OPTIMISATION OF RADIOLOGICAL PROTECTION IN DIGITAL RADIOLOGY TECHNIQUES FOR MEDICAL IMAGING

Radiography

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○ The digital radiography system
○ Optimisation of exposure factors and radiation quality
○ Other aspects of optimisation
○ Factors to consider in optimisation
○ Image post processing
○ Optimisation of the imaging workflow
○ Basic quality assurance (QA)
○ Approaches to Optimisation
Digital radiography systems
Radiography

• Most frequent examination
Digital Radiography

CR

IDR Indirect X-ray capture digital radiography

DDR Direct x-ray capture digital radiography
Optimisation of exposure factors and radiation quality

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Exposure parameters optimisation

mamography

Trunk

Trunk

Chest

Tube voltage (kV)

10:1

12:1
Grid

Source to Image Distance

- **Far** focus-grid decentering
- **Near** focus-grid decentering

Correct Distance

Centering

Lateral Decentering Caused by a Tilted Bucky

Coimbra Health School
Polytechnic of Coimbras
Grid

No grid  Virtual grid  Real grid
Grid

Fig. 2.5. Comparison of images of two patient knees obtained a) with an actual grid and b) with virtual grid software (Philips –Skyflow). Both radiographs show high image quality (Dean Pekarovic, University Medical Centre Ljubljana, Slovenia).
Automatic Exposure control (AEC)

Proper patient positioning

IC need to be calibrated according to the image receptor
Additional metal filters

Use of additional copper filtration reduce the ESAK and KAP in DR

mAs must be increased to maintain same level of quantum noise

<table>
<thead>
<tr>
<th>Copper Thickness</th>
<th>Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 Cu</td>
<td>&gt; 15-20%</td>
</tr>
<tr>
<td>0.2 Cu</td>
<td>&gt; 20-30%</td>
</tr>
</tbody>
</table>
Additional metal filters

<table>
<thead>
<tr>
<th>Copper Thickness</th>
<th>KAP Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 mm Cu</td>
<td>34 cGy cm²</td>
</tr>
<tr>
<td>0.1 mm Cu</td>
<td>22 cGy cm²</td>
</tr>
<tr>
<td>0.2 mm Cu</td>
<td>14 cGy cm²</td>
</tr>
<tr>
<td>0.3 mm Cu</td>
<td>11 cGy cm²</td>
</tr>
</tbody>
</table>

Fig. Pelvic radiographs taken at 81 kV with a Siemens Axiom Aristos FX showing the effect of additional copper filters. Exposures from left to right were taken with the following thicknesses of copper 0 mm, 0.1 mm, 0.2 mm, and 0.3 mm, and KAP values are 34 cGy cm², 22 cGy cm², 14 cGy cm², and 11 cGy cm², respectively (cadaver study- Dean Pekarovic, University Medical Centre Ljubljana, Slovenia).
SID and focal spot size

**Inverse Square Law**

- **SID 110–115 cm decrease ESAK and detector dose in 20%**
- **Expose more tissues**
- **Higher KAP**
- **Less image quality**
FOV and collimation
FOV and collimation

Fig. 2.3. Issues in image collimation. 2.3a and b show a portable babygram in a neo-natal intensive care unit to determine umbilical vein catheter placement position; a) The original image which is poorly collimated, and b) image with the appropriate collimation (Kimberly Applegate, USA). 2.3c and d exemplify very poor practice. They show an ostensibly collimated image which is in fact cropped. C shows the image with a normal window width and level, whilst d shows the image with an adjusted window width and level, demonstrating the actual radiograph as exposed. Images of this type can be used for auditing poor collimation practice where this is an issue (Dean Pekarovic, University Medical Centre Ljubljana, Slovenia).
Table 2.1. Exposure factors and expected dose levels for a range of imaging tasks.

<table>
<thead>
<tr>
<th>Anatomy</th>
<th>Projection</th>
<th>kV</th>
<th>Grid</th>
<th>Additional filtration (mm Cu)</th>
<th>ESAK* (mGy)</th>
<th>KAP* (Gy cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>PA</td>
<td>120–140</td>
<td>Yes</td>
<td>0.05–0.2</td>
<td>0.06–0.1</td>
<td></td>
</tr>
<tr>
<td>Chest</td>
<td>PA</td>
<td>75–85</td>
<td>No</td>
<td>0.3–0.5</td>
<td>0.06–0.1</td>
<td></td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>AP</td>
<td>75–90</td>
<td>Yes</td>
<td>2–6</td>
<td>0.7–1.5</td>
<td></td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>lateral</td>
<td>80–95</td>
<td>Yes</td>
<td>5–10</td>
<td>1.4–2.5</td>
<td></td>
</tr>
<tr>
<td>Abdomen</td>
<td>AP</td>
<td>75–90</td>
<td>Yes</td>
<td>2.5–5</td>
<td>1.4–2.5</td>
<td></td>
</tr>
<tr>
<td>Pelvis</td>
<td>AP</td>
<td>75–90</td>
<td>Yes</td>
<td>2–4</td>
<td>1.3–2.2</td>
<td></td>
</tr>
<tr>
<td>New-born &lt;5 kg</td>
<td>AP/PA</td>
<td>56–65</td>
<td>No</td>
<td>0.1–0.2</td>
<td>0.03–0.07</td>
<td>0.003–0.015</td>
</tr>
<tr>
<td>Infant 5-15 kg chest (4 m–3 y)</td>
<td>AP/PA</td>
<td>60–80</td>
<td>No</td>
<td>0.1–0.2</td>
<td>0.04–0.08</td>
<td>0.005–0.022</td>
</tr>
<tr>
<td>Infant 5-15 kg abdomen pelvis (4 m–3 y)</td>
<td>AP</td>
<td>60–80</td>
<td>No</td>
<td>0.1–0.2</td>
<td>0.3–0.6</td>
<td>0.05–0.15</td>
</tr>
<tr>
<td>Child 15-30 kg chest (4 y–10 y)</td>
<td>AP/PA</td>
<td>70–85</td>
<td>No</td>
<td>0.1–0.2</td>
<td>0.06–0.12</td>
<td>0.008–0.05</td>
</tr>
<tr>
<td>Child 15–30 kg abdomen pelvis (4 y–10 y)</td>
<td>AP</td>
<td>70–80</td>
<td>Yes</td>
<td>0.1–0.2</td>
<td>0.5–1.5</td>
<td>0.15–0.25</td>
</tr>
</tbody>
</table>

*Dose quantities represent a range of average values (1st and 3rd quartile values in a dose survey) and the adult ones are for a 70 kg patient. If an indirect DR system with CsI is used, then values should be towards the lower end of the range or lower. PA – postero-anterior, AP - antero-posterior. Doses from improved modern systems may go below the values listed.
Exposure indicators

Exposure index (EI) is related to the air kerma in μGy at the IR in the anatomical region of interest within the image and so is a linear function of tube current.

\[ DI = \log_{10} \left( \frac{EI}{EI_T} \right) \]

Target EI for a particular body part and task

Table 2.2. Recommended values of Deviation Index (DI) for determining acceptable imaging settings and required actions (AAPM, 2009)

<table>
<thead>
<tr>
<th>DI</th>
<th>Action required</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; +3</td>
<td>Excessive patient radiation exposure. Repeat only if relevant anatomy is clipped or “burned out”. Require immediate quality assurance (QA) management follow-up</td>
</tr>
<tr>
<td>+1 - +3</td>
<td>Overexposure. Repeat only if relevant anatomy is clipped or “burned out”.</td>
</tr>
<tr>
<td>-0.5 - +0.5</td>
<td>Target range</td>
</tr>
<tr>
<td>&lt;-1</td>
<td>Underexposure. Consult Radiologist for possible repeat</td>
</tr>
<tr>
<td>&lt;-3</td>
<td>Repeat (consider QA programme)</td>
</tr>
</tbody>
</table>
### Dose and EI

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number</th>
<th>KAP_average (µGy.m²)</th>
<th>KAP_median (µGy.m²)</th>
<th>DRL (µGy.m²)</th>
<th>KAP_med/DRL</th>
<th>EI_average</th>
</tr>
</thead>
<tbody>
<tr>
<td>T084 Pelvis AP</td>
<td>238</td>
<td>44.7</td>
<td>39.4</td>
<td>200</td>
<td>0.20</td>
<td>340</td>
</tr>
<tr>
<td>T084 Pelvis AP</td>
<td>188</td>
<td>48.1</td>
<td>42.6</td>
<td>200</td>
<td>0.21</td>
<td>322</td>
</tr>
<tr>
<td>T026a Lumbar-spine AP</td>
<td>171</td>
<td>43.6</td>
<td>35.4</td>
<td>130</td>
<td>0.27</td>
<td>327</td>
</tr>
<tr>
<td>W019a Cervical-spine AP</td>
<td>147</td>
<td>7.04</td>
<td>6.0</td>
<td>30</td>
<td>0.20</td>
<td>269</td>
</tr>
<tr>
<td>T090a Hip AP</td>
<td>137</td>
<td>25.5</td>
<td>24.0</td>
<td>95</td>
<td>0.25</td>
<td>312</td>
</tr>
<tr>
<td>W019b Cervical-spine Lat</td>
<td>131</td>
<td>6.25</td>
<td>5.7</td>
<td>35</td>
<td>0.16</td>
<td>326</td>
</tr>
<tr>
<td>W050 Shoulder joint AP</td>
<td>131</td>
<td>8.7</td>
<td>7.6</td>
<td>30</td>
<td>0.25</td>
<td>387</td>
</tr>
<tr>
<td>L026b Lumbar-spine Lat</td>
<td>130</td>
<td>187</td>
<td>155</td>
<td>230</td>
<td>0.68</td>
<td>360</td>
</tr>
<tr>
<td>L026b Lumbar-spine Lat</td>
<td>124</td>
<td>163</td>
<td>150</td>
<td>230</td>
<td>0.65</td>
<td>395</td>
</tr>
<tr>
<td>T026a Lumbar-spine AP</td>
<td>106</td>
<td>56.1</td>
<td>47.7</td>
<td>130</td>
<td>0.37</td>
<td>321</td>
</tr>
</tbody>
</table>

Fig. 2.2. A spreadsheet chart used for monitoring KAP and EI values for selected radiographic examinations. The exposure index target value (EI<sub>T</sub>) was set at 250, but could be modified by the user for each projection. (Urban Zdešar, University Medical Centre Ljubljana, Slovenia, reproduced with permission).
## Patient shielding

### Table 2.3. Recommendations for patient shielding in diagnostic radiology (Hiles et al, 2020, 2021)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Recommendation</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient contact shielding for</td>
<td>Not recommended</td>
<td>Use PA positioning rather than shielding for spinal and chest examinations where possible. If using AP projection then a Scoliosis shawl may be considered.</td>
</tr>
<tr>
<td>protection of breast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient contact shielding for</td>
<td>Not generally</td>
<td>May be used for paediatric patients in cephalometric radiography if evaluation of the cervical spine is not needed or obscured. The effectiveness of shielding outside the FOV is minimal and potential interference of the shield with the AEC must be avoided.</td>
</tr>
<tr>
<td>protection of thyroid</td>
<td>recommended</td>
<td></td>
</tr>
<tr>
<td>Patient contact shielding for</td>
<td>Not recommended</td>
<td>Male adult and paediatric patients: May be considered where gonads are less than 5 cm from the primary beam. Female adult and paediatric patients: Not recommended for imaging in the pelvic region.</td>
</tr>
<tr>
<td>protection of gonads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient contact shielding for</td>
<td>Not recommended</td>
<td>Use PA skull positioning, no recommendations for shielding.</td>
</tr>
<tr>
<td>protection of eye lens</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pregnant patients</td>
<td>Not recommended</td>
<td>For examinations within pelvic region (from diaphragm to knee), consider non-ionising imaging alternatives. If ionising radiation must be used carry out a thorough justification and risk assessment process.</td>
</tr>
</tbody>
</table>
Factors to consider in optimisation

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Factors to consider in optimisation

<table>
<thead>
<tr>
<th>Action</th>
<th>Effect on dose</th>
<th>Influence on image quality or diagnostic information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase mAs to reduce noise perception</td>
<td>Increase</td>
<td>Improvement in SNR</td>
</tr>
<tr>
<td>Increase mAs further to give significant reduction of noise (with detector saturation in some areas)</td>
<td>Increase</td>
<td>Deterioration, retakes</td>
</tr>
<tr>
<td>Use appropriate tube potential and establish correct radiographic techniques for digital systems</td>
<td>Decrease</td>
<td>May change appearance of image (optimisation)</td>
</tr>
<tr>
<td>Increase kV and reduce mAs to maintain same noise level</td>
<td>Decrease</td>
<td>Decrease in contrast (process of optimisation)</td>
</tr>
<tr>
<td>Inclusion of 0.1 mm or 0.2 mm copper filter in beam with increased mAs to maintain noise level</td>
<td>Decrease</td>
<td>Minimal effect, possible increase in exposure time</td>
</tr>
<tr>
<td>Implementation of dose and image quality indicators (KAP, EI, DI) on the console of x-ray system or PACS</td>
<td>Decrease</td>
<td>Potential improvement, potential decrease in retakes</td>
</tr>
</tbody>
</table>
Factors to consider in optimisation

<table>
<thead>
<tr>
<th>Action</th>
<th>Effect on dose</th>
<th>Influence on image quality or diagnostic information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in number of images per procedure (e.g., avoiding the lumbosacral spine image)</td>
<td>Decrease</td>
<td>Remains unchanged</td>
</tr>
<tr>
<td>Increase source to detector distance</td>
<td>Decrease</td>
<td>Improve geometry</td>
</tr>
<tr>
<td>Increase in size of x-ray tube focus</td>
<td>Unchanged</td>
<td>Reduced spatial resolution, decrease in exposure time</td>
</tr>
<tr>
<td>Decrease in size of x-ray tube focus</td>
<td>Unchanged</td>
<td>Improved spatial resolution</td>
</tr>
<tr>
<td>Expose full DR image plate and crop image to required anatomy (poor practice)</td>
<td>Increase</td>
<td>Loss of contrast due to scatter from other tissues</td>
</tr>
<tr>
<td>AEC system not set up for correct image receptor type or calibration incorrect</td>
<td>Increase or decrease</td>
<td>Potential degradation</td>
</tr>
<tr>
<td>AEC system not used</td>
<td>Increase or decrease</td>
<td>Degradation, retakes</td>
</tr>
<tr>
<td>AEC chambers not checked regularly</td>
<td>Increase or decrease</td>
<td>Degradation, retakes</td>
</tr>
<tr>
<td>Use of CR storage-phosphor plates beyond the recommended lifetime</td>
<td>Increase</td>
<td>Loss of quality, retakes</td>
</tr>
</tbody>
</table>
## Factors to consider in optimisation

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of a grid with too high a grid ratio</td>
<td>Increase</td>
<td>Susceptibility to grid misalignment faults</td>
</tr>
<tr>
<td>Use of a grid with too low a line density</td>
<td>Possible</td>
<td>Risk of aliasing artefacts</td>
</tr>
<tr>
<td>Use of virtual grid software</td>
<td>Reduce</td>
<td>Poorer image quality than using a grid</td>
</tr>
<tr>
<td>Deletion of image files at the viewing station or workstation of apparently non-useful images</td>
<td>Possible increase</td>
<td>Loss of information that might be useful in reject/retake analysis</td>
</tr>
<tr>
<td>Poorly adjusted / optimised diagnostic monitor (e.g., insufficient brightness, contrast, or resolution)</td>
<td>Possible increase</td>
<td>Loss of information, potential for repeats</td>
</tr>
<tr>
<td>Use of workstation with more facilities to visualise images (window, level, inversion, magnification)</td>
<td>Potential decrease</td>
<td>Obtain more information from the same image and decrease no. of repeats</td>
</tr>
<tr>
<td>Implementation of reject and retake analysis programme</td>
<td>Decrease</td>
<td>Possible improvement</td>
</tr>
<tr>
<td>Problems in postprocessing: hardware, network, etc. during archiving of images</td>
<td>Increase</td>
<td>Occasional loss of images or retakes</td>
</tr>
<tr>
<td>Loss of images in the network or the PACS due to improper identification or other reasons</td>
<td>Increase</td>
<td>Retakes</td>
</tr>
<tr>
<td>Use of incorrect post processing introducing false lesions or pathologies due to artefacts</td>
<td>Possible increase</td>
<td>Loss of information and need for retakes, potential misdiagnosis</td>
</tr>
<tr>
<td>Availability of workstation for post processing (and for radiographers) to avoid some retakes</td>
<td>Decrease</td>
<td>Improvement</td>
</tr>
</tbody>
</table>
Factors to consider in optimisation

<table>
<thead>
<tr>
<th>Action</th>
<th>Effect on dose</th>
<th>Influence on image quality or diagnostic information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowing easy access to the PACS and teleradiology to look at previous images</td>
<td>Decrease</td>
<td>Improvement</td>
</tr>
<tr>
<td>Use of alternative post processing option, which can sometimes avoid repetitions.</td>
<td>Decrease</td>
<td>Improvement</td>
</tr>
<tr>
<td>Inability to post process images stored in the PACS, so that re-analysis of images is not possible</td>
<td>Potential increase</td>
<td>Potential need for retakes</td>
</tr>
</tbody>
</table>
Image post processing

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Image post processing

Fig. 2.6. The basic steps in processing of digital x-ray image (Colin Martin, University of Glasgow)

Fig. 2.7. Windowing adjustment example. Paediatric chest images in NICU (a) with a higher mAs dose, and b) with a lower mAs dose, and c) where windowing has been used to improve contrast of the lower dose image (Dean Pekarovic, University Medical Centre Ljubljana, Slovenia).
Optimisation of the imaging workflow
<table>
<thead>
<tr>
<th>Box 2.4. Safety steps to image and verify for your patient (adapted from Image Gently)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prior to Starting the Exam</strong></td>
</tr>
<tr>
<td>1. Patient name selected from the worklist</td>
</tr>
<tr>
<td>2. Patient properly identified (two-point verification)</td>
</tr>
<tr>
<td>3. Appropriateness of request checked</td>
</tr>
<tr>
<td>4. Explained the exam to patient/parent</td>
</tr>
<tr>
<td>5. Verified Last Menstrual Period/pregnancy status if appropriate</td>
</tr>
<tr>
<td><strong>Image Capture During the Exam</strong></td>
</tr>
<tr>
<td>1. Beam body part image receptor aligned, SID checked, use of grid determined</td>
</tr>
<tr>
<td>2. Patient positioned and body part measured, cassette positioned (CR only)</td>
</tr>
<tr>
<td>3. Beam collimated</td>
</tr>
<tr>
<td>4. Technical factors selected</td>
</tr>
<tr>
<td>5. Shielding and markers placed</td>
</tr>
<tr>
<td>6. Final adjustment of tube and settings made</td>
</tr>
<tr>
<td>7. Breathing instructions given</td>
</tr>
<tr>
<td>8. Exposure taken</td>
</tr>
<tr>
<td><strong>Image Critique Immediately After Exposure</strong></td>
</tr>
<tr>
<td>1. Cassette transported to and processed in reader (CR only)</td>
</tr>
<tr>
<td>2. Images displayed and reviewed; identification confirmed</td>
</tr>
<tr>
<td>3. Image quality reviewed</td>
</tr>
<tr>
<td>4. Exposure indicator/index checked; deviation index compared to target exposure index</td>
</tr>
<tr>
<td>5. Image reprocessed or repeated as necessary</td>
</tr>
<tr>
<td><strong>Following Completion of the Examination</strong></td>
</tr>
<tr>
<td>1. Post-processing performed only if necessary</td>
</tr>
<tr>
<td>2. Exam verified and images archived to PACS for reporting</td>
</tr>
</tbody>
</table>
Basic Quality Assurance

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Example of detector tests

- Uniformity
- Special Resolution
- Contrast Noise Resolution
- Geometric acuity
- Artefacts

DICOM viewer

Mean and SD of pixel values
Analysis of EI
Approaches to optimisation

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Box 2.5. Arrangements that should be in place for facilities at different levels of optimisation, together with aims that would be pursued.

C: Basic
- Established protocols with appropriate tube potential and mAs settings for all common examinations
- Perform regular QC/QA tests on all digital x-ray units and CR readers
- Radiographers have received comprehensive training and receive further update training whenever new units or features are implemented

B: Intermediate
- Radiographers have access to diagnostic quality workstations
- Full range of protocols established based on specific clinical indications
- Image quality / exposure levels in protocols identified as low, medium or high based on clinical indication
- Exposure index values recommended for a wide range of examinations and monitored regularly.
- Continual development of protocols through regular radiographer / radiologist / medical physicist communication
- A quality management system is implemented to maintain performance levels
- Reject and repeat analysis programme implemented

A: Advanced
- Unified guidelines for clinical indication-specific examination protocols throughout organisation
- Utilisation of dose monitoring system for an organisation wide on-line monitoring of patient exposures and analysis of exposure parameters for optimisation
- Standard, objective and ongoing processes for evaluating optimisation undertaken with defined timelines
- Development of objective and quantitative image quality metrics based on diagnostic image quality criteria. Establishment of more comprehensive and consistent optimisation based on this.
- Use of anthropomorphic phantoms in optimisation.
- Use of a generic approach, whereby the optimisation of exposure and post-processing parameters, and related exposure index values could be included in the commissioning of new equipment.
Conclusion

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Conclusion

- A review of the exposure parameters and their impact on examination dose and image quality in radiography;
- How to optimise considering the imaging workflow;
- Different levels of optimisation to promote a continuous cycle.
Thank you

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