Radiologist Update on the Relative Patient Doses Associated with Diagnostic Imaging Modalities Today

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Introduction

The purpose of this presentation is to inform the busy practicing radiologist as to the relative patient doses from modern diagnostic imaging modalities, and the resources to answer questions pertaining to this subject.

Sometimes referring physicians will consult you for assistance to decide whether non-radiation imaging modalities should be used for pregnant women, potentially gravid women, and pediatric patients. The purpose of this presentation is to provide you with an informed comfort level to make those risk/benefit decisions.
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Radiation Biology Review

The relative sensitivity of cells is as follows in order of increasing radioresistance
White Blood Cells
Red Blood Cells
Intestinal Villae
Internal Organs
Muscle
Bone (excluding marrow)
Nerve
Radiation Sickness Syndrome

Thresholds for clinically-detectable biological responses

>25 REM (decrease in WBC, Hematopoietic response)

>200 REM, nausea, vomiting in Gastrointestinal response

>1000 REM, convulsion, confusion in CNS response region
Radiation Exposures in Perspective
Background Radiation: East Coast (100 mREM); Denver (300 mREM)

First observable deleterious biological effects: decrease in WBC at > 25 REM

Erythema threshold approximately 200 REM

Epilation threshold approximately 300 REM

Cataract induction threshold approximately 300 REM

LD 50/30 = Lethal dose in 30 days to half the population so exposed = 300-500 REM

Temporary to permanent sterility approximately 500-700 REM

LD 100/30 = 100% lethal dose, if no medical intervention, such as bone marrow transplant

Molecular death = dose to kill instantaneously – 10,000 REM
Somatic Cells vs. Genetic Cells

Somatic cells can recover and repair, genetic cells rarely recover and repair themselves, as broken strands of DNA have occurred.

The Doubling Dose = double the natural mutation rate = approximately 70 REM

A fluoroscopy burn from a cardiac study
Caution must be taken with the perception of risk and risk rates

It can be truthfully stated that for every one REM of exposure to a pregnant woman’s fetus, that there is a 40% increase in the risk of childhood malignancies (i.e. leukemia).

Since a 40% increase in salary is significant, you’ve got people’s attention with a comment like this.

The naturally-occurring rate of occurrence for leukemia in non-irradiated live births is about 1 in 100,000.

But a 40% increase in the risk rate changes it from 1 in 100,000 to 1.4 in 100,000.

Now does this statistic sound as dramatic? Both statements are true and correct. “It is all in the perception!” (How many times have you heard that?)
The A.C.R. once stated, “There is no series of diagnostic radiology procedures that provide enough dose to warrant a termination of pregnancy”

Is this still true today?

I contend that it is not, for the following reasons.

1. The nature of today’s litigious environment
2. Modern X-ray modalities and procedures that were not present or utilized when the above statement was originally made, i.e., Cath Labs, I.R., CT, CT Fluoroscopy, and Digital Photofluorospot imaging
Medical Patient Dose Comparisons

Today, more than ever, with new modalities emerging, patient doses are changing and attempts are continuously being made to compare them to some baseline. The worst such effort is the attempt to normalize all medical radiation doses into multiples of a chest X-ray exposure. I will explain why this is futile, as well as just wrong. I will also explain why it is improper to attempt to sum patient doses from various sources and modalities of medical exposure.
First we must decide why we are assessing this dose. Usually if not a fetal dose, it is to assess whether a significant risk to cancer is possible. The radiation-induced cancer with the lowest threshold is leukemia. So, remembering our radiation biology primer, we know that to damage the highest concentration of WBCs, the exposure must be to areas of the body with large concentrations of bone marrow, such as the region from the tip of the pelvis to the bottom of the femur. So, to assess the most sensitive detrimental risk to the body, one should determine the collective dose to this region only.
So doses to the head, shoulders, cervical spine, feet, ankles, lungs, etc. are not of immediate concern, and are not summed in the assessment. So how do we determine the dose from all potential modalities to the bone marrow in that region. We must sum all the doses to the bone from nuclear medicine studies, from C.T. studies to that region, and from radiographic and fluoroscopic projections to that region, at the depth of the bone marrow. The dose from nuclear medicine procedures to bone marrow are in the package inserts, which the technologists can provide for the studies in question. Doses in the pelvis and abdomen from 1-16 slice CT scanners is approximately 1-5 REM per series to the central axis and bone marrow.
Newer 64 slice CT scanners operating for cardiac imaging procedures can provide as much as 10-12 REM/series for cardiac studies. The heart exposure provides a negligible dose in the area we are selecting for bone marrow dose assessment. The dose to the bone marrow depth from radiographic and fluoroscopic projections is best assessed by the medical physicist, but as a rule of thumb, can be quickly estimated as 0.3 REM per radiographic projection in this region, and 5 REM/min of fluoroscopic exposure. Photospot and cine runs can result in a doses as high as 75 REM/min. Now these doses must be summed to get the total bone marrow dose.
Now let’s say you have a total dose of 100 REM bone marrow dose to a patient. But let’s stop and think for a moment. These exposures were over 20 years. How do we factor in “recovery and repair” of these somatic cells? We can’t quantitatively, so we must qualitatively. In other words, we have to keep in the back of our minds that we are calculating an overestimate, because the body will not respond as radically to this dose over 20 years, as it would have if delivered in one day.
What does 100 REM mean to the patient. Well all we really know is that for every REM he got, we have increased his risk for cancer. That’s all we know. We cannot adequately quantify this risk. We cannot factor in or out what other carcinogens he is exposed to. Radiation-induced cancer looks no different than non-radiation-induced cancer. So can a patient have “too many medical imaging radiation producing exposures”? The answer, of course, is wrapped in the “risk/benefit” decision that is made primarily by the practicing radiologist.
Sometimes referring physicians will consult you for assistance to decide whether non-radiation imaging modalities should be used for pregnant women, potentially gravid women, and pediatric patients. The purpose of this presentation is to provide you with an informed comfort level to make those risk/benefit decisions. In most instances communicating with the layman (whether a physician or patient), the best approach is to speak in qualitative terms and not quantitative.
Like, “the exposure of mammograms today are so much lower than they used to be through our diligent, highly-trained staff and our state-of-the-art” equipment” and “Our mammography doses are electronically-optimized to provide no more dose than is absolutely necessary to provide the best quality images”. Rather than, “Our mammograms are regulatorily-guaranteed to be less than 0.3 Rad per projection”, and we provide at least two projections per breast per patient”. The layman wants to hear quality and safety assurances that they can understand and relate to. They cannot properly put radiation exposures in perspective, and you do not have the time to educate them.
Old Dose Units versus Newer Standard International Units

Older Terms (still used frequently in USA)
Unit of Exposure (Roentgen)
Unit of Absorbed Dose (RAD)
Unit of Dose Equivalence (REM)
Radioactivity Unit (Curie, Ci)

Newer Terms (appearing in the literature, etc.)
Unit of Exposure (coulombs/Kg²)
Unit of Absorbed Dose (Gray, Gy)
Unit of Dose Equivalence (Sievert, Sv)
Radioactivity Unit (Bequerel, Bq)
Conversion of Units

1 R = 2.58 x 10^{-4} C/kg  (1 C/kg = 3876 R)

100 RAD = 1 Gy (10 mGy = 1 RAD)

100 REM = 1 Sv (10 mSv = 1 REM)

1 mCi = 37 MBq (1 Bq = 1 disintegration per second)
Remember:
REM = RAD x RBE or Q.F. (Relative Biological Effectiveness, or Quality Factor), and for X-rays and Gamma Rays 1 RAD = 1 REM, because the Q.F. is 1. Exposure in air is sometimes now called Air Kerma, measured in Joules/kg units. Exposure units and dose units are equivalent with medical X-rays and gamma rays to within about +/-13%. Radiation survey meters are often calibrated to read in exposure, mR/hr units.
Why a patient need not have a lead drape around their waist for a PA chest radiograph...
Unlike the dental lead apron that is useful in protecting the patient from scatter from a non-collimated open cone, the half lead aprons often used for chest radiography patients are useless. If used, they should be on the side of the patient facing the wall to protect from scatter from the primary beam back towards the gonads—not on the posterior side where the X-ray beam does not extend outside the field defined by the light field. Similarly, patients (even pediatric) need not be draped with a lead half apron when getting a diagnostic x-ray image of an extremity. Any scatter will be negligible, and the use of the lead apron on the patient will only serve as a false sense of security to the unknowing patient. The general rule, for all intents and purposes, is that there is no X-ray hazard outside the light field defined area. Some facilities offer the lead drape upon request rather than to try to “educate” the patient, thus perpetrating the myth of radiation risk from convention radiographic projections.
Radiation exposure outside the pink beam area is negligible and the placement of lead on the surface of the patient is not necessary unless the area is immediately adjacent to gonads, or in the case of a pediatric patient.
PA View

- 14 x 17 Chest light field
- 0.5 mm Pb drape
Light Field

Primary Beam

100 kVp

Scatter

5 kVp

100 kVp

70 kVp

70 kVp

10 kVp

Wall

0.5 mm Pb drape

Location A = 0 mR

Location B = 10 mR

Location C = 1 mR
Answers to Frequently-Asked Medical Patient Dose Related Questions (F.A.Q.s)

1. What is the approximate dose to a fetus from various medical imaging procedures?

A radiographic, fluoroscopic, or C.T. procedure with the projected field about 10 cm or more from the fetal area will result in negligible dose to the fetus.

A fluoroscopic dose in the fetal area will result in about 3 Rads/min.

A radiographic exposure will result in about 0.3 Rad/projection.

The average nuclear medicine dose will be about 0.2 Rad.

The average CT dose will be about 3 Rad per series of slices for 1-16 slice units; at least twice as much for 64 slice units operating in a respiratory-gated mode.
I have never evaluated a fetal dose that required a therapeutic abortion. I have evaluated doses close to ten Rads. 25 Rads is usually considered the “liberal” threshold for termination due to the increased risk of diminished mental capacity or risk of childhood malignancies.

When a patient is discovered to have received a dose of radiation to a fetus, contact the consultant medical radiation physicist or RSO for a letter assessing the dose and putting it into perspective.
2. A Patient is given a 15 mCi dose of F-18 FDG for a PET scan at 9:00 AM, and is to return to her job as a pediatric nurse at 3:00 PM, must (should) she be told to delay her return to work until the next day? The exposure from the patient at 1 meter is measured to be 8 mR/hr at 9:00 AM following her dosage.

Since F-18 has an approximate 2 hour half life, the exposure at 1 meter at 3:00 PM (assuming no biological excretion) would be 1 mR/hr. This exposure, although measurable, is not within regulatory or biologically-harmful concern. So it would be fine to allow the patient to return to work, especially since the half life is really 1.8 hr., and the patient will probably urinate during the 6 hours, reducing the exposure even more.
3. A pregnant patient presents in the E.R. with a suspicion of pulmonary distress. The radiologist is consulted for the “best” modality or approach to an effective diagnosis given the choices of a nuclear medicine lung scan or a C.T. of the lung.

As long as the C.T. of the lung series of slices does not extend to the region of the pelvis where the fetus is, negligible exposure to the fetus will result. The dose to the fetus from a Tc-99m MAA lung scan is about 0.2 RAD, which is also below concern for biological effects. If the C.T. field slices the pelvis and a portion of the fetus is in the field, an exposure of up to 4 RADs may result, and of course, a second series with contrast, could add an additional 4 RADs.
4. An interventionalist has left the fluoroscopy beam on for a cerebral angiogram for 60 minutes to the same projected area of the head. What, if any, biological squealae will result?

Assuming an average radiation output of 5 R/min, 300 RADs of exposure to the skin probably occurred. This could result in a patch of possible erythema or epilation in the shape of the collimated beam’s field size. The patient should recover from this radiation insult; however, they should also be informed of the possible side effect of the lengthy exposure-following the study.
5. A patient, a 65 yr. old nun, has been requested to move to the Vatican, and they want to know what her total radiation exposure is. What do you provide since the patient has had many radiographic exposures in her life (skull, feet, ankles, hands, lumbar spine, cervical spine, and chest). She has had fluoroscopy (pelvis), C.T. (head) and nuclear medicine scans (lung, bone, gall bladder).

First, we must assume she/they are concerned not of her gonadal exposure, rather her risk from cancer, i.e. leukemia. Therefore we assess the exposure to her major blood-forming bone marrow region from the tip of her pelvis to the base of the femur. We can exclude the following doses she got: radiographs of the skull, feet, ankles, hands, cervical spine, and chest.
We can exclude the nuclear medicine lung scan. We can exclude the C.T. of the head. We can sum the rest such as: bone and gall bladder dose to bone marrow = 0.4 RAD, 10 minutes of fluoroscopy at 80 kVp to the pelvis = 20 RADS, lumbar spine = 0.8 RAD, for a grand total of 21.2 RADs. This “total dose” must be stated to have been delivered over 45 years. Since much recovery and repair occurred in this time, this is not a significant total dose worthy of any personal concern. So what is the value of such a tally to either the person or the Vatican? Darned if I know, but I once had this request.
Fetal Dose and Letters to Genetic Counselors

Often, in spite of the staff’s best efforts to ask/test a patient to see if they might possibly be pregnant, a radiographic or fluoroscopic procedure is performed on an “unsuspecting” pregnant woman. Often, she or her referring physician, will request the “dose she received from her X-ray studies” to be sent to a genetic counselor. At this request, you should contact your in house medical physicist or consultant medical radiation health physicists from Walter L. Robinson & Associates. Either way, we will get the request to write a letter addressing this issue. In 34 years, I have never evaluated a fetal dose exceeding 10 RADs. The usual threshold for considering a therapeutic abortion in 25 RADs. Therefore, this letter’s purpose to put the risk from the dose in perspective, and to compare the dose to other exposures, if possible.
A Few Words About Some Other Important Issues

1. Liability Issues with PACs Workstations
2. CT and C.R. Patient Dose Reduction
3. Reduction of I.R. Radiation Exposure and Personnel Monitoring
PACs Workstation Liability Issues, and a Solution

Issue: When film/screen technology was used there was a serious film quality control program to assure film quality constancy. Today with C.R., D.R., and other Digital Imaging Modalities all being displayed on a PACs workstation, what Q.C. is performed, and how often. Is minimal brightness checked? Are left and right monitors checked for proper tolerances of differences? Is each monitor uniform throughout the display screen? If there was a professional liability court case pertaining to a digitally-displayed image, and the question came up: How do you (the radiologist) know from day-to-day that your workstation monitors all give uniform and adequate displays, and do you have a Q.C./Q.A. program, and if so, how frequently are the monitors checked? To what protocol are they checked? Is there a requirement to check them?
The answer at most hospitals, including this one, is that there is NO regular PACs workstation Q.C. There is C.R. reader Q.C., following my insistence. Some A.C.R. Accreditation Programs, i.e., M.R.I. requires the medical physicist to check the monitors for brightness and uniformity-annually. There have been talks and discussion of software and staff to perform this testing on a monthly basis, but to date, it remains an open issue. I believe it needs Radiologist encouragement. The State of PA BRP requires all X-ray imaging departments to have a Q.C./Q.A. Program. They do not spell out what is necessary. The AAPM has TG-18 guidelines. This is what I have discussed with biomedical staff.
C.T. Patient Dose Reduction

C.T. Dose Reduction can be achieved for pediatric and adult exposures. Unique pediatric acquisition parameters can be set to provide excellent image quality with a lower patient dose. Adult doses can be reduced by selecting higher kVp techniques, changes in matrix size, and less slices. This is an experimental process, but results in quality images of lower dose to the patient.
C.R. Patient Dose Reduction

C.R. Dose Reduction can be achieved by first understanding what the National Reference Levels of Radiographic X-ray Exposures are, and how your’s compares. With the change from film/screen to C.R. most hospitals have not “dialed in” optimal techniques to achieve the same contrast index with a lower dose. For instance, to raise the kVp for a given technique by 10 kVP will reduce the exposure significantly. Often, this change does not interfere with image quality, especially with the potential electronic adjustments of brightness and contrast. Certain procedures may suffer, and would not be candidates, but others could be reduced, with a concerted effort.
## Adult Diagnostic X-ray Reference Values

<table>
<thead>
<tr>
<th>Exam</th>
<th>MilliGray (mGy)</th>
<th>MilliRoentgens (mR)</th>
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<tbody>
<tr>
<td>PA Chest</td>
<td>0.25</td>
<td>25</td>
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<tr>
<td>AP Cervical Spine</td>
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<td>AP Abdomen</td>
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<td>AP Lumbar Spine</td>
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<td>CT Head/Body</td>
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<tr>
<td>Fluoro (Rate/min)</td>
<td>65</td>
<td>6500</td>
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Reduction of I.R. Staff Exposures, and Personnel Monitoring

Staff Exposure Reduction can be achieved with the use of the RADPAD, interposing lead acrylic shields, and the use of newer equipment using copper filters.

PA BRP Title 25 Chapter 215.28 states that: The deliberate exposure of, FAILURE TO USE, or improper use of a personnel monitoring device by an individual is prohibited!

For medico-legal reasons the RSO and the hospital encourages you to wear your personnel monitoring device especially in I.R. There are EDE formulas that can be applied for “credit” of your exposure reduction from wearing protective attire. You need not worry about exceeding a limit (5 REM/yr). This is the EDE, not the collar badge reading.
The EDE for Diagnostic Radiology

When one badge is worn on the collar, the EDE = 0.3 times that collar badge reading. When two badges are worn (collar, and under apron badge), then the EDE = 1.5 (under apron reading) + 0.04 (collar badge reading). This significantly reduces the EDE number.

When two badges are worn, extreme care must be taken not to switch the proper locations of the badges.
Which Garb to Wear?

The use of leaded thyroid collars, leaded wrap-around glasses, and kilt/vest tin/lead aprons all reduce exposures ALARA. When measured exposures are above 30% of M.P.D., then these devices become highly recommended. The use of T.L.D. ring badges are not recommended, as the interventionalist’s hand exposure is never above 30% of the 50,000 mREM limit (15,000 mREM/yr). Leaded thyroid collars are not always recommended-only if collar badge exposures exceed 15,000 mREM/yr. Lead glasses are recommended when the collar badge is over 4500 mREM/yr (0.3 x 15,000 mREM limit to eyes).
A Few Comments about X-ray Fluoroscopic Equipment with Dose and Dose-Area-Product (DAP) Readouts

GE has “AutoEx” which displays both Skin Dose and DAP.

The skin dose is calibrated at an assumed focal spot to skin distance of 55 cm (21.5”).

The DAP is calculated from the skin dose x field size being used.

Both will sum doses from conventional fluoroscopy plus digital photospots.

The skin dose readout accuracy varies with patient size and table positioning.

As the field size increases the DAP increases to remind the fluoroscopist that at a given dose rate, more cells are being effected by the larger field size.
HANDOUTS

1. New Radiation Shielding Policy
2. New Pregnant Personnel Policy
3. Associated Documents
ANY QUESTIONS???
Now? Or Later?
WLR@COMCAST.NET
1-800-446-7622 X-1
Pager: 1-800-254-4925