## 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!!!

## *NEXT Survey Results*

*(mR or R/min)*

| *Exam* | *Min* | *Max* | *Max/Min* |
|---|---|---|---|
| PA Chest | 2.4 | 81 | 33.8 |
| AP L. Spine | 62 | 2,154 | 34.7 |
| GI Exams | | | |
| Rate | 0.7 | 16.2 | 23.1 |
| Spot Film | 38 | 4,815 | 126.7 |
| CT Head | 1,600 | 14,000 | 8.8 |

## *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

## *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

| cm | NFDR | | |
|---|---|---|---|
| 0 | 0.2600 | 1.0000 | |
| 1 | 0.0458 | 0.1762 | 1.0000 |
| 2 | 0.0338 | 0.1300 | 0.7380 |
| 3 | 0.0265 | 0.1019 | 0.5786 |
| 4 | 0.0206 | 0.0792 | 0.4498 |
| 5 | 0.0167 | 0.0642 | 0.3646 |
| 6 | 0.0136 | 0.0523 | 0.2969 |

HVL in tissue ~3.5 cm

*Felmlee JP, Gray JE, Leetzow ML, Price JC. Estimated fetal radiation dose from multislice CT studies. AJR 1990; 154:185-190.

## Effect of Depth in Tissue of Sensitive Organ

| Depth (cm) | Relative Dose | |
|---|---|---|
| 0 | 1 | 1.00 |
| 7 | 1/4 | 0.250 |
| 14 | 1/16 | 0.063 |
| 28 | 1/64 | 0.016 |

## 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.
$H = w_r D$, $w_r = 1$ 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.)

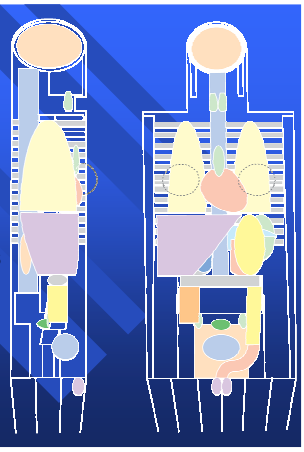
Weighted organ doses used for calculating Effective Dose

## 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

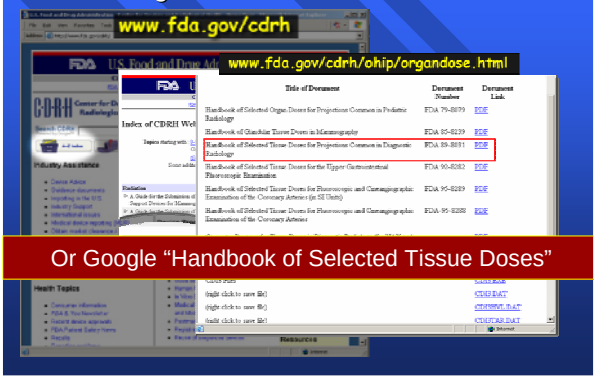
One source…CDRH
(Other sources available)

Good news…
Free on web!

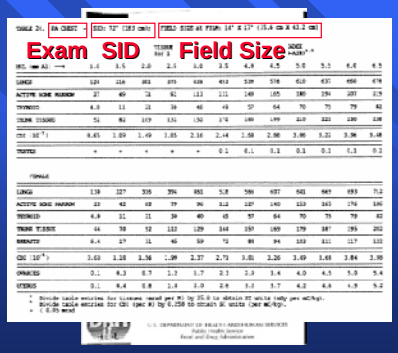
Bad news…
Non-trivial to find!

## Calculating Organ Doses – Radiographic Exams

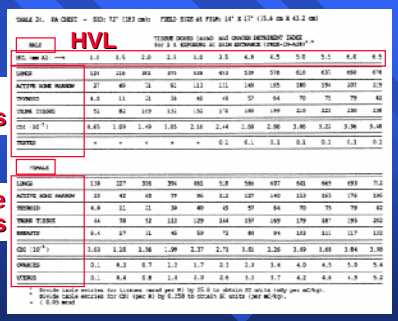
Finding the Monte Carlo Data on Web




## Calculating Organ Doses – Radiographic Exams

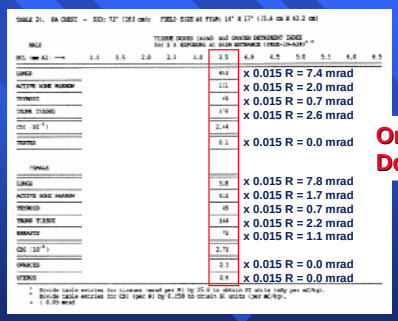



## Calculating Organ Doses – Radiographic Exams




## Calculating Organ Doses – Radiographic Exams

EXAMPLE: Measured ESE =15 mR



## *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

## *Relating Organ Doses to Whole Body Dose*

Organ dose x weighting factor summed over all organs

$$\begin{aligned} & \text{Dose}_{\text{Lung}} \times w_{\text{Lung}} \\ + \; & \text{Dose}_{\text{Breast}} \times w_{\text{Breast}} \\ + \; & \text{Dose}_{\text{Thyroid}} \times w_{\text{Thyroid}} \\ & \vdots \\ \hline = \; & \text{“Whole Body Equiv Dose”} \end{aligned}$$

## *Relating Organ Doses to Whole Body Dose*

| Organ | ICRP 26 | ICRP 60 |
|---|---|---|
| Gonads | 0.25 | 0.20 |
| Red Bone Marrow | 0.12 | 0.12 |
| Colon | - | 0.12 |
| Lung | 0.12 | 0.12 |
| Stomach | - | 0.12 |
| Bladder | - | 0.05 |
| Breast | 0.15 | 0.05 |
| Liver | - | 0.05 |
| Esophagus | - | 0.05 |
| Thyroid | 0.03 | 0.05 |
| Skin | 0.01 | 0.01 |
| Bone Surface | 0.03 | 0.01 |
| Remainder* | 0.30 | 0.05 |

2 Choices of Weighting Factors

*Very specific instructions for calculating the remainder dose!

## *Relating Organ Doses to Whole Body Dose*

**ICRP 26 (1977)**

$H_E = \sum w_t H_t$ Effective Dose Equivalent

- Fewer organs

**ICRP 60 (1990)**

$E = \sum w_t H_t$ Effective Dose

- More organs
- Monte Carlo data not necessarily available

## *Example: Effective Dose Equivalent*

| Organ | ICRP 26 | | Organ Dose Male (mrad) | | EDE $H_E$ |
|---|---|---|---|---|---|
| Gonads | 0.25 | x | 0.0 | = | 0.0 |
| Red Bone Marrow | 0.12 | x | 2.0 | = | 0.24 |
| Lung | 0.12 | x | 7.4 | = | 0.89 |
| Thyroid | 0.03 | x | 0.7 | = | 0.02 |
| Remainder (Trunk) | 0.30 | x | 2.6 | = | 0.78 |

Sum = 1.9 mrem
(0.02 mSv)

## *Calculating Organ Doses – Fluoroscopic Exams*

www.fda.gov/cdrh/ohip/organdose.html

| Title of Document | Document Number | Document Link |
|---|---|---|
| Handbook of Selected Organ Doses for Projections Common in Pediatric Radiology | FDA 79-8079 | PDF |
| Handbook of Glandular Tissue Doses in Mammography | FDA 85-8289 | PDF |
| Handbook of Selected Tissue Doses for Projections Common in Diagnostic Radiology | FDA 89-8031 | PDF |
| Handbook of Selected Tissue Doses for the Upper Gastrointestinal Fluoroscopic Examination | FDA 92-8282 | PDF |
| Handbook of Selected Tissue Doses for Fluoroscopic and Cineangiographic Examination of the Coronary Arteries (in SI Units) | FDA 95-8289 | PDF |
| Handbook of Selected Tissue Doses for Fluoroscopic and Cineangiographic Examination of the Coronary Arteries | FDA-95-8288 | PDF |
| Computer Program for Tissue Doses in Diagnostic Radiology (for VAX and IBM-Compatible PC Systems) - Report | | PDF |
| User Guide: Computer Program for Tissue Doses in Diagnostic Radiology (CDID - IBM Compatible PC Version) | | PDF |
| CDID Files | | CDID.EXE |
| (right click to save file) | | CDID.DAT |
| (right click to save file) | | CDIDIVL.DAT |
| (right click to save file) | | CDIDTAB.DAT |

## *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!

## *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**

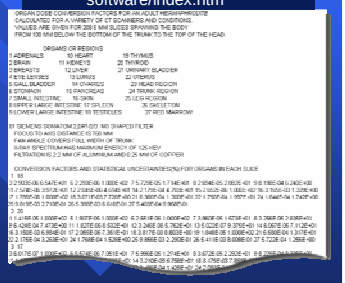
www.fda.gov/cdrh/ohip/organdose.html
XDOSE (john_le_heron@nrl.moh.govt.nz)
CHILDOSE (john_le_heron@nrl.moh.govt.nz)

## Calculating Organ Doses – CT

Monte Carlo conversion data

One Source…NRPB
(Other sources available)

www.hpa.org.uk/radiation/publications/software/index.htm



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…

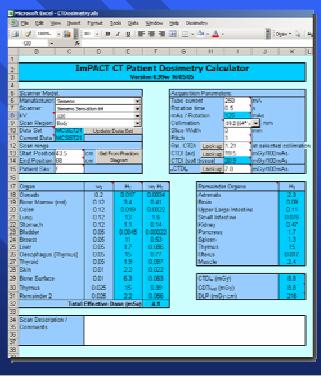
CT Dosimetry from ImPACTscan.org
(Other tools available)

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

## Assume?

*Makes an*

**ASS**

*Out of*

**U**

*And*

**ME**

## General Information for Radiology Staff

Assumes that there is some understanding of risk

General terms

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

## General Information for Radiology Staff

Radiologists are familiar with ESE—

| | |
|---|---|
| Chest x-ray | 15 mR |
| AP lumbar spine | 300 mR |
| Fluoro | 1-2 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

## *Comparative Risks*

Probability of Death from
Radiation Induced Cancer and Other Causes

| *Activity* | *Risk per 10,000** |
|---|---|
| Smoking (all causes) | 30 |
| CT of Kidneys or Liver | 12.5 |
| Smoking (only cancer) | 12 |
| Driving a car | 2.4 |
| AP Lumbar Spine | 0.06 |

*Per Exposure or Year's Activity
CT risk is > 200 X that of AP lumbar spine

## *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

## *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

## *Research Study— IRB*

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?*

## *Research Study– IRB*

*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!!!

## *Research Study– IRB*

*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

## *Patient Comunication*

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

## *Patient Communication*

Make eye contact but *NOT* physical contact

Listen!!!

Talk about whatever Mrs. Smith wants to talk about!

Be honest with the patient

Do *NOT* downplay patient's fears

*Patient's perception IS their reality!!*

This is a professional consultation– What does Mrs. Smith expect when she has an OB-GYN consult?

## *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 what ever the person wants to talk about!

This is a professional consultation– What does the patient expect when she has an OB-GYN consult?

## *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!*

## *News Media*

And…last but not least…

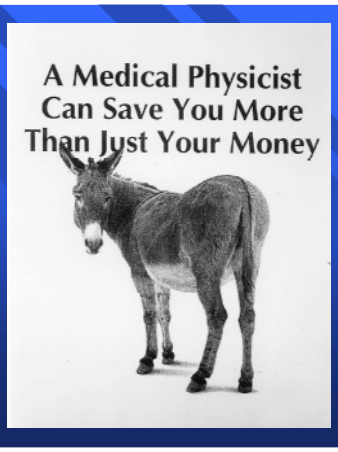
***KISS!!!***

***Expect the unexpected!!!***

## *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

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