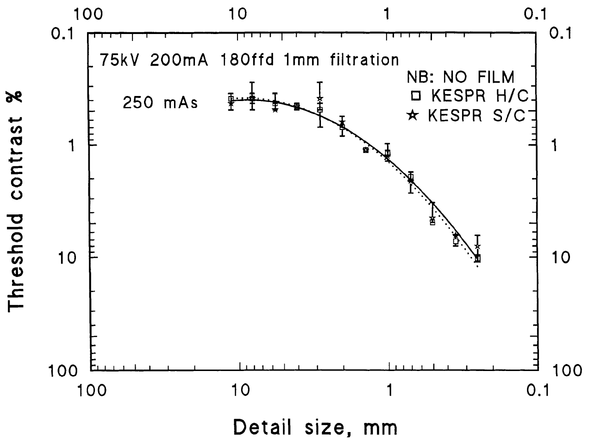

Figure 9. Contrast detail curve for Leeds test object TO20 at 250 mAs.

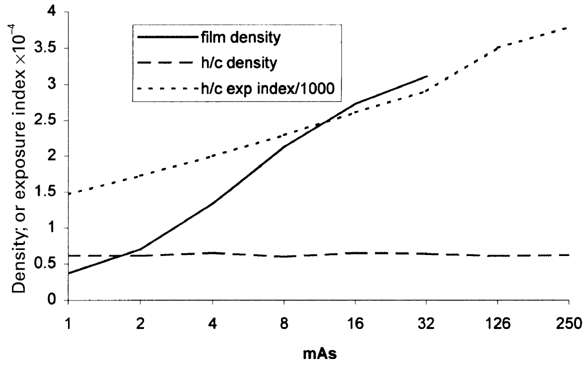

Figure 10. Comparison of the responses of film and CR hard copy to variation in mAs.

using the KESPR system and whose image is stored locally on the hard disk of the workstation, information about the first examination is available at the quality control workstation (QCW) to assist the radiographer when undertaking subsequent examinations. Details of the exposure factors (kV and mAs), focus-to-film distance, patient position and processing algorithm used are immediately available but the exposure index is not provided. It is the view of the authors that the exposure index should be part of the information provided to assist the radiographer undertaking the next examination in order to allow the radiographic technique to be adapted if the exposure index indicates that the patient radiation dose is higher than expected. It is unlikely that, when images are satisfactory, users of the system will routinely search for information about the exposure index but it is likely that this information will only be sought when there is a problem with an image such as when the image has "mottle" caused by underexposure.

It should be noted that the optimum value of the exposure index depends on the set-up and calibration of the unit, and may vary for the same unit after recalibration and is likely to vary between similar units. However, after calibration a baseline range of optimum exposure indexes is available and, for the Kodak system, higher values suggest higher plate doses. For the PACS discussed in this paper, during the period of the study the manufacturer recommended that exposure indexes in the range 1800–2000 should be obtained. It had previously been recommended that exposure indexes between 1600 and 1800 should be obtained [17]. The CR curves shown in Figure 1, which are almost identical to the film curve, were produced with an exposure index of 2033, *i.e.* higher than the recommended value. Indeed it was found in clinical practice that it was necessary to obtain values around 2200, otherwise the radiologists commented that some images were unsatisfactory for diagnosis owing to the

Table 1. The variation of the measured density of film and hard copy CR images and the exposure index of the KESPR images with change in mAs

Exposure factor (mAs)	Film density	CR density	CR exposure index
1	0.37	0.61	1470[a]
2	0.70	0.61	1730[a]
4	1.34	0.65	2000
8	2.13	0.60	2290
16	2.73	0.65	2610
32	3.11	0.64	2910
126	Off scale	0.61	3510
250	Off scale	0.62	3800

[a] The image had a very "mottled" appearance owing to underexposure.

presence of a mottled appearance and the examination had to be repeated.

PACS equipment from other manufacturers

The CR system studied in this paper was manufactured by Kodak, but the lack of information relating to patient dose on soft copy images is not unique to their equipment. The PACS produced by both General Electric and Agfa, which are installed and operating in the UK, also provide an indication of dose on hard copy images but do not provide this information on soft copy images by default. It is the view of the authors that this information should be available by default on all soft copy images in order to ensure that an increasing drift in exposures does not occur with a subsequent increase in population dose.

Conclusions

The CR system tested had a much wider latitude than film with doses that were higher than those that produced acceptable film images. Since there is no indication of plate/patient dose by default on soft copy images there is the danger that, in order to improve the information in the images, patients will receive higher doses than are necessary for a diagnosis to be made.

Users should be made aware that, whilst increasing dose (by more than 250 times as demonstrated here) improves the image, this is not consistent with the ALARA principle [18]. Manufacturers of equipment should provide information on the default soft copy images that gives some indication of the patient dose associated with the production of the image.

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