Nordic project: Establishing diagnostic reference levels for pediatric patients

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Nordic Working Group on Medical Applications
Setting DRLs for children

New trends
- BSS focus on DRL for special groups
- DRLs should be indication based

Special challenges – paediatric DRLs
- Large span in patient size
  - Weight: from less than 1 kg to more than 70 kg
  - Height/Length: from around 50 cm to 180 cm
- Number of examinations
  - Children constitute only ≈20 % of the population
  - Lower number of examinations for children than for adults
- Even more pronounced for small countries
Project set-up

Data collection in
- Denmark
- Norway
- Iceland
- Sweden

Finnish data to be used for comparison
- Recent DRL values from 2015 (CT) and 2018

Time line
- Project plan approved December 2017
- Data collection started March 2018
  - Planned to end in September 2018 - extended
- Data analysis under way

Inspiration

- Guidelines published 2018
- Recommendations
  - Body examinations: Weight groups or DRL curves
  - Head examinations: Age groups

- Publication 135
  - Diagnostic reference levels in medical imaging
## Examinations per year

### Conventional radiology (incl. fluoroscopy) 2016

<table>
<thead>
<tr>
<th>Examination</th>
<th>Denmark</th>
<th>Finland</th>
<th>Iceland</th>
<th>Norway</th>
<th>Sweden</th>
<th>Estimated Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>19.327</td>
<td>53.393</td>
<td>1.964</td>
<td></td>
<td>36.500</td>
<td>110.000</td>
</tr>
<tr>
<td>Pelvis, hip joints</td>
<td>5.574</td>
<td>3.943</td>
<td>438</td>
<td></td>
<td>6.000</td>
<td>16.000</td>
</tr>
<tr>
<td>Abdomen</td>
<td>3.512</td>
<td>1.492</td>
<td>388</td>
<td></td>
<td>7.800</td>
<td>13.000</td>
</tr>
<tr>
<td>Scoliosis</td>
<td>3.376</td>
<td>4.289</td>
<td>41</td>
<td>5.000</td>
<td>1.900</td>
<td>9.600</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>2.325</td>
<td>2.277</td>
<td>43</td>
<td></td>
<td>2.300</td>
<td>7.000</td>
</tr>
<tr>
<td>Small intestine passage</td>
<td>277</td>
<td>299</td>
<td>124</td>
<td></td>
<td>1.700</td>
<td>2.300</td>
</tr>
<tr>
<td>MCU</td>
<td>251</td>
<td>290</td>
<td>30</td>
<td></td>
<td>900</td>
<td>1.400</td>
</tr>
</tbody>
</table>

Denmark, Finland, Iceland:
- Registry data

Sweden, Norway:
- Estimates

0-15 years (Iceland 0-14 years)
## Examinations per year

<table>
<thead>
<tr>
<th>CT 2016</th>
<th>Denmark</th>
<th>Finland</th>
<th>Iceland</th>
<th>Sweden</th>
<th>Estimated Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>1.542</td>
<td>1.412</td>
<td>220</td>
<td>10.200</td>
<td>13.400</td>
</tr>
<tr>
<td>Spine</td>
<td>1.460</td>
<td>847</td>
<td>32</td>
<td>1.300</td>
<td>3.600</td>
</tr>
<tr>
<td>Adomen, pelvis</td>
<td>413</td>
<td>184</td>
<td>83</td>
<td>1.500</td>
<td>2.200</td>
</tr>
<tr>
<td>Chest</td>
<td>546</td>
<td>509</td>
<td>84</td>
<td>1.040</td>
<td>2.200</td>
</tr>
<tr>
<td>Joints, soft tissue</td>
<td>0</td>
<td>100</td>
<td></td>
<td>1.275</td>
<td>1.400</td>
</tr>
<tr>
<td>Trauma</td>
<td>302</td>
<td>139</td>
<td></td>
<td>810</td>
<td>1.300</td>
</tr>
<tr>
<td>Hip joints</td>
<td>46</td>
<td>45</td>
<td>16</td>
<td>310</td>
<td>400</td>
</tr>
<tr>
<td>Urinary track</td>
<td>74</td>
<td>29</td>
<td></td>
<td>80</td>
<td>200</td>
</tr>
</tbody>
</table>

**Denmark, Finland, Iceland:**
- Registry data

**Sweden:**
- Estimates

0-15 years
(Iceland 0-14 years)
Data collection

Protocol – main parameters

• Conventional
  – Grid
  – FFA
  – Filtration
  – Focus size

• CT
  – kV
  – Axial/ spiral
  – Pitch
  – Number of phases
  – Dose modulation
  – Iterative reconstruction – description
  – Slice thickness – Scanned and reconstruction
  – Rotation time

Patient

• Common
  – Age
  – Height and Weight (except for head exams)

• Conventional
  – Number of images
  – DAP
  – kV
  – Automatic exposure control used
  – mAs

• CT
  – kV
  – CTDI\text{vol}
  – DLP

Equipment – manufacture and type
### How much data?

**Conventional examinations**

<table>
<thead>
<tr>
<th>Examination type</th>
<th>0-48 months</th>
<th>4-15 years</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdomen</td>
<td>66</td>
<td>150</td>
<td>216</td>
</tr>
<tr>
<td>Chest, bed</td>
<td>221</td>
<td>11</td>
<td>232</td>
</tr>
<tr>
<td>Chest, standing</td>
<td>310</td>
<td>453</td>
<td>763</td>
</tr>
<tr>
<td>Pelvis</td>
<td>99</td>
<td>144</td>
<td>243</td>
</tr>
<tr>
<td>Pelvis / hip joints</td>
<td>128</td>
<td></td>
<td>128</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>3</td>
<td>44</td>
<td>47</td>
</tr>
<tr>
<td>Scoliosis, primary</td>
<td>2</td>
<td>153</td>
<td>155</td>
</tr>
<tr>
<td>Scoliosis, follow-up</td>
<td>4</td>
<td>77</td>
<td>81</td>
</tr>
</tbody>
</table>
## How much data?

### CT

<table>
<thead>
<tr>
<th>Examination Type</th>
<th>Indication</th>
<th>0-48 months</th>
<th>4-15 years</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdomen with contrast</td>
<td>Tumor, infection, obstruction, birth defect</td>
<td>12</td>
<td>212</td>
<td>224</td>
</tr>
<tr>
<td>Brain</td>
<td>Infarct/haemorrhage</td>
<td>391</td>
<td>876</td>
<td>1267</td>
</tr>
<tr>
<td>Brain</td>
<td>Ventricular size/shunt</td>
<td>16</td>
<td>41</td>
<td>57</td>
</tr>
<tr>
<td>HRCT</td>
<td></td>
<td>19</td>
<td>67</td>
<td>86</td>
</tr>
<tr>
<td>Chest with contrast</td>
<td>Tumor, birth defect, metastases</td>
<td>39</td>
<td>82</td>
<td>121</td>
</tr>
<tr>
<td>Head, chest, abdomen</td>
<td>Trauma</td>
<td>1</td>
<td>26</td>
<td>27</td>
</tr>
</tbody>
</table>
Data check

Example:
Conventional chest

0.1 mGy·cm²

= 1 Gy·cm²

= 100 µGy·cm²

= 1000 mGy·cm²

= 1,000,000 µGy·cm²

Reported in µGy·cm² instead of mGy·cm²
Data analysis – basics

Dependence of patient dose on patient size

• Attenuation increases exponentially with patient diameter
  - Patient diameter increases with body weight (and age)
• Field size increases slowly with increasing size of patient
  ➢ Assume overall exponential increase with body weight (or age)

Body examinations
  ➢ Dose values plotted vs. patient weight and fitted with exponential function

Head examinations
  ➢ Dose values plotted vs. patient age and fitted with exponential function
Data analysis – determining DRLs

Data pooling
• Ideally: By hospital – requires very large numbers of data
• Other possibilities:
  – By healthcare region / country
  – By manufacturer, e.g. for CT

Fitting process
• Exponential fit for each pool of data: \( DLP_i = DLP_{0,i} \cdot \exp(a_i \cdot \text{Weight}) \)
• Common exponential factor determined: \( a \)
  – Weighted average of \( a_i \)
  – Weighted by the number of data points in each pool
• Calculate \( DLP_{0,dp} \) from each individual data point based on \( a \)
• Calculate values from all of \( DLP_{0,dp} \) values
  – 50% quartile – achievable level
  – 75% quartile – reference level (DRL)
CT Abdomen

Pooled by country

<table>
<thead>
<tr>
<th>Weight [kg]</th>
<th>DRL</th>
<th>Ach.</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>59</td>
<td>45</td>
</tr>
<tr>
<td>70</td>
<td>340</td>
<td>257</td>
</tr>
</tbody>
</table>

\[ y = 79,723e^{0.0184x} \]

\[ y = 19,245e^{0.0492x} \]

\[ y = 34,235e^{0.0272x} \]
CT Abdomen

Pooled by manufacturer

### Table

<table>
<thead>
<tr>
<th>Weight [kg]</th>
<th>DRL</th>
<th>Ach.</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>62</td>
<td>46</td>
</tr>
<tr>
<td>70</td>
<td>333</td>
<td>248</td>
</tr>
</tbody>
</table>

### Equations

- $y = 78,492e^{0.0142x}$
- $y = 136,64e^{0.0147x}$
- $y = 31,503e^{0.03x}$
- $y = 87,625e^{0.0171x}$
Comparison

- Finnish DRLs 2015
- Current results
CT Brain

0-4 years
- Age in months

4-15 years
- Age in years

Common analysis?
- Seems feasible
- Curve is a possibility
Next steps

Further data analysis

Consultation with paediatric radiologists
• Presentation of results
• Comparison of protocols

Publication
• Collected data
• Guidance DRLs

• In website of Nordic Working Group of Medical Applications
• In national websites

Encourage further work with optimisation of paediatric x-ray examinations
Thank you for your attention