PreDos Study
Evaluation of the radiation dose delivered to premature new-borns in the Belgian Neonatal Intensive Care Units

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SCK•CEN, Radiation protection Dosimetry and Calibration

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Neonatal Intensive Care Units (NICU)

- Premature new-borns
  - Less than 37 weeks of gestation
  - Birth weight as low as 500g
- Specific pathologies
- Need for specialised care

- 19 formally recognised NICUs in Belgium
  - Advanced technology
  - Trained healthcare professionals
Importance of dose optimisation in the NICU?

- Frequent use of radiography
  - Diagnostic
  - Follow-up
- Neonates
  - Increased radiosensitivity
  - Longer life-expectancy

Despite their frequent use, the number of radiographs and their contribution to the dose were widely unknown in Belgian NICU...

Objectives

- Overview of the local and national doses...
  - Per Examination
    - Entrance Surface Kerma (ESK), Kerma Area Product (KAP)
    - Organ doses
  - Per patient’s stay in the NICUs
    - Number of examinations,
    - Cumulative doses

- ...for dose optimisation purposes
  - National reference dose levels
  - Recommendations for Good Practices
Material and methods

- Eligible study subjects
  - Premature neonates (less than 37 weeks of gestation)
  - 3 weight categories: (<1000 g, [1000 - 2000 g], >2000 g)

- 17 Belgian NICUs (of 19) participated in the study
  - Evenly distributed between the three geographic regions

- The most commonly performed radiographs were studied
Material and methods

- Collection of theoretical protocols (if any)

- Data collected for at least 40 examinations per centre
  - X-ray system characteristics
  - Radiograph settings
    - Tube voltage (kVp), tube load (mAs)
    - Focus-skin distance (FSD), Focus-detector distance (FDD)
  - Patient’s characteristics
    - Weight, height
    - Gestational age, pathology
Material and methods
Dosimetric quantities in the NICU

Entrance Surface Kerma (ESK)

- Kerma at intersection of the X-Ray beam with the entrance surface of the patient

- **Calculations** based on
  - examination settings and tube output measurements (OP)
  \[ ESK = OP_{kVp} \times mAs \times FSD^{-2} \]

- Individual cumulative dose
  \[ Dose_{tot} = \sum_{cat_i} \sum_{type_j} (Dose_{av,ij} \times N_i) \]
Material and methods
Dosimetric quantities in the NICU

Kerma Area Product (KAP)

- Product of **kerma and irradiated surface**
  - Kerma (Gy) ~ examination settings (mAs, kVp,...)
  - Area (m²) ~ collimation

**Easily available in practice**
- Ionisation chamber mounted on the x-ray system
- Available in 15 centres (of 17 participants)
Data collection
Mostly chest and combined chest-abdomen examinations, less abdomen examinations

Complete sample

Weight categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete sample</td>
<td>499</td>
<td>60%</td>
</tr>
<tr>
<td>Complete sample</td>
<td>83</td>
<td>10%</td>
</tr>
<tr>
<td>Complete sample</td>
<td>248</td>
<td>30%</td>
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</table>

<table>
<thead>
<tr>
<th>Weight category</th>
<th>Value</th>
<th>Percentage</th>
</tr>
</thead>
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<tr>
<td>&lt;1000g</td>
<td>139</td>
<td>58%</td>
</tr>
<tr>
<td>1000g&lt;...&lt;2000g</td>
<td>241</td>
<td>60%</td>
</tr>
<tr>
<td>&gt;2000g</td>
<td>53</td>
<td>28%</td>
</tr>
<tr>
<td>&gt;2000g</td>
<td>119</td>
<td>62%</td>
</tr>
</tbody>
</table>
## Protocols

- Overview of protocols in Belgium
  - Specific protocol defined in 16 (of 18 centres)
  - Mostly weight-specific

<table>
<thead>
<tr>
<th>Hospital A</th>
<th>Detector plate under the baby</th>
<th>weight (g)</th>
<th>kVp</th>
<th>mAs</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td>&lt;500</td>
<td>50</td>
<td>0.8</td>
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<tr>
<td></td>
<td></td>
<td>&gt;500</td>
<td>50</td>
<td>1</td>
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<tr>
<td></td>
<td></td>
<td>&gt;1000</td>
<td>55</td>
<td>1.6</td>
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</table>

<table>
<thead>
<tr>
<th>Hospital A</th>
<th>Detector plate inside the bucky table</th>
<th>weight (g)</th>
<th>kVp</th>
<th>mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt;500</td>
<td>52</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;500</td>
<td>52</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;1000</td>
<td>57</td>
<td>2</td>
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</table>

<table>
<thead>
<tr>
<th>Hospital D</th>
<th>weight (g)</th>
<th>kVp</th>
<th>mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>500-800</td>
<td>66</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>800-2000</td>
<td>70</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>2000-4500</td>
<td>73</td>
<td>0.71</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hospital G</th>
<th>weight (g)</th>
<th>kVp</th>
<th>mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>60</td>
<td>0.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hospital I</th>
<th>weight (g)</th>
<th>kVp</th>
<th>mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>63</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>800</td>
<td>63</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>1100</td>
<td>63</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>1300</td>
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<td>1700</td>
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<td>1</td>
<td></td>
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<tr>
<td>2800</td>
<td>70</td>
<td>1</td>
<td></td>
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<tr>
<td>3000</td>
<td>73</td>
<td>1</td>
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</tr>
<tr>
<td>4000</td>
<td>73</td>
<td>1.25</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Hospital M</th>
<th>weight (g)</th>
<th>kVp</th>
<th>mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;1000</td>
<td>63</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>1000-2000</td>
<td>77</td>
<td>0.7</td>
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<tr>
<td></td>
<td>2000-3000</td>
<td>81</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>&gt;3000</td>
<td>81</td>
<td>1</td>
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Dose overview per single chest examination
Large spread of ESK and KAP

- **ESK, T**: 12 to 157 μGy
- **TA**: 8 to 117 μGy

- **KAP, T**: 1 to 14 mGy.cm²
- **TA**: 4 to 28 mGy.cm²

- Large interhospital spread of the median ESK and KAP (ratio 13:1 and 15:0) are observed
- Trends observed for ESK are not always similar for KAP (ex: K, Q)

Why such variations in dose?
Technical parameters in practice:

- **Tube load, T**
  - Median: 0.3 to 4 mAs
  - Ratio 12:1

- **Tube voltage, T**
  - Median: 44 to 77 kVp
  - European guidelines: 60 to 65 kVp

- **FSD**
  - Median: 55 to 93 cm
  - Min/max: 23 to 97 cm

- Explains the large dose spread
- Following the protocol is not common practice
Dose overview per single chest examination

- Usually increase in dose with weight category
  - Explained by the examinations settings defined in the protocol
Usually increase in dose with weight category

- Explained by the examinations settings defined in the protocol

→ Need for optimisation and harmonisation of the practice!
Skewed distribution
Wide inter- and intra-hospital variation
- From 1 to 71 examinations
- ~50% patients undergo less than 5 examinations

Interest of investigation of relation between underlying pathology and number of examinations
- Skewed distributions
  - 22% patients received less than 50 µGy
  - 52% patients received less than 150 µGy
  - 6% patients received 1 mGy or more

- High cumulative ESK due to high number of examinations and/or high ESK per examination
Organ doses

- **Calculated** with PCXMC (Monte Carlo simulation)

- Calculated with **standardised field size** (radiologists' advice)
  - Wide deviation in practice; inappropriate field positioning
Cumulative organ doses

- Organ doses > 50 µGy
  - 14% for thyroid
  - 21% for bone marrow
  - 46% for colon
  - 63% for lungs
  - 79% for breast

- Narrow distributions for thyroid and bone marrow
- Highest doses to the lungs and the breast (included in the majority of the examinations)
Objectives

- Overview of the local and national doses...
  - Per Examination
    - Entrance Surface Kerma (ESK), Kerma Area Product (KAP)
    - Organ doses
  - Per patient’ stay in the NICUs
    - Number of examinations,
    - Cumulative doses

- ...for dose optimisation purposes
  - National reference dose levels
  - Recommendations for Good Practices
Diagnostic Reference Levels

In theory (ICRP 73)
- Optimisation tools for identification of unusually high doses
- Trigger for corrective measures if exceeded
- 75\textsuperscript{th} percentile of the dose distribution for a specific examination

![Dose distribution graph]
- 75% below DRL
- 25% above DRL
## Diagnostic Reference Levels

In practice
- In terms of ESK and KAP
- Examination specific
  - Sufficient number of data collected for chest (T) and combined chest-abdomen (TA)
  - Preliminary levels for abdomen (A)

<table>
<thead>
<tr>
<th>ESK (μGy)</th>
<th>&lt;1000g</th>
<th>1000g...&lt;2000g</th>
<th>&gt;2000g</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25&lt;sup&gt;th&lt;/sup&gt;</td>
<td>75&lt;sup&gt;th&lt;/sup&gt;</td>
<td>25&lt;sup&gt;th&lt;/sup&gt;</td>
<td>75&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>T</td>
<td>21</td>
<td>40</td>
<td>19</td>
<td>47</td>
</tr>
<tr>
<td>TA</td>
<td>24</td>
<td>47</td>
<td>27</td>
<td>51</td>
</tr>
<tr>
<td>A</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>KAP (mGy.cm²)</th>
<th>&lt;1000g</th>
<th>1000g...&lt;2000g</th>
<th>&gt;2000g</th>
<th>Total</th>
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<tbody>
<tr>
<td></td>
<td>25&lt;sup&gt;th&lt;/sup&gt;</td>
<td>75&lt;sup&gt;th&lt;/sup&gt;</td>
<td>25&lt;sup&gt;th&lt;/sup&gt;</td>
<td>75&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>T</td>
<td>1.1</td>
<td>5.1</td>
<td>3.7</td>
<td>7.1</td>
</tr>
<tr>
<td>TA</td>
<td>5.8</td>
<td>9.8</td>
<td>7.7</td>
<td>11.5</td>
</tr>
<tr>
<td>A</td>
<td>/</td>
<td>/</td>
<td>/</td>
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</tr>
</tbody>
</table>
In practice

- **< 25th percentile**: most optimised practices
- **> 75th percentile**: Identification of highest doses

→ Local dose assessment and dose optimisation strategies
Recommendations for Good Practices

- **Well-defined protocol**
  - Facilitates dose optimisation
  - Avoids inter-operator variations

- **High kVp coupled to low mAs**
  - Eliminates soft part of X-rays
  - European Commission guidelines for chest examinations: 60 to 65 kVp
  - Lowest mAs achievable

- **High FSD/FDD**
  - No significant image quality loss
  - Ex: Increase of FSD from 72 to 80 cm: ESK decreases by 20%

- **Appropriate collimation**
  - Avoids unnecessary organ irradiation from diagnostic point of view
  - Decreases quantity of scattered radiation
  - Recommendation to record KAP
Recommendations for Good Practices (continued)

- Image quality was not evaluated in the study
  - should always be accounted for during the dose optimisation process!!
Conclusions and perspectives

- National overview of **examinations settings**, and the resulting doses (**ESK and KAP**), for the three most performed radiographs in the NICUs.

- Distribution of **number of examinations** and **cumulative dose** per stay

- **National DRLs** in terms of ESK and KAP were defined for chest and combined chest-abdomen radiographs.

- **Recommendations** on radiograph settings for dose reduction.
  
  → Available on the website of the AFCN•FANC

**Perspectives:**

→ **Evaluation of doses coupled to image quality**

→ **Investigation of the effect of the underlying pathology**
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