Evaluation and Consulting on Patient Dose in Diagnostic Imaging

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Medical Physicists’ Responsibilities

- Provide dose and risk information
- Advising medical staff of doses and risks
- Consulting with IRBs regarding research uses of radiation
- Determining specific organ dose, e.g., uterine and fetal doses
- Consulting with patients and allaying their fears

Required Information

Information necessary to provide dose and risk estimates—
- Patient entrance skin exposure (ESE)
- Specific organ doses based on ESE
- Effective dose
- Risk estimate
- Relative risks of other activities

“Negotiating” Research Protocols

Medical physicist plays vital role in research protocols

- Provide information regarding dose and risk for IRB
- “Negotiate” with research proponent relative to best modality (provide best images), minimizing dose, etc.
**Patient ESE—Simple??**

Know the kVp, mAs, SSD and calculate the ESE?

NO!!!!!!!!!!!!!!!

Why not??

Variation of x-ray system output?
Variation from one tech to another
Variation, variation, variation

How much variation?
From 10X to 130 X!!!

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**NEXT Survey Results**

(mR or R/min)

<table>
<thead>
<tr>
<th>Exam</th>
<th>Min</th>
<th>Max</th>
<th>Max/Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA Chest</td>
<td>2.4</td>
<td>81</td>
<td>33.8</td>
</tr>
<tr>
<td>AP L. Spine</td>
<td>62</td>
<td>2,154</td>
<td>34.7</td>
</tr>
<tr>
<td>GI Exams</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate</td>
<td>0.7</td>
<td>16.2</td>
<td>23.1</td>
</tr>
<tr>
<td>Spot Film</td>
<td>38</td>
<td>4,815</td>
<td>126.7</td>
</tr>
<tr>
<td>CT Head</td>
<td>1,600</td>
<td>14,000</td>
<td>8.8</td>
</tr>
</tbody>
</table>

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**Variation Within a Facility**

Personal experience—
Major East Coast teaching hospital
AP Lumbar spine ESE
16.4 X range in ESE!!!!!
1.10 mSv to 18.0 mSv
Mixture of CR and screen-film
Screen-film ESE ~3.00 mSv
CR dose based on location and x-ray equipment manufacturer

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**Variation Within a Facility**

Major East Coast teaching hospital
No in-house physicist or equipment QC program
Consulting physicist visited once per year to meet regulatory requirements
Did NOT measure patient ESEs, only mR/mAs
mR/mAs tells nothing about how the equipment is used nor absorbers in the beam after the patient!!!
First Three Rules of Dose Determination

Measure the ESE!!!
Measure the ESE!!!
Measure the ESE!!!

*It is morally, ethically, and professionally irresponsible NOT to measure the ESE!!!

Which ESE Do You Measure?

Ask the tech what technique they used?
Which tech? Which machine? Which day?
Measure the ESE for a standard phantom?
American approach
Determine the ESE for a group of patients?
European approach (Vaño, et al.)

Effect of Patient Variation on Dose

Patient size variation—
Neonate to beached whale
5 cm thickness to 40 cm thickness
Fetal dose estimates— you will know patient size,
i.e., these are retrospective estimates
Research protocols are prospective estimates—
you will know only the age range of patients
AP lumbar spine range—
0.30 mGy to > 60.0 mGy
Dose tables are based on “standard man”

Standard (Reference) Man (Woman)

Defined by ICRP 23 and 89
Height, weight, skin area, chemical composition, etc., etc., etc.
Reference man— 70 kg, 170 cm
Reference woman— 58 kg, 160 cm
### Standard (Reference) Man (Woman)

Defined by ICRP 23 and 89,
- Height, weight, skin area, chemical composition, etc., etc., etc.
- Reference man: 70 kg, 170 cm (154 lb, 5’7”)
- Reference woman: 58 kg, 160 cm (128 lb, 5’3”)

### Dose Estimate Error??

What error in estimated dose is acceptable in diagnostic imaging?
- < 1% (precise therapy doses)
- 2% to 4% or 5% (typical therapy doses)
- 10% ??
- 20% ??
- 30% ?? (personnel dosimetry)
- 50% ??
- 100% *not* unreasonable!!

### Dose Estimate Error??

Depends on—
- Patient size
- Technique (kVp, mAs, SSD, etc.)
- Location of sensitive tissue from beam, e.g., distance of fetus from irradiated volume
- Room-to-room variation
- Room scatter??
- Tube leakage??

### Dose Estimate Error??

Location of sensitive tissue relative to irradiated volume
- In direct x-ray beam
- Depth is important
- HVL in centimeters of tissue at 80 kVp ~3.5 cm
- Outside of irradiated volume
- Felmlee data
**Distance of Fetus From Irradiated Volume* and HVL in Tissue For CT**

<table>
<thead>
<tr>
<th>cm</th>
<th>NFDR</th>
<th>HVL in tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.2600</td>
<td>1.0000</td>
</tr>
<tr>
<td>1</td>
<td>0.0458</td>
<td>0.1762</td>
</tr>
<tr>
<td>2</td>
<td>0.0338</td>
<td>0.1300</td>
</tr>
<tr>
<td>3</td>
<td>0.0265</td>
<td>0.1019</td>
</tr>
<tr>
<td>4</td>
<td>0.0206</td>
<td>0.0792</td>
</tr>
<tr>
<td>5</td>
<td>0.0167</td>
<td>0.0642</td>
</tr>
<tr>
<td>6</td>
<td>0.0136</td>
<td>0.0523</td>
</tr>
</tbody>
</table>


**Effect of Depth in Tissue of Sensitive Organ**

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Relative Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>7</td>
<td>1/16</td>
</tr>
<tr>
<td>14</td>
<td>0.063</td>
</tr>
<tr>
<td>28</td>
<td>0.016</td>
</tr>
</tbody>
</table>

**Dose Estimate Error??**

Taking into account all of the variables—

How accurately can **YOU** estimate the dose to a specific sensitive organ?

How accurate must the dose be for a dose **estimate**?

What are the medico-legal implications?
Terms and Definitions

**Exposure**: Ionization per mass of air. C/kg (R)

**Absorbed Dose (D)**: Energy imparted per mass. Gy = 100 rad

**Dose Equivalent (H)**: Considers radiation type. $H = w_D D$, $w_\gamma = 1$ for x-rays. Sv = 100 rem

**Effective Dose (E)**: Weights specific organ doses for whole-body equivalent. $E = \sum w_T H_T$, $Sv = 100$ rem

Excellent summary: Table 3-6, The Essential Physics of Medical Imaging, Bushberg, Seibert, Leidholdt, and Boone. Lippincott Williams and Wilkins (2002)

-Calculating Organ Doses-

Typically use tabulated Monte Carlo data

Exposure-to-dose conversion factors

Specific characteristics of exam and equipment (HVL, field size, etc.)

Weighted organ doses used for calculating Effective Dose

Conversion Factors

Determined using mathematical models

Specific organ sizes, locations, and properties

Models everyone, but not any one

-Calculating Organ Doses-

Radiographic Exams

First, need Monte Carlo conversion data

One source... CDRH
(Other sources available)

Good news... Free on web!

Bad news... Non-trivial to find!
Calculating Organ Doses – Radiographic Exams

Finding the Monte Carlo Data on Web

Or Google “Handbook of Selected Tissue Doses”

EXAMPLE: Measured ESE = 15 mR

\[ 0.015 \times R = 7.4 \text{ mrad} \]

\[ 0.015 \times R = 2.6 \text{ mrad} \]

\[ 0.015 \times R = 0.0 \text{ mrad} \]

Organ Doses
Relating Organ Doses to Whole Body Dose

The effective dose is the mean absorbed dose from a nonuniform, partial-body irradiation that results in the same total radiation detriment as from a uniform whole-body irradiation.

McCollough CH and Schueler BA, Calculation of Effective Dose, Med. Phys. 27 (5), May 2000

Dose Organ x weighting factor summed over all organs

\[
\begin{align*}
\text{Dose}_\text{Lung} \times w_{\text{Lung}} \\
\text{Dose}_\text{Breast} \times w_{\text{Breast}} \\
\text{Dose}_\text{Thyroid} \times w_{\text{Thyroid}} \\
\vdots
\end{align*}
\]

\[= \text{"Whole Body Equiv Dose"}\]

ICRP 26 and ICRP 60 (1990)

\[\text{ICRP 26 (1977)}\]

\[
\text{He} = \sum w_i H_i \quad \text{Effective Dose Equivalent}
\]

- Fewer organs

\[\text{ICRP 60 (1990)}\]

\[
E = \sum w_i H_i \quad \text{Effective Dose}
\]

- More organs
- Monte Carlo data not necessarily available

*Very specific instructions for calculating the remainder dose!
## Example: Effective Dose Equivalent

<table>
<thead>
<tr>
<th>Organ</th>
<th>ICRP 26</th>
<th>Organ Dose</th>
<th>Male (mrad)</th>
<th>EDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonads</td>
<td>0.25</td>
<td>x 0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Red Bone Marrow</td>
<td>0.12</td>
<td>x 2.0</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Lung</td>
<td>0.12</td>
<td>x 7.4</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.03</td>
<td>x 0.7</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Remainder (Trunk)</td>
<td>0.30</td>
<td>x 2.6</td>
<td>0.78</td>
<td></td>
</tr>
</tbody>
</table>

Sum = 1.9 mrem  
(0.02 mSv)

## Calculating Organ Doses – Fluoroscopic Exams

1. **Calculating R-F Doses – Practical Issues**
   - **Field size # Reference Field Size**
     - Some refs offer correction factors
     - Multiply by ratio of field areas
   - Fluoro conversion factors not available
     - Estimate with closest radiographic exam
     - Correct for field areas
     - Estimate “dwell” times over areas
   - Other corrections (Tech. differences, atypical circumstances)
     - Use reasonable assumptions
     - No need to consider nth-order details
     - Dose estimate
   - ** ALWAYS record all assumptions, reasoning, and refs!**

2. **Other R-F Dose Resources**
   - Monte Carlo Organ Dose Conversion data
     - CDRH (www.fda.gov/cdrh/ohip/organdose.html)
     - GSF (www.gsf.de)
     - HPA (formerly NRPB) (www.hpa.org.uk/radiation/)
   - Software
     - www.fda.gov/cdrh/ohip/organdose.html
     - XDOSE (john_le_heron@mrl.moh.govt.nz)
     - CHILDOSE (john_le_heron@mrl.moh.govt.nz)
Calculating Organ Doses – CT
Monte Carlo conversion data
One Source... NRPB
(Other sources available)

Good news...
27 organs or regions
208 5mm sections
Many scanners & configurations
Many software tools

Bad news...
Not free (but not $$$)

Calculating Doses – CT
One software tool...
CT Dosimetry from ImPACTscan.org
(Other tools available)

Needs NRPB datasets
Excel-based
Many features
• GUI
• Scanner matching
• Typical values
Free

Calculating CT Doses – Practical Issues
Be careful to calculate CTDI correctly
• GFS data normalized to air (f-factor=0.87)
• NRPB normalized to muscle (f-factor=0.94)
• Use TOTAL Collimation for slice thickness in MDCT
• Does electrometer need correction for CT chamber?

Be careful to use the correct technique
• Siemens uses Effective mAs (=mAs/pitch)

Other corrections (Technical differences, atypical circumstances)
• Use reasonable assumptions
• No need to consider nth-order details
• Dose estimate

ALWAYS record all assumptions, reasoning, and refs!

Other CT Dose Resources

Monte Carlo Organ Dose Conversion data
GSF (www.gsf.de)
HPA (formerly NRPB) (www.hpa.org.uk/radiation/)

Software
CTDosimetry (ImPACTscan.org)
CTDOSE (john_le_heron@nrl.moh.govt.nz)

Website
ImPACTscan.org Very comprehensive CT dose and imaging resource
Risk Estimate Error??

What is the error for typical risk estimates?
1:1,000, 1:10,000, 1:100,000
Always rounded to powers of 10
What is error in risk estimates of exposure to ionizing radiation? Better than a SWAG!
Dose and dose rate dependence
Age dependence, fatal breast cancer
15 – 45 – 55 year old
1/15 – 1/50 X

Risk Estimate Error??

Sex
Sensitive subpopulations
Enhancement of one carcinogen by another
Age at exposure and expression
Human data?
Fractionation

Breast cancer, probability of fatal cancer at 1Gy
0.60 (0.28 – 1.05) or 3.75 X or ± 50%
Based on average age!!

Communicating Risk Estimates

What is the purpose of the risk estimate?
General information for radiology staff
Estimate for research study
For investigators
For IRB
Patients
Lay public, news media
General Information for Radiology Staff

Assumes that there is some understanding of risk

General terms
- ESE
- Effective dose (tends to minimize appearance of risk)

Assume?

Makes an ASS
Out of
U
And
ME

General Information for Radiology Staff

Radiologists are familiar with ESE—
- Chest x-ray 15 mR
- AP lumbar spine 300 mR
- Fluoro 1 R/min
- CT Body 3,000 mR

Providing effective dose will be misleading to them—
- Chest x-ray 2 mrad
- AP lumbar spine 20 mrad
- Fluoro 40-80 mrad/min
- CT Body 800 mrad
**Effective Dose**

Summation of risk to all sensitive tissues

*Used ONLY when multiple organs are exposed

*NOT used for mammography

Appropriately weighted to specific tissue

Provides a single number for an imaging projection or volume

Related to the risk of cancer mortality from an equivalent uniform, total-body dose of radiation

Tends to make the dose appear much lower than it is to a specific tissue

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**Comparative Risks**

Probability of Death from Radiation Induced Cancer and Other Causes

<table>
<thead>
<tr>
<th>Activity</th>
<th>Risk per 10,000*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking (all causes)</td>
<td>30</td>
</tr>
<tr>
<td>CT of Kidneys or Liver</td>
<td>12.5</td>
</tr>
<tr>
<td>Smoking (only cancer)</td>
<td>12</td>
</tr>
<tr>
<td>Driving a car</td>
<td>2.4</td>
</tr>
<tr>
<td>AP Lumbar Spine</td>
<td>0.06</td>
</tr>
</tbody>
</table>

*Per Exposure or Year’s Activity

CT risk is ~200 X that of AP Lumbar spine

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**Research Study— Investigators & IRB**

Do NOT speak in terms of cancer incidence or deaths per 100,000

Speak in terms of “safe” doses which are those similar to which radiation workers are exposed

Some institutions have different review processes for low, medium, and high dose procedures

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**Research Study— Investigators**

Present dose estimate in terms of effective dose and specific organ doses

Discuss alternative imaging procedures

- Non-ionizing radiation?
- Higher kVp?
- Higher speed screens, CR system, etc.?
- Modify technique, e.g., fewer slices

Don’t forget— improved imaging techniques for better information for research study
Most IRB members do not understand ESE, effective dose, specific organ dose, or anything else related to dose and risk!!

Best presentation??
Single number— effective dose
Never, never, never use ESE
nor sum of ESE!!!

Their only concern—
Is this dose (and risk) low, medium, or high?

Is this dose (risk) low, medium, or high?
Low doses—
Naturally occurring background radiation <3 mGy*/year
Maximum dose to public— 1 mGy*/year
“Safe” x-ray procedures
AP chest— 0.15 mGy (ESE)
AP lumbar spine— 2 to 3 mGy (ESE)
Mammogram— 2 to 3 mGy (MGD)

*Use only one unit for IRB, i.e., mGy ONLY!! Forget all pretenses of scientific purity— go for simplicity!!!

Is this dose (risk) low, medium, or high?
Medium doses—
Maximum annual dose to worker— 10 mGy/year
CT scan of head or body— 10 to 30 mGy
2 minutes of fluoro— 20 to 40 mGy

High Doses—
Maximum one time dose to worker— 50 mGy
Cardiac catheterization— > 50 mGy

Patients primarily want one thing from your consultation—
Is this examination safe?

Your job— to communicate this in a professional but warm and friendly manner!
**Patient Communication**

Professional appearance!!!
Professional demeanor— Mrs. Smith, not Patty
Professional but understandable terminology
**TAKE TIME**— Turn off your pager, don’t give the appearance of being rushed
Your job for the next XX minutes is to put Mrs. Smith at ease, nothing more, nothing less

**Take Time**—

**Lay Public, News Media**

Two basic rules of dealing with the media—

- **KISS!!!**  
- Expect the unexpected!

- Professional appearance!!!
- Professional demeanor
- Professional but understandable terminology
- **TAKE TIME**— Turn off your pager, don’t give the appearance of being rushed
- Your job for the next XX minutes is to put the person at ease, nothing more, nothing less
- Make eye contact but **NOT** physical contact
- Listen!!!
- Talk about whatever the person wants to talk about!

**News Media**

News media is always “on deadline”
Offer to review whatever they write or develop
You will seldom have this opportunity, but offer
Do **NOT** be afraid to say “I don’t know” or “That question relates to medical practice— I can put you in contact with a radiologist that can answer that for you”
You are **NOT** a physician, regardless of the initials after your name!!!


**News Media**

Never speculate-- especially regarding hypothetical questions
Answer only questions related to your area of expertise
The media is searching for the unusual, controversial, or spectacular-- **BE CAREFUL!!!**
Think about the question and your response-- *and the way it could be quoted out of context!*

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**News Media**

And...last but not least...

**KISS!!!**

*Expect the unexpected!!!*

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**Where Do I Learn More?**

Highly recommended!!

ACR, RSNA, AAPM, etc. offer programs and refresher courses on dealing with the media

Role play with experienced colleagues or PR-marketing folks from your institution
A Medical Physicist Can Save You More Than Just Your Money

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