Radiation Protection in Medicine: Past, Present and Future

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What did we have 50 years ago?

- Radiography ✓
- Fluoroscopy ✓
- CT: No
- Interventional procedures: No
- MRI, US: No ionizing radiation
Radiotherapy & Nuclear Medicine

- Mainly Cobalt-60, No Linac
- Radium for brachytherapy
- Iodine-131: Queen of nuclear medicine
• Calcium Tungstate screens, 200 speed
• Rare earth screens: ≈ 2 times faster
• Patient dose ≈ Half or still better
• Compared to emulsions or direct radiography- patient dose ↓ by a factor of few tens
• Operator dose, similar proportion, depending upon shielding
Radiography

How much time Radiographer works with radiation/day?
Radiography
Radiation ON Time

Workload= (say)100 exposures/day

CxR = 50x50 m sec = 2500 = 2.5 sec

Abdomen/LS/Skull = 50x800 m sec = 40000=40s

Total time = 45 sec/day
=90 sec for 200 exp/day

About 1.5 min/day/200exp
A radiographer can manage a work load of 200 exposures /day and still get <1 mSv/yr using protection
Radiography

Patients & Operator are SAFER Today than 50 years ago by a factor of $>10$
Radiography: Future

- Digital
- Patient dose can be low but is typically higher
- More awareness, training

Editorial

BMJ X ray imaging goes digital
Kwan-Hoong Ng and Madan M Rehani

BMJ 2006;333;765-766
doi:10.1136/bmj.38977.669769.2C
Digital Radiology

How to make patients safer

Avoidance of Unnecessary Dose to Patients While Transitioning from Analogue to Digital Radiology

IAEA-TECDOC-1887

International Atomic Energy Agency

Atoms for Peace: The First Half Century
http://rpop.iaea.org
Digital Radiography

Digital Radiography & Fluoroscopy

Digital radiology may represent the greatest technological advancement in medical imaging over the last decade. The use of radiographic films in x-ray imaging might become obsolete in a few years. An appropriate analogy that is easy to understand is the replacement of typical film cameras with digital cameras. Images can be immediately acquired, deleted, modified, and subsequently sent to a network of computers.

The benefits from digital radiology are enormous. It can make a radiological facility or department filmless. The referring physician can view the requested image on a desktop or a personal computer and often report in just a few minutes after the examination was performed. The images are no longer held in a single location; but can be seen simultaneously by physicians who are kilometres apart. In addition, the patient can have the x-ray images on a compact disk to take to another physician or hospital.

Establishing a digital radiography facility

1. Do I need a darkroom when I buy a digital X-ray system?
2. Do I have to throw away my old X-ray equipment when I move to digital imaging?
3. Do I have to be a computer expert to use digital imaging?
4. Do I need to have special training to interpret digital X rays?
5. The salesman says CR is better than DR? What do these terms mean, and is this true?

Operational aspects

6. Can I perform angiographic procedures with a digital radiography X-ray unit?
7. Can digital X-ray units be mobile?
8. If the image of one of the patients examined a few days ago is not found in the DR workstation, what should I do before repeating the examination?
9. How do I recognize if a digital chest image has been obtained with 120 kV or with 70 kV?
10. Should I process numerically the overexposed digital images to get image useful for diagnosis?
Free Material

- Diagnostic and Interventional Radiology
- Radiotherapy
- Nuclear Medicine
- Prevention of Accidental Exposure in Radiotherapy
- Cardiology
- PET/CT
- Paediatric Radiology
- Digital Radiology
- Doctors using fluoroscopy outside radiology (Urologists, Gastroenterologists, Orthopaedic surgeons etc.)
241,546 visits came from 205 countries/territories
<table>
<thead>
<tr>
<th></th>
<th>Country</th>
<th>Value</th>
<th>Unit</th>
<th>Time</th>
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This country/territory sent 920 visits via 29 cities
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<tr>
<td>2.</td>
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<td>62</td>
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<tr>
<td>3.</td>
<td>Beersheba</td>
<td>57</td>
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<tr>
<td>4.</td>
<td>Haifa</td>
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<td>5.</td>
<td>Ramat Gan</td>
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<td>6.</td>
<td>Rishon Leziyyon</td>
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<td>7.</td>
<td>Givatayim</td>
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<td>9.</td>
<td>Netanya</td>
<td>7</td>
<td>1.14</td>
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<td>Holon</td>
<td>6</td>
<td>1.00</td>
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<td>11.</td>
<td>Ashqelon</td>
<td>4</td>
<td>1.25</td>
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<td>12.</td>
<td>Petah Tiqwa</td>
<td>4</td>
<td>1.50</td>
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<td>13.</td>
<td>Rehovot</td>
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<td>14.</td>
<td>Nazareth</td>
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<td>15.</td>
<td>Yehud</td>
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<td>16.</td>
<td>Raananna</td>
<td>3</td>
<td>3.67</td>
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<td>17.</td>
<td>Qiryat Ono</td>
<td>3</td>
<td>1.00</td>
</tr>
<tr>
<td>18.</td>
<td>Ashdod</td>
<td>3</td>
<td>1.00</td>
</tr>
<tr>
<td>19.</td>
<td>(not set)</td>
<td>3</td>
<td>1.00</td>
</tr>
<tr>
<td>20.</td>
<td>Hod Hasharon</td>
<td>3</td>
<td>1.67</td>
</tr>
<tr>
<td>21.</td>
<td>Lod</td>
<td>3</td>
<td>1.33</td>
</tr>
</tbody>
</table>
Significant material available from IAEA for making patients and staff safer
Diagnostic fluoroscopy: Past & Present

• Past: Dark room fluoroscopy
• Now Image intensified or digital detectors e.g. flat panel
• Day light systems, better image quality
• Exposure to patient can be down by 2 or more
• Exposure to operator can be down by similar factor
• Operator – better shielding now
Diagnostic Fluoroscopy: Present

Patients & Operator are SAFER Today than 50 years ago
Diagnostic Fluoroscopy: Future

• Like digital radiography
• Awareness, education and training
• Monitoring of patient dose
Interventional Procedures - Staff

- Potential for higher exposures to staff than in radiology, nuclear medicine and even radiotherapy
- Fluoroscopy times >30 min are not uncommon
- No real comparison with 50 years possible
- Technology better but safety not, mostly because of
  - better information. For same information, dose ↓
  - lack of utilization of protection means by operator
Interventional Procedures - Staff

- Cataract risk substantial
- Some risks of skin injuries and hair loss
- Other risks (stochastic - carcinogenic) can be managed through utilization of better protection
April 2011: Dose limit for Eye Lens reduced from 150 mSv to 20 mSv/yr, by a factor of 7.5
Risk of eye lens opacity for operator & support staff higher than 50 years ago
Hair loss in leg of interventional cardiologist

Legs of an interventional cardiologist in Yerevan, Armenia as collected by Dr. Madan Rehani, IAEA through Dr. Vahan Mkhtarian, showing hair loss primarily in right leg.
Almost a thing of past for Operators in medical radiation facilities

But risks for interventional radiologists, fluoroscopists in operation theatre e.g. orthopedic surgeons.... PREVENTABLE
Much lesser Risks of injuries to hands of operators despite higher use
But for Patients- this is IN
Patients are having these injuries
Where do the injuries occur in interventional procedures?

• Severe injuries have occurred from the neck to the buttocks
• Sometimes anteriorly &
• On the side of torso

non-cardiac procedures
Current situation

A case of radiation induced skin injury is filed in US courts every 4 to 6 weeks currently, primarily from interventional procedures

$\approx 10$ cases/year
Interventional Procedures - Patient

- MUCH better outcomes
- Replacement of surgery
- Risks can be substantial if not cared for
  - Skin injury
  - Carcinogenic risks
Nuclear Medicine

- I-131 replaced by and large by Tc-99m
- Patient doses better than half
- PET/CT: 15-25 mSv
- Cardiac imaging: 10-40 mSv
- Patient doses higher but mainly because of new applications
- Main RP issues are with hybrid imaging and radioiodine therapy
An estimated **5.1 million** courses of radiotherapy treatment were administered **annually** between 1997 and 2007 (up from an estimated **4.3 million** in 1988)*

* UNSCEAR 2008 Report
Radiotherapy

- At least 3000 patients have been affected by radiotherapy incidents and accidents in last 3 decades.
- Radiation accidents involving medical uses have accounted for more acute radiation deaths than any other source, including Chernobyl.
- These accidents do not only affect patients directly (e.g. harm and death), but might also undermine the public’s confidence in the treatment.
- Preventable medical errors overall also cost countries billions of dollars each year.
Why Safety Reporting and Learning?

From: S. Derreumaux, IRSN, France

France 2004

From: W. Bogdanich, N.Y.Times, USA

USA 2009?

From: W. Bogdanich, N.Y.Times, USA

A Pinpoint Beam Strays Invisibly, Harming Instead of Healing
Why Safety Reporting and Learning?

SIMILAR ACCIDENTS:
- Linac field opening set too large when using stereotactic collimator mounted on linac
- Large volumes outside target were given very high absorbed dose

From: S. Derreumaux, IRSN, France

From: W. Bogdanich, N.Y. Times, USA
Accidents and incidents still tend to “repeat themselves” – i.e. we need to be better at learning from previous events.
Computed Tomography (CT)

- Invented in 1972
- Most beneficial technique
- Technology has been improving fast
- BUT usage pattern and extent of usage has resulted in increased risks
Over-exposure: 2010 Regulatory actions
Besides accidental exposures

Some patients undergoing Tens of CT scan in few years

Again something that has started in this decade
## Levels of Radiation Exposure

**—Comparison between A-bomb and other exposures—**

<table>
<thead>
<tr>
<th>Atomic Bomb Radiation (Distance from Hypocenter)</th>
<th>3km</th>
<th>2.5km</th>
<th>2km</th>
<th>1.5km</th>
<th>1km</th>
<th>0.5km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose (mSv)</td>
<td>0.1</td>
<td>1</td>
<td>10</td>
<td>100</td>
<td>1,000</td>
<td>1</td>
</tr>
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</table>

### Other radiation exposure
- **Astronaut**: 15/month
- **Airline Crew**: 2/year
- **Upper GI**: 4/exam
Announcement few years ago:
The era of few hundreds of Euros for flying within Europe is gone
• The era of double digit mSv for a CT scan should go
• Lower single digit or Sub-mSv CT scan

Slice war>>>>>> Dose war
## Sub-mSv Imaging

<table>
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<tr>
<th>Imaging</th>
<th>Remark</th>
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</thead>
<tbody>
<tr>
<td>Cardiac CT</td>
<td>Almost a reality</td>
</tr>
<tr>
<td>Other body parts</td>
<td>Projected</td>
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</table>
History
1998- ICRP

• CT usage increasing and likely to grow
• Lack of awareness among users on relatively higher patient doses in CT
• Manufacturers not really concerned about patient doses as hardly customers asked for it
• Most emphasis on faster and faster CT scanners
Task Group of ICRP set up in 1999

• M.M. Rehani (Chairman)

• Members:
  • G. Bongartz (Switzerland); S.J. Golding (UK);
    L. Gordon (Sweden); W. Kalender (Germany);
    T. Murakami (Japan); P. Shrimpton (UK)

• Corresponding members:
  • R. Albrecht (USA) and K. Wei (China)
ICRP Publication 87 (2001)


Rehani & Berry

*BMJ* 2000;320:593-594 (4 March)

**Editorials**

Radiation doses in computed tomography

The increasing doses of radiation need to be controlled
Diagnostic Imaging Online  
April 13, 2000

CT radiation dose questions draw international attention

Radiation dosage from CT scans could become a matter of debate if international calls for reduced radiation levels move forward.

Writing last month in the British Medical Journal, Dr. Madan Rehani, chairperson of an international task force on safer dosage standards for CT scans, made the case for a closer look at CT radiation levels.

"The increasing doses of radiation need to be controlled worldwide," he said.

The task force was established by the International Commission on Radiological Protection (ICRP). The organization meets in Zurich this month to discuss safer dosage recommendations.

While the ICRP believes that there is cause for concern about high radiation dosage in CT scans, some physicians claim that there is no basis for alarm.

"The FDA approves a technology only after due research. Radiation is used discerningly in our country. America is one of the most conscious medical communities when it comes to radiation safety, and radiation is used wisely by physicians only after weighing cost and benefit, keeping in mind safety of the patients," said Dr. Jonathan Goldin, an assistant professor of radiology at the University of California, Los Angeles, who studies radiation effects and radiation dose reduction.
CT scans in children linked to cancer later

By Steve Sternberg
USA TODAY

Each year, about 1.6 million children in the USA get CT scans to the head and abdomen — and about 1,500 of those will die later in life of radiation-induced cancer, according to research out today.

What’s more, CT or computed tomography scans given to kids are typically calibrated for adults, so children absorb two to six times the radiation needed to produce clear images, a second study shows. These doses are “way bigger than the sorts of doses that people at Three Mile Island were getting.”

David Brenner of Columbia University says, “Most people got a tenth or a hundredth of the dose of a CT.”

Both studies appear in February’s American Journal of Roentgenology, the nation’s leading radiology journal. The first, by Brenner and colleagues, is the first to estimate the risks of radiation-induced fatal cancer” from pediatric CT scans. Until a decade ago, CT scans took too long to perform on children without giving them anesthesia to keep them still. Today’s scanners spiral around the patient in seconds, providing cross sections, or “slices,” of anatomy. Doctors use CT scans on children to search for cancers and ailments such as appendicitis and kidney stones.

“Here’s a huge number of people who don’t just receive one scan,” says Fred Mettler of the University of New Mexico, noting that CT scans are used for diagnosis and to plan and evaluate treatment. “The breast dose from a CT scan of the chest is somewhere between 10 and 20 mammograms. You’d want to think long and hard about giving your young daughter 10 to 20 mammograms unless she really needs it.”

Mettler recently published a study showing that 11% of the CT scans at his center are done on children younger than 15, and they get 70% of the total radiation dose given to patients. Children have more rapidly dividing cells than adults, which are more susceptible to radiation damage. Children also will live long enough for cancers to develop.

Researchers led by Lane Donnelly at Cincinnati’s Children’s Hospital found that children often get radiation doses six times higher than necessary. Cutting the adult dose in half would yield a clear image and cut the risk a little amount, Brenner says. “Radiologists genuinely believe the risks are small,” he says. “I suspect they’ve never been confronted with numbers like this.”

Brenner, Lee Rogers, Paterson, Donolly, Nickoloff, Haaga
Turning point in the history

Manufacturer vying with each other on patient dose
Good that it happened

Pity that it needed media attention to accelerate changes
### Patient exposure

#### Typical PET/CT investigations

**PET-contribution**

<table>
<thead>
<tr>
<th>Study</th>
<th>Radionuclide</th>
<th>Radiopharmaceutical</th>
<th>Activity (MBq)</th>
<th>Effective dose (mSv)</th>
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<tr>
<td>Tumour</td>
<td>$^{18}$F</td>
<td>FDG</td>
<td>300-400</td>
<td>5.7-7.6</td>
</tr>
<tr>
<td>Tumour</td>
<td>$^{18}$F</td>
<td>Choline</td>
<td>300</td>
<td>5.3</td>
</tr>
<tr>
<td>Tumour</td>
<td>$^{11}$C</td>
<td>Choline</td>
<td>300</td>
<td>1.4</td>
</tr>
<tr>
<td>Alzheimer</td>
<td>$^{11}$C</td>
<td>PiB</td>
<td>300</td>
<td>1.4</td>
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<tr>
<td>Tumour</td>
<td>$^{11}$C</td>
<td>Acetate</td>
<td>400</td>
<td>1.4</td>
</tr>
<tr>
<td>Tumour</td>
<td>$^{11}$C</td>
<td>Methionine</td>
<td>800</td>
<td>6.7</td>
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<tr>
<td>Bone</td>
<td>$^{18}$F</td>
<td>Fluoride</td>
<td>300</td>
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**Diagnostic CT**

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<tr>
<td><strong>Low dose CT</strong></td>
<td>2-4</td>
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</table>
Effective dose, mSv

- 100
  - PET/CT \textsuperscript{FDG}, SPECT/CT, CT trauma (foetus)
  - CT abdomen/pelvis, PET-FDG

- 10
  - CT colon

- 1
  - CT thorax/lungs, SPECT
  - CT head, Low dose CT colon
  - CT facial skeleton

- 0.1
  - Low dose CT lungs

- 0.01
  - Low dose CT facial skeleton

Actions needed to reduce PET/CT and SPECT/CT-doses?
CT + NM = 22% of all investigations, but 75% of the collective dose NM is dominated by PET and SPECT

<table>
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<tr>
<th>Procedure</th>
<th>Per caput effective dose, mSv</th>
<th># Investigations</th>
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<td>1980s</td>
<td>2006</td>
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<tr>
<td>Radiography and fluoroscopy</td>
<td>0.36  (68%)</td>
<td>0.33 (11%)</td>
</tr>
<tr>
<td>CT</td>
<td>0.16  (3%)</td>
<td>1.47 (49%)</td>
</tr>
<tr>
<td>Nuclear medicine</td>
<td>0.14  (26%)</td>
<td>0.77 (26%) 75%</td>
</tr>
<tr>
<td>Interv. Fluroscopy</td>
<td>0.018 (3%)</td>
<td>0.43 (14%)</td>
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<tr>
<td>Total</td>
<td>0.53</td>
<td>3.00</td>
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Dose reduction

- Technology Driven
- Operator Driven

- Who is going to drive industry: Professional societies; Accidents & Media.
Recap

• Radiography: Safer for patient & staff
• Digital Radiography: Actions needed to make it safer
• Diagnostic fluoroscopy: Safer for patient & Staff
• Digital fluoroscopy: Actions needed
• Interventional procedures: Issues of staff (Eye lens, hair loss) and patient protection (skin injury, cancer risk) that cannot be ignored
Recap

• **Nuclear Medicine:** PET/CT, SPECT/CT
• **Radiotherapy:** Continued actions needed
• **CT:** Major and growing source but future looks good
• >90% of patients and staff are safer than 50 years ago
• Smaller percentage at significant risks which are new and challenging
Thank You

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