CT pediatry: influence of new technologies on patient dose

N Buls
Department of Radiology
VUB – B.E.F.Y.

BVS, Brussel, 20 juni 2008
Content

Technical evolution in CT
   Influence on clinical outcome pediatrics

CT dosimetry
   Standards for pediatric CT
   Pediatric dose surveys

Dose optimisation strategies

Advanced applications MSCT and RP tools
Technical evolution
Technical evolution
From slice imaging to isotropic voxels

1989: spiral CT

1998: multislice CT (MSCT)

1 slice – 5 min

complete volume scan – few sec

Kalender W, Eur Radiol (2005)

RSNA 2007:
Toshiba: 320 rows
Philips: 128 rows
Siemens: 64 x 2 rows
MSCT has potential of imaging faster, imaging larger volumes, imaging same volume at better geometrical resolution

1. Faster
   allows examinations where motion artefacts previously contraindicated its use
   young children, severe pain, reduced i.v. contrast, general anaesthesia with intubation (CT ↔ MR)

MSCT reduces sedation rate in pediatric CT
2. Larger volumes
allows to survey large volume in short time
e.g. malignant lymphoma staging neck and entire trunk in children

Donnelly et al, AJR (2000)

3. Image quality
improved isotropic resolution allows organ evaluation in different planes
children have smaller organs and less fat, multi-phase imaging, 3D post-processing
Impact of MSCT on clinical management

“MSCT improves all areas of pediatric CT imaging”
Yekeler E. EJR, 2004

“The benefit of MSCT in pediatric patients is very high”
EU MSCT guidelines, 2004

Due to this clear clinical benefit we can expect:

- increasing number of CT examinations / exposure
- increasing dose per examination ….
  - larger volumes / more phases
  - increased resolution
  - advanced applications
Impact of MSCT on clinical management

U.S.
Today, 62 million scans per year, compared to 3 million in 1980s


No. CT-scans per year

No. CT-scans per year
Impact of MSCT on clinical management

**U.S.**

CT-scans in **children** have increased from 4% to 11% of all CT examinations

- 1/3 before age 10
- 1/6 before age 5


**be**

Data from 2003.

70% > 45 yr

~3% < 15 yr
CT dosimetry
CT dose indices

Dose from one tube rotation
- weighted CT dose index \( (\text{CTD}_{\text{w}}) \)
- volume weighted CT dose index \( (\text{CTD}_{\text{v}}) \)

Dose from one scan sequence
- dose-length product \( (\text{DLP}) \)

In addition
- organ dose / effective dose \( (E) \)

Basis for DRL’s and scan parameter optimisation
CT dose indices

CTDI = the integral along a line parallel to the axis of rotation (z) of the dose profile, $D(z)$ for a single slice, divided by total detector acquisition width ($N \times T$)

$$n_{CTDI}^{100,x} = \frac{1}{N \times T} \cdot \int_{-50\,mm}^{+50\,mm} D(z) \cdot dz$$

fixed integration length of 100 mm (-50 to +50 mm)

Phantom standards 32 cm and 16 cm diameter
CT dose indices

How is the volume scanned?

\[ CTDI_{VOL} = \frac{CTDI_w}{\text{pitch}} \]

What is the length of the sequence?

\[ DLP = CTDI_{VOL} \times L \]

DLP includes all technical scan parameters and scanner characteristics.

CTDI\textsubscript{vol} and DLP indicated on scanner console.

IEC (2003) standard 60601-2-44
Organ dose calculations from CTDI$_{VOL}$ by MC simulation

- Windose
- NRPB, report SR250
- ImPACT
- GSF, bericht 30/91
- CT-Expo, *Nagel*
Considerations for pediatrics

Influence of diameter on CTDI

Displayed CTDI on console does not reflect actual dose in paediatric patients

Paediatric dose is much higher than adult dose: $16\text{cm} \approx \text{CTDI} \times 2 \approx \text{DLP} \times 2$


Increased CTDI and DLP

CT potentially poses significantly greater risk to children

Increased E/DLP

from Shrimpton, NRPB-PE/1 (2004)

Increased radiosensitivity

Donnelly L, AJR (2001)
Brenner D, AJR (2001)
In CT, the technical limitation of the x-ray tube/generator determines the maximum amount of exposure, not the detector.

all patients can be scanned with the same technical settings (kV, mAs)

“it is not unusual that radiologists apply adult protocols for children” Paterson et al, AJR (2001)
Dose surveys
Suggest potential for dose reduction

NRPB-W67 (2003)
UK review CT doses

- sample of 126 scanners
- adults and children
- ~25% UK scanners
- DRLs

EU guidelines for MSCT (2004)
Bongartz G et al.

- field survey
- UK, CH, NL
- 4 indications
- chest (0-1 y old)

![Histogram showing the effective dose at 19 departments.](image)
Dose surveys
Suggest potential for dose reduction

- Australia
- 9 centers
- chest (7 y old)

- Belgium, regional
- 7 centers
- abdomen (1 y old)

<table>
<thead>
<tr>
<th>CT unit</th>
<th>DLP (mGycm)</th>
<th>DRL (mGycm)</th>
<th>E (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-year-old</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>217</td>
<td></td>
<td>4.6</td>
</tr>
<tr>
<td>B</td>
<td>171</td>
<td>4 &gt; 330</td>
<td>3.9</td>
</tr>
<tr>
<td>C</td>
<td>576</td>
<td></td>
<td>15.5</td>
</tr>
</tbody>
</table>

same scanner
Surveys Suggest potential for dose reduction

Results from CT pediatric surveys show

- substantial dose variations for same age group
- no common trend in parameter selection
- suggest realistic potential for dose reduction
Dose optimisation strategies
Halve value thickness of tissue in CT is approximately 4 cm

Patient diameter – 4 cm → intensity at detector x 2

Dose optimisation
Adapting tube current

Recommendations to user:
“adapt tube current (mAs) manually to patient size”

- manually…hmmmm…
- what is the size of this patient?
- how much mAs is required?
- mA or mAs? tube rotation?
- mAs scanner A mAs ≠ mAs scanner B
- standardized guidelines?

TABLE 1: Suggested Tube Current (mA) by Weight of Pediatric Patients for Single-Detector Helical CT

<table>
<thead>
<tr>
<th>Weight</th>
<th>mA Chest</th>
<th>mA Abdomen or Pelvis</th>
</tr>
</thead>
<tbody>
<tr>
<td>10–19</td>
<td>4.5–8.9</td>
<td>40</td>
</tr>
<tr>
<td>20–39</td>
<td>9.0–17.9</td>
<td>50</td>
</tr>
<tr>
<td>40–59</td>
<td>18.0–26.9</td>
<td>60</td>
</tr>
<tr>
<td>60–79</td>
<td>27.0–35.9</td>
<td>70</td>
</tr>
<tr>
<td>80–99</td>
<td>36.0–45.0</td>
<td>80</td>
</tr>
<tr>
<td>100–150</td>
<td>45.1–70.0</td>
<td>100–120</td>
</tr>
<tr>
<td>&gt;150</td>
<td>&gt;70</td>
<td>≥140</td>
</tr>
</tbody>
</table>

Brenner D et al, AJR (2001)
Donnelly L, AJR (2001)
Dose optimisation
Adapting tube current to size: TCM and AEC

TCM
According patient overall size

AEC
For each axial slice position (along z-axis)

Angular
(alpha)

Goal: constant IQ, dose optimised, reduces tube load, less artefacts
Dose optimisation
Adapting tube current to size: AEC and TCM

Courtesy of
U.Baum, University Hospital Erlangen
Dose optimisation
Adapting tube current to size: AEC and TCM

“20-25% dose reduction can be achieved with AEC compared to fixed mA”

Nowadays, ATM and AEC is standard on most high-end CT scanners
Subsecond scanning requires high tube output and thus high kV (120 – 130 kV).

\[ \text{tube output} \propto \text{mA} \cdot kV^{2.5} \]

In pediatric applications smaller volumes are scanned and tube load parameters can be reduced.

Image noise increases but the effect is minimal in smaller phantoms.
Dose optimisation  
Spectral optimisation

**Lower kV can be applied routinely for contrast studies and soft tissue imaging**

Using **80 kV instead of 120 kV** can reduce dose by **50% - 70 %** for constant CNR  

**Tube voltages of around 60 kV should be made available for scanning small children**  

**Changing kV requires effort!**
- beam hardening artefacts  
- CT (HU) numbers change
- radiologists have to adapt to different image impression
Advanced applications and RP tools
Advanced applications…
**Cardiovascular imaging: typical high dose**

Non-invasive viewing of coronary arteries
Visualisation, analysis of stenoses and plaques

Also applied for **children**!
**congenital heart disease** (age: 1 day – 15 yr)
Advanced dose optimisation strategies
ECG triggered tube current modulation

Acquisition and reconstruction only during selected phase of cardiac cycle

tube current

100 %

20 %

time

Systolic phase
Diastolic phase
Early papers w/o ECG modulation describe patient doses in the range of 10 – 20 mSv.

Recent studies w ECG modulation show typical dose reductions of ~50%.

Recent studies show applicability of ECG modulation in daily practice.
Advanced dose optimisation strategies

ECG triggered tube current modulation

Herzog et al, *AJR*, May 2008

<table>
<thead>
<tr>
<th>Measure of Radiation Exposure</th>
<th>64-MDCT with ATCM</th>
<th>60 kVp (n=17)</th>
<th>100 kVp (n=9)</th>
<th>120 kVp (n=12)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube current–time product (mAs)</td>
<td>Actual value</td>
<td>24.8 ± 3.9</td>
<td>65.1 ± 45.9</td>
<td>76.7 ± 48</td>
<td>54.1 ± 44</td>
</tr>
<tr>
<td>Reference value&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.3 ± 7.9</td>
<td>144.4 ± 70.3</td>
<td>174.2 ± 84.9</td>
<td>56.0</td>
<td>57.8</td>
</tr>
<tr>
<td>Difference (%)</td>
<td>65.7</td>
<td>54.9</td>
<td>56.0</td>
<td>57.8</td>
<td></td>
</tr>
<tr>
<td>(p)</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td></td>
</tr>
<tr>
<td>CTDI&lt;sub&gt;vol&lt;/sub&gt; (mGy)</td>
<td>Actual value</td>
<td>0.5 ± 0.1</td>
<td>2.2 ± 1.8</td>
<td>5.3 ± 3.2</td>
<td>2.8 ± 3.1</td>
</tr>
<tr>
<td>Reference value&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.5 ± 0.2</td>
<td>4.7 ± 2.4</td>
<td>12.2 ± 5.7</td>
<td>6.4 ± 6</td>
<td></td>
</tr>
<tr>
<td>Difference (%)</td>
<td>66.6</td>
<td>53.2</td>
<td>56.6</td>
<td>56.3</td>
<td></td>
</tr>
<tr>
<td>Dose–length product (mGy × cm)</td>
<td>Actual value</td>
<td>8.5 ± 2.9</td>
<td>59.4 ± 50.9</td>
<td>156.8 ± 123.5</td>
<td>77.1 ± 103.7</td>
</tr>
<tr>
<td>Reference value&lt;sup&gt;a&lt;/sup&gt;</td>
<td>24.6 ± 8</td>
<td>128.1 ± 70.3</td>
<td>346.1 ± 220.2</td>
<td>171 ± 200.2</td>
<td></td>
</tr>
<tr>
<td>Difference (%)</td>
<td>65.4</td>
<td>53.6</td>
<td>54.7</td>
<td>54.9</td>
<td></td>
</tr>
<tr>
<td>Radiation dose equivalent (E) (mSv)</td>
<td>Actual value</td>
<td>1.0 ± 0.2</td>
<td>1.9 ± 1.5</td>
<td>4.4 ± 2.1</td>
<td>2.5 ± 2.1</td>
</tr>
<tr>
<td>Reference value&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9 ± 0.7</td>
<td>4.5 ± 2.4</td>
<td>10.6 ± 3.7</td>
<td>6.3 ± 4.4</td>
<td></td>
</tr>
<tr>
<td>Difference (%)</td>
<td>65.5</td>
<td>57.8</td>
<td>58.5</td>
<td>60.3</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Values for 64-MDCT without ATCM were estimated from prevailing actual 64-MDCT mAs values.
Advanced dose optimisation strategies

Adaptive overscanning collimation

All helical MSCT require overscanning

tissue exposure beyond boundaries of imaged volume

X-ray tube penumbra

Reconstruction prerequisite
Advanced dose optimisation strategies

Adaptive overscanning collimation

How much extra dose?

Penumbra

Effect diminishes for larger $z$:
- 4-slice: ~ 10%
- 64-slice: ~ 3%

Reconstruction


Children 0 – 15 yrs

Normalized E:
Helical versus axial (26% to 70%)!
Advanced dose optimisation strategies
Adaptive overscanning collimation
Advanced applications
CT colonography – virtual colonoscopy

Non-invasive method for the evaluation of the colon lumen

Also reported for children!


Study group:
- 100 childr, age 30d – 16yr
- Low dose protocol (90 kV)

Major advantage over conventional colonoscopy:
- no anesthesia or sedatives
- no complications

Pedunculated polyp in sigmoid colon
Advanced applications
Dual Energy CT scanning

New?
Kelcz F et al, Med Phys (1979)
Noise considerations in dual energy CT scanning

Elemental composition of tissues/materials

\[ \text{CT value} = 1000 \times \mu_{\text{water}} / \mu_{\text{tissue}} \]

- **80kV**
  - Bone: 670 HU
  - Iodine: 296 HU

- **140kV**
  - Bone: 450 HU
  - Iodine: 144 HU
Advanced applications

Dual Energy CT scanning

Arterial calcification

CT angiogram

Fishman E, Appl Radiol 2006
The benefit of MSCT in pediatric imaging is very high

# examinations will probably further increase

Currently, strong development going on....

Shift from HU slice imaging to advanced, functional applications (perfusion, DE, cardiac)

Pediatric CT imaging requires careful scan parameter selection

studies report doses up to 20 mSv per scan

surveys show substantial variations between centers
Conclusions

Recent years (~2001) RP received a lot of attention

recent reports show decreased doses

efforts from manufacturers side include
  - AEC and TCM
  - dedicated paediatric scan protocols
  - advanced techniques (cardiac, helical, etc)

Legislation

- special attention children and CT
- paediatric DRLs become available for MSCT
- local dose audits
There is still a lot of work

Operating AEC efficiently is not straightforward

AEC systems require understanding of newer concepts

AEC systems should be included in scanner QC

CT dosimetry in children is not a trivial task

Scan protocol optimisation and advanced applications
Thank you for your attention

If you require a copy of this presentation
email Nico.Buls@uzbrussel.be