Can scatter correction software replace a grid in DR pelvic examinations?

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CAN SCATTER CORRECTION SOFTWARE REPLACE A GRID IN DR PELVIC EXAMINATIONS?

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The purpose was to examine if scatter correction software could replace a grid while maintaining image quality and reducing radiation dose for pelvic DR examinations. Grid images was produced with 70 kV and 16mAs. Anthropomorphic- and Contrast Detail RADiography (CDRAD) non-grid images were produced with 60 kV, 80 kV and 90 kV combined with five different mAs and scatter correction software. The anthropomorphic images were analyzed by absolute Visual Grading Analysis (VGA). The CDRAD images were analyzed using the CDRAD analysis software. The results showed a total of 54.6% non-grid images were evaluated as unsuitable for diagnostic use by the VGA. The CDRAD grid images showed that the IQF_inv values were significantly different (p = 0.0001) when compared to every group of non-grid images. Hereby, the conclusion stated that the scatter correction software did not compensate for the loss in image quality due to scattered radiation at the exposure levels included in a pelvic examination.

INTRODUCTION

The use of pelvic digital radiography (DR) examination in Danish hospitals is increasing, and is one of the 10 most performed examinations in the medical imaging departments1. With this frequency, and the relatively high radiation dose, this type of examination is prioritised in the optimisation process when a new technical development is available2. The main challenge regarding image quality in pelvic DR examinations is that the combination of high kV and compact bone structure covered by muscles and fat (soft tissue) generate scattered radiation3. As (some of) the scattered radiation will also hit the detector, but without any structural information about the tissue, the effect of the scattering on the resulting image is to decrease the image contrast4. The reduced visual contrast might affect the radiologist’s interpretation of anatomical structures and therefore influence the diagnosis. Usually a grid is used to filter out (some of) the scattered radiation before hitting the detector, resulting in improved image quality, but on the expense of also increasing the radiation dose with a factor 2–6, depending on the characteristics of the grid (ratio and lines per cm)4. As radiation sensitive organs are included in the radiation field in pelvic examination, the growing risk for a radiation induced cancer is 1:10 0005.

Newly released scatter correction software (Control Software NE V2.14 with Scatter Correction, Canon Europe, Amstelveen, The Netherlands) is developed to remove the scattered radiation, improve image quality and in theory make it possible to reduce the radiation dose6. Canon has made a pilot test evaluation of the software in clinical mobile X-ray chest examinations, although not using a proper scientific method. The project was based on comparing 80 bedside chest examinations taken with a grid with the follow up without using a grid on the following day. The radiologists involved were not aware of the change in technical setup and concluded that using the software and going from an average exposure setting of 141 kV and 1.25 mAs to 0.5 mAs, the image quality could be maintained with a 60% decrease in radiation dose7.

Other companies have developed similar software, and a few papers/posters where their software is tested or described have been published. Fuji Film released a software described as a virtual grid that automatically adapts its processing to replicate the use of a grid to reduce image quality degradation caused by scattered...
radiation\(^8\). Philips made a scatter correction software called SkyFlow that seems to have the potential to allow for grid-less image acquisition in mobile chest radiography with an image quality approaching that of grid images\(^9\)–\(^11\). The software seems to have an overall potential for dose reduction, but tests for pelvic examination settings, using both technical and anthropomorphic phantoms and with extensive image analyses by independent research groups are, to our knowledge, still missing. The aim of this study was to examine if newly released scatter correction software could replace a grid while maintaining image quality and reducing radiation dose for pelvic DR examinations.

MATERIALS AND METHODS

Two different sets of images were produced and analysed. One set included 70 radiographs of an anthropomorphic pelvic phantom, and one included 570 radiographs of a technical phantom. The images were taken with varying exposure settings (mAs and kV), and the effects on image quality using the scatter correction software were studied.

DR system, detector and scatter correction software

A DR system with a CXDI-401C detector and a MLT(S) MFP version NE 7.1 software (Canon Europe, Amstelveen, The Netherlands) was used for all the radiographs. The processing settings for the pelvic examinations were optimised for clinical practice by DR super users based on recommendations by the manufacturer\(^12\). For comparison, an image taken using a grid focused to 110 cm source to image distance (SID), 52 lines/cm and a ratio on 8:1 (Dunlee Medical Components, Best, The Netherlands) was also included.

The scatter correction software has three overall parameter settings. The first setting, called Kernel, is set depending on the tube voltage used (kV). The second, called Ratio (values 0–10)\(^6\), corresponds to the ratio of the scattered radiation filtered by the virtual grid. The third setting, Target Type, is selected according to organ type, and in our experiments set to ‘pelvis’. All parameter settings are summarised in Table 1.

Phantoms

A Sectional Lower Torso Phantom (SK 250, The Phantom Laboratory, New York, USA) was used to visualise the lumbar spine, the pelvic and the proximal part of the femur bone closest possible to human anatomy. Using anthropomorphic phantoms in combination with observer panels in optimisation efforts are both extensive and costly, but the best way to reach a result comparable to the clinical practice in patients, even with the limitations that phantom gives. Using technical phantoms, as for instance the conventional Contrast Detail RADiography phantom (CDRAD) (version 2.0, Artinis, Elst, The Netherlands) is another way to evaluate image quality optimisation, although the results are difficult to compare to results based on anatomical structures in patients. On the other hand, the quality assessments of technical phantom images can be evaluated by a computer, yielding an objective indicator of image quality, and with no need of an expert panel. Therefore, a CDRAD phantom experiment, using 21.5 cm Plexiglas in front of the phantom as absorber corresponding to thickness of the pelvic anthropomorphic phantom\(^13\), was also conducted.

Technical settings

The imaging parameters for both anthropomorphic and technical phantom images are listed in Table 1. The grid image is taken at exposure settings comparable to those used in clinical practice. The experimental image exposure parameters include three different kV levels matching the kernel settings in the anti-scatter software and closest possible to the grid image\(^6\), \(^14\). These kV settings were chosen to match the kVs for optimal performance of the scatter correction software. The mAs values chosen to yield images with both higher and lower Signal to Noise ratios (SNR) of the processed image compared to the grid image to test how the software can compensate. Furthermore, we aimed for images with different Contrast to Noise ratios (CNR), both higher and lower than the grid image, to achieve images with visually different contrast. The settings are comparable to experience from a clinical pilot study\(^7\), also including higher absorbed radiation dose to investigate if the scatter correction software could improve image quality. A 110 cm source to image distance

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**Table 1. Technical parameters used in the experimental exposures.**

<table>
<thead>
<tr>
<th>Settings</th>
<th>kV</th>
<th>mAs</th>
<th>Grid</th>
<th>Software ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid image</td>
<td>75</td>
<td>16</td>
<td>Yes</td>
<td>Off</td>
</tr>
<tr>
<td>Experimental images</td>
<td>60</td>
<td>6.3</td>
<td>12.5</td>
<td>25 32</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>4</td>
<td>8</td>
<td>10 12.5</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>3.2</td>
<td>6.3</td>
<td>8 10 12.5</td>
</tr>
</tbody>
</table>
(SID), large focal spot, and a collimation of 26 × 36 cm for the pelvic and 28 × 28 cm for the CDRAD phantom, was used. For each exposure level, the Dose-Area-Product (DAP), the deviation indices (DJ), and the reached exposure index value (REX) were recorded. The DAP is measured by a DAP-metre attached at the X-ray tube. The REX value was measured on the background of a manually selected region of interest (ROI) placed within the caput femoris area. Both the DAP and REX value were measured as averages over 10 repeated exposures. All parameters, except for dose and the scatter correction software parameters (see Table 1), were kept constant during the exposures.

The 74 anthropomorphic phantom images were obtained through three kV settings and five mAs settings, using four levels of the scatter correction software ratio, respectively. These parameter combinations gives 60 images, plus the grid image, as illustrated in Table 1. Additionally, 13 of the images were duplicated in order to measure intra-observer agreement, giving in total 74 images to be evaluated.

The 570 technical phantom images were taken with the same technical settings as described for the anthropomorphic phantom, although 10 images were produced for every exposure combination for statistical reasons.

### Image analysis

Assessment of the anthropomorphic phantom images was carried out using absolute Visual Grading Analysis (VGA) as a measure of subjective image quality. The absolute VGA were scored on a scale from 1 to 5 on a set of predefined image quality criteria (Table 2). Each of the 74 pelvic images was scored by four experienced radiographers working in three different Danish hospitals, all holding a postgraduate degree in reporting of the appendicular/axial skeleton. The image quality criteria, shown in Table 3, were based on the European Guidelines approved by all four observers. All images were presented to the observers using ViewDEX (Viewer for Digital Evaluation of X-ray images). The images were presented blinded and in an individually randomised order, and the scoring marks were noted directly using the computer keyboard. The quality ratings of each observer were stored individually with ViewDEX and subsequently exported into Microsoft Excel for further analysis. In order to reduce bias in the VGA score, the observers were given ‘unlimited’ time and allowed to work undisturbed. To reduce the inter-observer variation, a training session was performed before the image evaluation to illustrate best and worst possible image quality. The scorings from the training session were not used in the analysis. The VGA experiment was undertaken at the same location, using the same diagnostic monitor and physical surroundings.

### Table 2. VGA scale for scoring image quality.

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Poor image quality: image not usable, loss of information</td>
</tr>
<tr>
<td>2</td>
<td>Restricted image quality: relevant limitations for clinical use, clear loss of information</td>
</tr>
<tr>
<td>3</td>
<td>Sufficient image quality: moderate limitations for clinical use, no substantial loss of information</td>
</tr>
<tr>
<td>4</td>
<td>Good image quality: minimal limitations for clinical use</td>
</tr>
<tr>
<td>5</td>
<td>Excellent image quality, no limitations for clinical use</td>
</tr>
</tbody>
</table>

### Table 3. Image criteria for femur images.

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Visually homogene reproduction of periarticular soft tissue</td>
</tr>
<tr>
<td>2</td>
<td>Visually sharp reproduction of the trabecular structure in caput femoris</td>
</tr>
<tr>
<td>3</td>
<td>Visually sharp reproduction of the demarcation between cancellous bone and compact bone</td>
</tr>
<tr>
<td>4</td>
<td>Visualisation of os sacrum, foramina intervertebralis and collum femoris</td>
</tr>
<tr>
<td>5</td>
<td>Visually sharp reproduction of articulation sacroiliaca</td>
</tr>
<tr>
<td>6</td>
<td>Is the image approved for diagnostics use</td>
</tr>
</tbody>
</table>

The results of the VGA study can be summarised in a score using the following equation:

\[
VGAS = \frac{\sum_{i=1}^{O_i} S_c}{N_I N_O}
\]

\(S_c\) is the individual score for observer \(O\) (radiologist) and image criteria \(I\)
\(N_I\) is the total number of image criteria
\(N_O\) is the total number of observers

The CDRAD images were assessed using the CDRAD analysis software version 2.0 from Artinis, yielding an objective measure for image quality, the Inverse Image Quality Figure (IQF_inv).

### Statistical analysis

The analysis of the subjective image quality experiments was performed using ordinal logistic regression (proportional odds model), with the log of the relative VGA-scores for each image quality criteria, as dependent variable, to be explained by the independent variables mAs, tube voltage (kV), and the scatter correction ratio. For image criterion no. 6 (approved for diagnostics), a simple logistic regression model was used, as the VGA score was a binary dependent variable. As each exposure was only represented once in the VGA study, DAP values had a variance of zero, and therefore only expressed graphically. Inter-observer agreements for multiple readers for each criteria were assessed using Fleiss’
Kappa, while intra-observer agreements were calculated with Cohen's weighted kappa.

For the objective image quality assessment analysis, logistic regression was used on the IQF_inv values to test for all different parameter combinations, and the results shown as box plots. For every combination of exposure settings in the non-grid images, a Kruskal-Wallis test was used to ascertain if the level of scatter correction applied had any impact on IQF_inv within each group.

Correlation between VGA-scores and IQF_inv values are shown in a scatterplot with linear regression line, and $R^2$ value calculated.

All statistical analysis was done using STATA 13IC (StataCorp, College Station, TX, USA).

RESULTS

Overall the scatter correction software produced DR images of the pelvis with a lower quality, compared to those acquired with a physical anti-scatter grid. For a visual impression of the images see Figure 1.

Parameters as DAP, DI and REX were significantly different between parameter combinations ($p < 0.0001$) and did therefore not influence the results inappropriately, see Table 4.

Subjective image quality results (VGA)

Combined Visual Grading Analysis Scores (VGAS) for the different imaging parameter combinations and scatter correction levels are summarised in Figure 2.

In general, 45.2% of the images with a REX value higher than the reference image were evaluated as 'not acceptable', while the same held true for 92.3% of the images with a lower REX. In comparison, 31.7% percent of images with a DAP higher than the reference standard were not acceptable, compared to 69.9% with lower DAP.

All images acquired using grid were deemed acceptable by all four observers. All images with a DAP of $128 \mu$Gy*cm$^2$ or less, were judged unsuitable for diagnosis by all observers, regardless of levels of scatter correction applied. Only two images with DAP less than $211 \mu$Gy*cm$^2$ were deemed to be sufficient for diagnostics (by three different observers).

Ordinal and binary logistic regression results are shown in Table 5. For all VGA image criteria, scatter corrections has a significant negative influence on VGA scores (OR < 1) compared to the reference image. Significance of $kV$ and mAs in all VGA image criteria shows that image quality is increasing significantly (OR > 1). Furthermore, the observers commented on an overall drop in visual contrast in the experimental images without a grid.

Inter-observer agreement was found to be poor to fair, as seen in Table 6. Intra-observer agreement was assessed through 13 identical images that were scored twice in each viewing session, and results are tabulated for each reader and criteria in Table 7, all
showing substantial good to excellent performance. A score of 1 means perfect agreement between readings.

**Objective image quality results (CDRAD)**

A plot of VGA-scores vs. IQF_inv values for all possible combinations of mAs, IQF_inv and scatter correction, shows significant linear correlation between subjective and objective evaluated image quality (Figure 3). The linear model showed significance, with high linear regression coefficient, \( R^2 = 0.796 \), and indicates the possibility of predicting subjective image quality from CDRAD exposures.

**DISCUSSION**

Table 4. DAP (\(\mu\)Gy*cm\(^2\)), DI, and REX for all imaging parameter combinations for the Pelvis and the CDRAD study. Values in parentheses are standard deviations within the ten CDRAD exposures. The reference image (with grid) is marked in grey. For the pelvis study, the percentage of diagnostically acceptable images for each combination is listed.

<table>
<thead>
<tr>
<th>kVp</th>
<th>90</th>
<th>80</th>
<th>60</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>mAs</td>
<td>3.2</td>
<td>6.3</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Pelvis DAP</td>
<td>129.8</td>
<td>254.8</td>
<td>324</td>
<td>406.6</td>
</tr>
<tr>
<td>CDRAD DAP</td>
<td>108.1</td>
<td>211.1</td>
<td>269.0</td>
<td>336.7</td>
</tr>
<tr>
<td>Pelvis DI</td>
<td>1.36</td>
<td>4.29</td>
<td>5.36</td>
<td>6.38</td>
</tr>
<tr>
<td>Percentage of accepted images</td>
<td>0</td>
<td>37.5</td>
<td>56.3</td>
<td>65.0</td>
</tr>
<tr>
<td>CDRAD DI</td>
<td>-0.50</td>
<td>2.69</td>
<td>3.69</td>
<td>4.63</td>
</tr>
<tr>
<td>Pelvis REX</td>
<td>273</td>
<td>537</td>
<td>687</td>
<td>858</td>
</tr>
<tr>
<td>CDRAD REX</td>
<td>198</td>
<td>371</td>
<td>468</td>
<td>580</td>
</tr>
<tr>
<td>(3.98)</td>
<td>(2.69)</td>
<td>(1.83)</td>
<td>(2.88)</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 2. VGA-scores for the different parameter combinations and levels of scatter correction used.](https://academic.oup.com/rpd/advance-article-abstract/doi/10.1093/rpd/ncz129/5492609)
Subjective assessment of image quality

In clinical practice, the REX value is often used as a practical measure for diagnostic quality. However, as the REX value is affected by several components, such as software settings, physical ROI placements etc., it should be used with caution\(^\text{[23]}\). The fallacy of using REX to predict clinical image quality is highlighted by the fact that almost half of images with a higher REX-value than the reference image were scored non-diagnostic. For example, no images in the 90 kV/3.2 mAs combination were evaluated as acceptable, despite having a significantly higher DI, and thus presumably more noisy. However, given that the highest non-grid combination with a lower DAP than the grid images (80 kV/10 mAs) resulted in 15\% non-acceptable ratio, and significantly reduced objective, as well as subjective image quality, it is unlikely to be implemented in clinical practice for a dose reduction less than 10\%. Non-diagnostic exposures are by definition unnecessary radiation, and repeated exposures can quickly negate any dose reduction.

The DI values were found ranging from \(-4.86\) to 7.30 in the experimental images. The reference image had a DI value of \(-0.34\) and 185 in REX, which is, in theory, comparable to a perfect image. It seems like a DAP value of approx. 128 \(\mu\text{Gy*cm}\) is found as a threshold for diagnostic approved image quality by all readers, regardless of the level of scatter correction software applied.

The results from the ordinal logistic regression also suggested that scores for all criteria were affected positively by increasing kV and mAs, but negatively by increasing the level (‘Ratio’) of scatter correction. This might be caused by the well-known image impression altered, leading to insecurity bias from the observers. The overall findings of lower VGA scores compared to the reference image was not expected. The software may be useful for optimising image quality in trauma cases or alike, and the anatomy of pelvis show a smaller dose reduction than the criteria regarding noise and visualisation &
contrast had less negative influence. Overall, a decrease of the visual contrast was found, for which the scatter correction software could not compensate. This is not in correspondence with the studies by Mentrup et al.\(^9\) and Renger et al.\(^11\), as they demonstrated comparable or improved image quality although only in chest radiography. Other studies\(^9\)–\(^11\),\(^26\) have used anthropomorphic phantoms, although the image analysis differed. Most studies only focused on either visibility of a catheter using a simple subjective scoring scale including three observers or objective ROI measurements for contrast. These methods can be hard to compare to our image analysis assessment. The different anatomical structures, and different exposure parameters, in pelvis and chest radiography might explain some of the differences found. No other studies, as we know, have tested the software on skeletal anatomy until now. Renger et al.\(^11\) showed a decrease in contrast when changing from grid exposures to non-grid exposures with scatter correction software, which is in correspondence with our findings.

The inter-observer reliability was found to be acceptable and the intra-observer reliability performance of the four reporting radiographers was found to be good. This validated the subjective image quality evaluation of this study and verified the methods used.

### Objective image quality assessment

The CDRAD image analysis showed a significantly higher IQF_inv value for the reference image compared to the experimental images using the scatter correction software (Figure 4), implying that the spatial and low contrast resolution is better using a physical grid compared to using the scatter correction software. The descriptive analysis of the results (Figure 4) showed that the IQF_inv value increased with increasing kV and mAs combinations, and that the influence of the scatter correction software was limited. The scatter correction software did not have a statistically significant influence on the IQF_inv values (Table 8), implying that the software did not make a difference on image quality regarding details and contrast at any of the exposure settings used in this study. The reason could be that the amount of scattered radiation at the kV parameters used in this study is too low for the software to process properly, and which, as a result, decreases the contrast details and spatial resolution as observed in the IQF_inv values. To our knowledge, no companies have yet succeeded in developing a satisfactory scatter correction software for the larger bone structures. Either smaller anatomies or small patients (paediatrics) could possibly take advantage of the software for optimisation of image quality.

### Correlation between subjective and objective image analysis

A significant correlation, with a high linear regression coefficient \(R^2 = 0.796\), was found between the

![Figure 4. IQF_inv for all combinations of exposure parameters and scatter correction. Reference images with grid are marked in grey.](https://academic.oup.com/rpd/advance-article-abstract/doi/10.1093/rpd/ncz129/5492609)

<table>
<thead>
<tr>
<th>Technical settings</th>
<th>(p)</th>
<th>OR</th>
</tr>
</thead>
<tbody>
<tr>
<td>kV</td>
<td>&lt;0.0001</td>
<td>2.77</td>
</tr>
<tr>
<td>mAs</td>
<td>&lt;0.0001</td>
<td>1.13</td>
</tr>
<tr>
<td>Scat_cor</td>
<td>0.061</td>
<td>1.00</td>
</tr>
</tbody>
</table>

![Figure 3. Scatterplot of mean VGAS and IQF_inv for identical parameter combinations, with linear regression line and 95% CI.](https://academic.oup.com/rpd/advance-article-abstract/doi/10.1093/rpd/ncz129/5492609)
subjective and the objective image quality results. This clarify the methods behind the results found using both the anthropomorphic pelvic and the technical CDRAD phantom for this type of studies. Based on the correlation, it seems that quite a large increase in dose would be needed to reach the level of image quality by using a physical grid. Although looking at the results from the pelvic and the CDRAD phantom experiments, respectively, the DI and REX values are substantially higher for the anthropomorphic pelvic exposures compared to the CDRAD exposures (Table 4), suggesting that the Plexiglas thickness used in the CDRAD experiments was too small.

Limitations

The limitations of this study are primarily the different exposure settings for the grid (one combination) and the non-grid images. This means that, even if one particular non-grid setting had been found that could produce equal image quality with a lower dose, one could not rule out the possibility that this could also be produced for the same dose, using a grid. To be able to do that, different exposure parameter combinations would have to be examined both with and without a grid. Furthermore, a significant limitation is the use of anthropomorphic and technical phantoms, not real patients. It also seems that too much Plexiglas was used in front of the CDRAD phantom, resulting in a lower SNR in these images. A poor inter-observer agreement was found, which might have been caused by the observers background from different hospitals, with possibly different preferences for image quality. Observers from one of the hospitals commented that the symphysis area lacked trabecular structure in many of the images, thus making the detection of e.g. bony metastases difficult—an important differential diagnosis. This was not included in the criteria, but contributed to many images being rated diagnostically unacceptable. Caution should also be taken in interpreting the results of the logistic regression results, as the numbers of evaluated images are low.

CONCLUSION

The scatter correction software produced images of lower quality to DR images of the pelvis, compared to those acquired with a physical anti-scatter grid. This conclusion was supported by the fact that both the overall subjective image scores, as well as the technical image results, were in qualitative agreement, and that all grid images were rated as suitable for diagnostic use. The scatter correction software might have a positive influence on image quality in other anatomical regions, e.g. chest, thinner patients or children, where the amount of scattered radiation is lower than in the pelvis examination and at higher kV levels, which have to be explored in future studies.

ACKNOWLEDGEMENTS

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DISCLOSURES

None.

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