Radiation Dose Management in CT, SPECT/CT and PET/CT techniques

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Medical imaging

- Tremendous and undeniable benefit of medical imaging
- A dramatic development during the last few decades
- This development continues!
The evolution of diagnostic imaging

**PAST**

**Anatomic**
- X-rays, CT, MRI, US

**Present**

**Functional**
- Angiography, Doppler US, NM, MRI, PET

**Hybrid**
- PET/CT, SPECT/CT, PET/MR

**“Future”**

**Molecular**
- NM, PET, SPECT, MRS, Optical, PET/MRI
- Contrast-enhanced MRI/US/CT

- Increasing radiation exposure of patients
  - CT, nuclear medicine, interventional
- Increasing interest from patients about their exposure situation, also from health professionals, authorities and manufacturers
- Increasing occupational exposure
  - Interventional procedures, nuclear medicine-PET
Radiological examinations in Sweden 2005

CT and NM constitutes **16%** of the number of radiological investigations and contributes with **64%** to the collective dose.
CT + NM = 22% of all investigations, but 75% of the collective dose
NM is dominated by PET and SPECT
Good reasons to combine PET and SPECT with CT:

• 1: Improved attenuation correction in PET and SPECT >> Superior quantification
• 2: Complementary information: structure + function, anatomy + physiologi/biochemistry
• 3: Exact localization

But combination of two “high-dose” investigations!
Can anything be done to reduce PET/CT and SPECT/CT-doses?

Risk for cancer later in life...

Effective dose, mSv

Coronary angiography

PET/CT, SPECT/CT

Colon

CT abdomen/pelvis, PET-FDG

CT thorax/lungs

CT head

Low dose CT colon

Low dose CT facial skeleton

Low dose CT lungs

99mTc-substances

Urography

Lumbar spine

Mammography

Lungs

Facial skeleton

Hand, foot

Teeth (single picture)
... also to avoid tissue injuries

Imanishi et al.
What can be done to reduce CT doses?

• Optimise scanning parameters
  – Adequate mAs and kV levels
  – Reduction of scanning length
  – Minimising the number of scans
• Automatic Exposure Control (AEC) - an effective technique for patient dose reduction
• Organ based dose reduction
• Adaptive collimation to reduce effect of "overscanning"
• Iterative image reconstructions
Automatic Exposure Control (AEC)

• Adaptation of the tube current relative patient attenuation
• Different AEC techniques:
  - Longitudinal modulation (z)
  - Angular modulation (x,y)
  - Combined modulation (x,y,z)  

Illustration courtesy of Siemens
Organ based dose modulation – Siemens X-Care

- Up to 40% reduced sensitive-area (breast) radiation exposure without loss of image quality
'Over-scanning', the additional rotation of the x-ray tube at each end of the scan length, which allows the first and last slices to be reconstructed, contributes significantly to overall patient exposure during the examination.

„Adaptive dose shield“
„Adaptive collimation“

Dose reduction: 5-25%

Deak P D et al.
Radiology 2009;252:140-147
Iterative image reconstruction

- GE – ASIR (Adaptive Statistical Iterative Reconstruction)
- Siemens – IRIS (Iterative Reconstruction in Image Space)
- Philips – iDose
- Toshiba – QDS (Quantum denoising software)
Summary of dose reduction possibilities in CT

- Iterative reconstruction reduction with 60% of the dose
- The AEC systems available in modern CT scanners can contribute to a significant reduction in radiation exposure to the patient, ~ 35-60%
- Elimination of “overscanning” reduction with 5-25%
- Dose saving for specific organs (eg. breasts, eye lenses, thyroid) 30-40%

The manufacturers “slice war” has been turned into a ”dose war”
PET/CT has now replaced standalone PET for many applications.

Oncology, cardiology, neurology, psychiatry.
Typical effective dose and organ dose values for common diagnostic CT investigations

<table>
<thead>
<tr>
<th>Investigation</th>
<th>Effective dose (mSv)</th>
<th>Organ absorbed doses (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head CT</td>
<td>2</td>
<td>Lens of the eye: 50, Thyroid: 1.9</td>
</tr>
<tr>
<td>Chest CT</td>
<td>6</td>
<td>Breast: 21, Thyroid 2.3, Lens of the eye: 0.14</td>
</tr>
<tr>
<td>Abdomen CT</td>
<td>16</td>
<td>Uterus and ovaries: 8</td>
</tr>
<tr>
<td>Pelvis CT</td>
<td>8</td>
<td>Uterus and ovaries: 25</td>
</tr>
<tr>
<td>Total body</td>
<td>20-30</td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Radio-nucl</td>
<td>Radio-pharmaceutical</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Tumour</td>
<td>$^{18}$F</td>
<td>FDG</td>
</tr>
<tr>
<td>Tumour</td>
<td>$^{18}$F</td>
<td>Choline</td>
</tr>
<tr>
<td>Tumour</td>
<td>$^{11}$C</td>
<td>Choline</td>
</tr>
<tr>
<td>Alzheim</td>
<td>$^{11}$C</td>
<td>PiB</td>
</tr>
<tr>
<td>Tumour</td>
<td>$^{11}$C</td>
<td>Acetate</td>
</tr>
<tr>
<td>Tumour</td>
<td>$^{11}$C</td>
<td>Methionine</td>
</tr>
</tbody>
</table>
• Superior to planar imaging with gammacamera
• Bone scintigraphy
• Myocardial perfusion imaging
• Functional brain imaging
• Somatostatin receptor scint
• Parathyroid scint
• Adrenal gland scint
• Detection of sentinel nodes
**Typical effective dose values for common SPECT/CT investigations (SPECT contribution)**

<table>
<thead>
<tr>
<th>Study</th>
<th>Radio-isotope</th>
<th>Radiopharmaceutical</th>
<th>Activity (MBq)</th>
<th>Eff dose (mSv)</th>
<th>Examples of organ doses (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone</td>
<td>$^{99m}$Tc</td>
<td>Phosphonates</td>
<td>600</td>
<td>3.4</td>
<td>Bladder wall 30, Red bone marrow 6, Ovary 2, Testes 1.4</td>
</tr>
<tr>
<td>Myocardial perf</td>
<td>$^{99m}$Tc</td>
<td>Tetrofosmin sestamibi</td>
<td>600</td>
<td>4.2-4.6</td>
<td>Bladder wall: 10-16, Gall bladder: 16-22</td>
</tr>
<tr>
<td>Brain</td>
<td>$^{99m}$Tc</td>
<td>HMPAO</td>
<td>800</td>
<td>7.4</td>
<td></td>
</tr>
<tr>
<td>Tumour</td>
<td>$^{123}$I</td>
<td>MIBG</td>
<td>400</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>White cell</td>
<td>$^{111}$In; $^{99m}$Tc</td>
<td>In vitro labelled leucocytes</td>
<td>18; 185</td>
<td>6.5; 2.0</td>
<td></td>
</tr>
</tbody>
</table>
Typical effective doses:

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET/CT</td>
<td>28 mSv</td>
</tr>
<tr>
<td>SPECT/CT</td>
<td>25 mSv</td>
</tr>
</tbody>
</table>
Low dose CT or "Diagnostic" CT to combine with PET (SPECT)?

If there is a recent "diagnostic" CT make PET/Low dose CT

If there is no recent "diagnostic" CT, make PET/"Diagnostic" CT

1. PET /Low-dose CT = 14 mSv
2. PET/Diagnostic CT = 28 mSv
3. PET /Low-dose CT + Diagnostic CT = 36 mSv
Justification of an investigation

We have not yet succeeded to fully implement this principle. Something must happen!

*Finnish study:* Of 200 **CT-examinations** on patients less than 35 years, 59 (30%) were not justified *(European Radiology 19 (2009) 1161-1165)*

*Swedish study:* Of all CT investigations, done during one specific day in Sweden, about 20% were unjustified *(Almén et al. 3rd European IRPA, Helsinki, 2010)*
Possible explanations

Referrers

• Lack of risk awareness?
• No idea about patient exposure at different investigations?
• Not well informed about imaging methods?
• Want to be on the safe side

Radiology departments

• There is a pressure to perform by demand from referrers
• There is a pressure of increasing demand on radiology generally
• Lack of radiologists and radiographers
• Need for more MR and US capacity

Need for an increased awareness of the physicians prescribing the examination

- Need for their education and training
- Need for clear referral guidelines
It started long time ago

CT-investigations were far from optimal
1999 - ICRP initiates a “Task Group on Patient doses in CT”

Manufacturers were not at all concerned “as no customers have raised the question” !!!

Editorial in Br Med J in March 2000

BMJ 2000;320:593-594 (4 March)
Editorials
Radiation doses in computed tomography
The increasing doses of radiation need to be controlled

Newspapers 2001

Brenner et al., AJR 176 (2001) 289-296
• Since 2002 the manufacturers have radiation dose on the top of the agenda
• 2007 - ICRP Publication 102

Now new very important actors:
IAEA´s Radiation Protection of Patients Group (http://rpop.iaea.org/RPoP/RPoP/Content/index.htm)
Image Gently (http://www.imagegently.org)
Exposure of staff members is a consequence of:

- External exposure during preparation and handling of radiopharmaceuticals
- External exposure from the patient
- Internal exposure as a result of contamination
### $^{18}$F-FDG doses to technicians

<table>
<thead>
<tr>
<th>Reference</th>
<th>&quot;Effective dose&quot;, nSv/MBq</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total&lt;sup&gt;x&lt;/sup&gt;</td>
</tr>
<tr>
<td>Chiesa et al., 1997</td>
<td>12</td>
</tr>
<tr>
<td>Benatar et al., 2000</td>
<td>17</td>
</tr>
<tr>
<td>Guillet et al., 2005</td>
<td>9</td>
</tr>
<tr>
<td>Roberts et al. 2005</td>
<td>11</td>
</tr>
<tr>
<td>Sejerstad et al., 2006</td>
<td>25</td>
</tr>
<tr>
<td>Leide-Svegborn, 2010</td>
<td>15</td>
</tr>
</tbody>
</table>

<sup>x</sup> from filling of syringe to patient departure

For an annual number of less than 500 patients, an annual individual dose for the technicians would realistically be less than 2–3 mSv
**Finger doses $^{18}$F-FDG**

<table>
<thead>
<tr>
<th>Normal laboratory standard</th>
<th>2 $\mu$Sv/MBq</th>
<th>Linemann et al., 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;</td>
<td>2.6 $\mu$Sv/MBq</td>
<td>Leide-Svegborn et al., 2010</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Normal laboratory standard</th>
<th>0.2-0.6 $\mu$Sv/MBq</th>
<th>Guillet et al., 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ syringe drawing device and semiautomatic injector</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Normal laboratory standard</th>
<th>&lt; 0.02 $\mu$Sv/MBq</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>+ fully automatic dispensing technique</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For an average injected activity of 350 MBq per patient, the dose limit (500 mSv to fingers) is reached after handling of 500, 2400 or many more patients annually.
Good manual working technique

(ICRP Publ 106, 2008)

Automatic dispensing technique
Medical radiation physics Malmö
Lund university, Skåne university hospital Malmö

…thank you for listening!