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SHORT COMMUNICATION

Lumbar spine radiography — poor collimation practices after implementation of digital technology

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Objectives: The transition from analogue to digital radiography may have reduced the motivation to perform proper collimation, as digital techniques have made it possible to mask areas irradiated outside the area of diagnostic interest (ADI). We examined the hypothesis that collimation practices have deteriorated since digitalisation.
Methods: After defining the ADI, we compared the proportion of the irradiated field outside the ADI in 86 digital and 86 analogue frontal lumbar spine radiographs using the Mann–Whitney test. 50 digital images and 50 analogue images were from a Norwegian hospital and the remainder from a Danish hospital. Consecutive digital images were compared with analogue images (from the hospitals' archives) produced in the 4 years prior to digitalisation. Both hospitals' standard radiographic procedures remained unchanged during the study. For digital images, the irradiated field was assessed using non-masked raw-data images.
Results: The proportion of the irradiated field outside the ADI was larger in digital than in analogue images (mean 61.7% *vs* 42.4%, $p<0.001$), and also in a subsample of 39 image pairs that could be matched for patient age ($p<0.001$). The mean total field size was 46% larger in digital than in analogue images (791 cm^2 *vs* 541 cm^2).
Conclusion: Following the implementation of digital radiography, considerably larger areas were irradiated. This causes unnecessarily high radiation doses to patients.

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In medical imaging, radiation doses to patients should be kept as low as reasonably achievable [1]. This requires proper collimation. Limiting the irradiated field to the area of diagnostic interest (ADI) is essential, since the dose increases with irradiated area [2]. Digital image processing programs can be used in daily practice to mask an unnecessarily large collimation so that you can no longer see whether the image is optimally collimated or electronically edited [3]. This could reduce the motivation to carry out proper collimation. However, no previous studies have evaluated this issue. We therefore examined the hypothesis that collimation practices have deteriorated since the implementation of digital radiography.

Methods and materials

This study was conducted at a large Norwegian and a smaller Danish hospital. To avoid any temporary changes in collimation practices owing to the study itself, the data acquisition was completed prior to informing the relevant staff. Norwegian Social Science Data Services approved the study. No approval was required from the Danish Data Protection Agency or the appropriate research ethics committee.

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Sampling of images

We included 86 analogue and 86 digital lumbar spine frontal radiographs, 50 of each from the Norwegian hospital and 36 of each from the Danish hospital. Both hospitals' lumbar spine radiography procedures remained unchanged for the duration of the study. An image was eligible for this study if the patient was aged over 18 years and the image was not taken using fluoroscopic guidance (not an acceptable practice) and did not reveal osteosynthesis materials (may require larger collimation).

In both hospitals' archives, analogue images were stored in envelopes that were sorted consecutively by date of birth, year of birth and social security number. Starting with an arbitrary date of birth, consecutive envelopes were searched for eligible images from the last 4 years prior to both hospitals starting digitalisation in 2000. The images were included consecutively in the order they were found. Eligible digital images from 1 January 2008 to 1 September 2008 were included consecutively in the order they had been taken, from three radiography rooms at the Norwegian hospital and from the only radiography room at the Danish hospital used for lumbar spine radiography. Sampling continued until the stated number of images had been included from each hospital.

Collimation

To assess collimation, size measurements (in centimetres) were made of the analogue films using a ruler. Digital raw-data images showing the total non-masked irradiated field were only available at the radiography rooms' workstations, which lacked practical tools for measuring size. The measurements were therefore made on the workstations' monitors using a physical ruler. The monitors displayed the images at reduced size. We calculated the proportion of the irradiated field that was outside the ADI for each analogue and digital image. Finally, we compared the proportions outside the ADI for the analogue and digital images as a whole.

We defined the ADI for the purpose of this study based on the literature [4], the Norwegian hospital's standard projection and measurement considerations. This ADI served as a reference enabling collimation to be compared between images — not as a standard against which every collimation can be judged. It was defined as the area bordered cranially by a horizontal line at the cranial border of the medial part of the 12th rib, caudally by a horizontal line at the caudal border of vertebra S1, and laterally on each side by a vertical line at the lateral border of the transverse processes.

The height and width of the total irradiated field were measured, as was the distance from the ADI to the outermost edge of the irradiated field on the cranial, caudal, right and left sections of the image (Figure 1). The same observer performed all the measurements. To assess measurement variations, this observer measured all distances twice on 10 analogue and 10 digital images in a pilot study. As a percentage of the mean measured distance, the mean (maximum) difference between the two measurements was 1.4% (7.8%) for analogue and 2.0% (7.8%) for digital images.

The percentage of the irradiated field outside the ADI in the cranial part of the image was calculated as the height of the cranial area outside the ADI divided by the total height of the irradiated field multiplied by 100. Similar calculations were performed for each image section and for the total area outside the ADI (Figure 1). It was not possible to perform these calculations for images lacking parts of the ADI and therefore they were not included (4 of 90 digital and 8 of 94 analogue, otherwise the rest were eligible images).

We also calculated the mean total irradiated field size in square centimetres. For analogue images, we used the measured mean value. Since digital images were visualised at a reduced size on the monitors, the measured mean value for these images was scaled up. We assumed an equal mean size of the ADI in square centimetres in digital and analogue images (unchanged patient size after digitalisation). We defined the scaling factor, f, as the measured mean ADI for analogue images divided by the measured mean ADI for digital images. The mean total irradiated field size in square centimetres for digital images was calculated as the measured mean size multiplied by f.

The assumption of equal mean size of the ADI in square centimetres in digital and analogue images was supported by digital test images of a steel ruler placed inside the computed radiography (CR) cassette at the Danish hospital. A 10.0 cm distance on the steel ruler measured 5.2 cm on the monitor when the ruler was placed vertically and 4.9 cm when it was placed horizontally. We multiplied the mean ADI measured on this monitor by: $1/(0.52 \times 0.49)$. The resulting mean ADI (751 cm^2) for digital Danish images was similar to the mean ADI for analogue Danish images (773 cm^2, *i.e.* only 2.9% larger). Partly owing to the reorganisation of radiography rooms, we did not obtain test images of a ruler at the Norwegian radiography rooms.

Analysis

We compared results from digital and analogue images using the Mann–Whitney test, because histograms indicated that the data distribution differed from the normal distribution. Since patient age could affect collimation, the area outside ADI was also compared in those digital and analogue images that could be matched in pairs by patient age in whole years (39 image pairs comprising 78 of the 172 included images).

Results

The proportion of the irradiated field outside the ADI was larger in digital than in analogue images (mean 61.7% *vs* 42.4%, $p<0.001$). The distance from the ADI to the outermost edge of the irradiated field was larger cranially, caudally and on both sides ($p<0.001$) (Table 1).

The irradiated area outside the ADI was also larger in digital than in analogue images at each hospital (Norwegian: mean 63.1% *vs* 37.5%; Danish: mean 59.8% *vs* 49.1%; $p<0.001$ for both). This applied to all sections of the Norwegian images ($p<0.001$) and laterally ($p<0.001$), and caudally ($p=0.012$) but not cranially ($p=0.66$) in the Danish images.

Patients in the digital group were older (mean 57 years, median 58 years, range 19–87 years) than patients in the analogue group (mean 52 years, median 51 years, range 18–94 years). However, the age difference did not contribute to an increase in irradiated area outside the ADI. In images matched for patient age the proportion of the irradiated field outside the ADI was significantly larger in the digital than in the analogue images (mean 60.9% *vs* 38.0%, $p<0.001$).

In the whole sample, the mean total irradiated field in digital and analogue images was 791 cm^2 and 541 cm^2, respectively (*i.e.* 46% larger in digital images).

Discussion

We found a marked and consistent deterioration in collimation of lumbar spine radiographs at two different hospitals, with considerably larger areas being irradiated

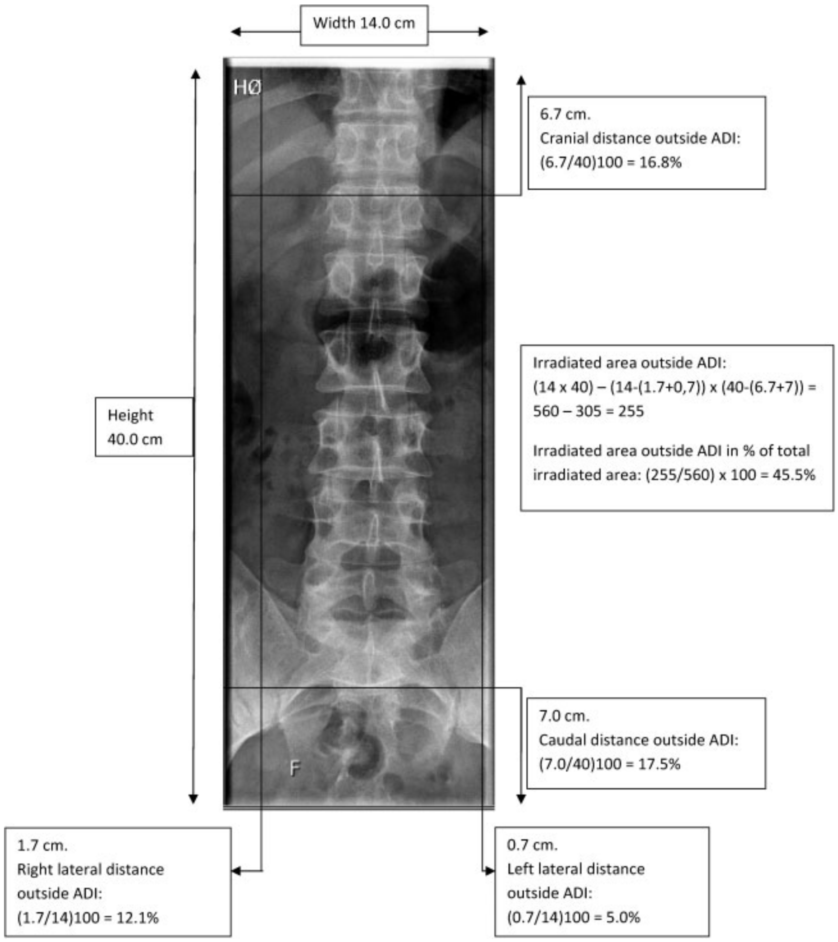

Figure 1. Example of measurements and calculations based on the area of diagnostic interest (ADI).

after the implementation of digital radiography. The 46% increase in irradiated field size indicates a similarly higher radiation dose to patients. Such an increase may go unnoticed, since it can be masked on the final images.

The lumbar region contains radiation-sensitive tissue types and has greater tissue thickness, which in turn can produce scattered radiation [5]. Lumbar spine radiography contributed a larger mean effective dose per 1000 inhabitants in Norway in 2002 (39 mSv) than any other radiographic examination except barium enema (64 mSv) and pelvic/hip radiographs (45 mSv) [6]. Based on national data from 2006, the Danish National Board of Health states that a 1.4 mSv effective dose is the reference dose for lumbar spine radiography and that a 7 mGy entrance skin dose (ESD) is the reference dose for anteroposterior projection [7]. Our findings indicate that improved collimation could be used to lower these doses.

In daily practice, the irradiated field cannot exactly match the ADI. Attempts to achieve this would result in frequent retakes. However, large radiation doses can be avoided by, at the least, reverting to the ''analogue'' collimation practice (analogue images were also substantially bigger than the ADI). To achieve this, one might consider continued focus on collimation in the education of radiographers, standard procedures that do not allow masking of the irradiated area and automated

Table 1. Irradiated field outside the area of diagnostic interest (ADI) in 86 analogue and 86 digital lumbar spine frontal radiographs

	Mean (minimum–maximum)	
	Analogue	**Digital**
Total area outside ADI as a % of total irradiated field	42.4 (15.4–63.1)	61.7 (47.6–82.4)
Cranial distance from ADI to edge of irradiated field as a % of total irradiated height	14.4 (0.3–2.8)	21.3 (4.4–40.4)
Caudal distance from ADI to edge of irradiated field as a % of total irradiated height	12.9 (0.3–40.3)	18.5 (0.0–32.9)
Left lateral distance from ADI to edge of irradiated field in % of total irradiated width	10.7 (0.8–24.7)	17.5 (4.7–33.7)
Right lateral distance from ADI to edge of irradiated field as a % of total irradiated width	10.3 (0.7–28.8)	19.2 (8.3–47.1)

All percentages are significantly larger for digital images than for analogue images: $p<0.001$, Mann–Whitney test.

technology that closes the collimators when new projections are selected to ensure active collimation.

This study has both strengths and limitations. We took the opportunity to assess changes in collimation practices before the analogue images were destroyed. Hospitals in Norway and Denmark are obliged to store all radiological images for at least 10 years and the study hospitals had all relevant images available. We ensured that there was time for any new ''digital'' collimation practices to develop, we did not assess images from the first 3 to 5 years after digitalisation. During this period, factors other than digitalisation could cause poorer collimation practices. However, we ruled out two potential causes, that is, changed radiography procedures and increased patient age.

Data on radiation dose, patient size and radiographer characteristics were not available. However, the large image samples prevented random errors owing to uneven distribution of patient size in the two image groups and ensured that many different radiographers had produced the images. Based on rotation plans, workforce size and the length of the data acquisition period, we estimate that the digital images were taken by 47 different radiographers. The analogue images were from a longer time period and may therefore have involved a larger number of radiographers. We have no data indicating that the deterioration in collimation may be due to reduced radiographer experience.

Our consistent findings regarding lumbar spine radiographs from two different hospitals in two different countries may also be valid elsewhere. Collimation can be masked on any digital projection and we are not aware of any specific issues related to lumbar spine imaging that would cause poorer collimation compared with other images after digitalisation. Our findings are therefore likely to apply to other digital images, but this will need to be confirmed in further studies.

Conclusion

This initial study of lumbar spine radiographs provided support for the hypothesis that collimation practices have deteriorated since the transition from analogous to digital X-ray equipment. Such a change in practices causes unnecessarily high radiation doses to patients and should be reversed.

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