

Biological Effects of Ionizing Radiation
Module 8 - AAPM/RSNA Curriculum

Radiation Biology
Bushberg– Chapter 25
Lecture 2

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a copy of this lecture may be found at:
<http://courses.washington.edu/radxphys/PhysicsCourse.html>

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1

Module 8 – Biological Effects of Ionizing Radiation

Fundamental Knowledge:

- ❖ Explain the risk of carcinogenesis due to radiation.
- ❖ Understand the latencies for different cancers.
- ❖ Describe the effect of radiation on mutagenesis and teratogenesis.
- ❖ List the most probable *in utero* radiation effects at different stages of gestation.
- ❖ Recognize the risk vs. benefit in radiation uses, and recognize the information sources that can be used to assist in assessing these risks.
- ❖ Describe the different dose response models for radiation effects.

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2

Epidemiologic Investigations of
Radiation-Induced Cancer

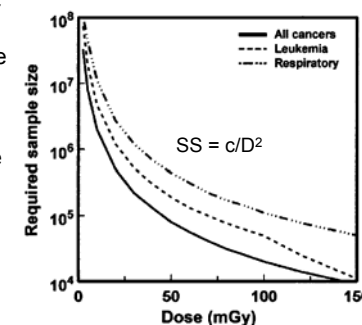
- ❖ Cancer induction is the most important delayed somatic effect of radiation exposure
- ❖ Dose-response relationships for cancer induction at high dose and dose rate have been well established
- ❖ Not so for low dose exposures like those resulting from diagnostic and occupational exposures
- ❖ Very difficult to detect a small increase in the cancer rate due to radiation
 - ❖ Natural incidence of many forms of cancer is high ($\approx 22\%$)
 - ❖ The latency period is on the order of years for all cancers, with leukemia having the shortest latency period, e.g. 5-15 years, and most solid tumors having latency periods from 10-60 years.
- ❖ To rule out simple statistical fluctuations, a very large irradiated population is required

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3

Difficulties in Quantifying Low Dose Risk

- ❖ If excess risk proportional to dose, then large studies are required for low absorbed dose to maintain statistical precision and power; the necessary sample power increases approximately as the inverse square of dose
- ❖ This relationship reflects a decline in the signal (radiation risk) to noise (natural background risk) ratio as dose decreases.
 - ❖ 500 persons needed to quantify the effect of a 1,000 mSv dose
 - ❖ 50,000 for a 100 mSv dose
 - ❖ 5 million for a 10 mSv dose (a single abdominal CT = 7.6 mSv)



National Research Council (1995) *Radiation Dose Reconstruction for Epidemiologic Uses*. Natl. Acad. Press © UW and Kalpana Kanal, PhD, DABR

4

What is the Evidence?

- Major epidemiological investigations that form the basis of current cancer dose-response estimates in human populations are shown in the table
- In these studies most individuals received a large dose
- Extrapolation (using some model/curve) to low dose!

TABLE 25-6. SOURCES OF DATA ON RADIATION EXPOSURE TO HUMANS

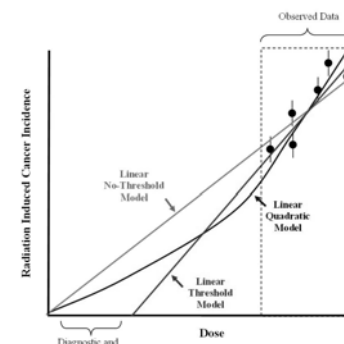
Atomic-bomb detonation exposures and fallout
Survivors
Offspring of survivors
Medical exposures
Treatment of tinea capitis
X-ray treatment of ankylosing spondylitis
Prenatal diagnostic x-ray
X-ray therapy for enlarged thymus glands
Fluoroscopic guided pneumothorax for the treatment of tuberculosis
Thorotrast (radioactive contrast material used in angiography, 1925-1945)
Treatment of neoplastic diseases (e.g., breast cancer, Wilms' tumor, cancer of the cervix and leukemia)
Occupational exposures
Radium dial painters (1920s)
Uranium miners and millers
Nuclear dockyard workers
Nuclear-materials enrichment and processing workers
Participants in nuclear weapons tests
Construction workers
Industrial photography workers
Radioisotope production workers
Reactor personnel
Civil aviation and astronautic personnel
Phosphate fertilizer industry workers
Scientific researchers
Diagnostic and therapeutic radiation medical personnel
Epidemiologic comparisons of areas with high background radiation

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5

Risk Estimation Models Dose-Response Curves

- Dose-response models predict cancer risk from exposure to low levels of ionizing radiation → dose-response curves
- The most conservative approach for radiation protection and risk analysis is to use the *linear no-threshold* model and this hypothesis is used by all advisory and regulatory agencies when setting limits for radiation exposure.
- In the *linear-quadratic model*, it is assumed the incidence of induced cancer at low dose levels increase linearly with radiation dose but the incidence increases much more rapidly at high dose levels, i.e. changes from a linear relationship at low dose levels to a quadratic relationship at high dose levels



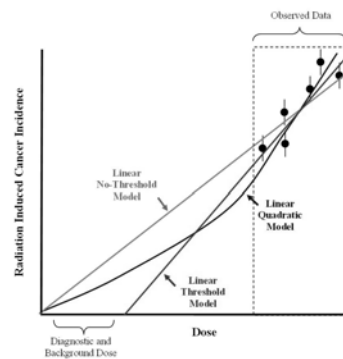
c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 844.

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6

Risk Estimation Models Dose-Response Curves

- The linear-quadratic model is derived from a large number of animal studies that demonstrate this fit in specific cancers, e.g. leukemia and non-melanoma skin cancer.
- But the shape of the linear quadratic fit to other cancers suggests that there is a large variation in the curve fitting parameters making the extrapolation to low dose levels variable depending on the cancer and/or cell type and utilizing these fits to predict cancer in other animals/humans is limited.



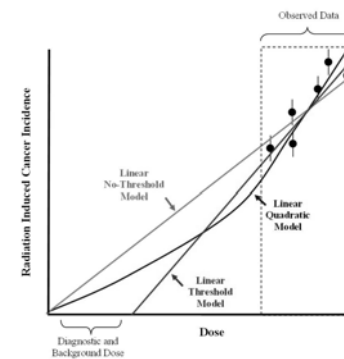
c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 844.

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7

Risk Estimation Models Dose-Response Curves

- In the linear models the incidence of induced cancer is linearly proportional to the dose at all dose levels, one is no-threshold and one is with threshold
- This is a highly controversial topic and the decision on which model to use may need to be based on how the results are going to be used
- e.g. if the model is used to determine excess cancers that may arise from a patient population that receives medical exposures the use of a threshold may be appropriate using risk/benefit analysis,
- but if the model is going to be used to define dose limits for radiation workers or the general public a no-threshold model would be more conservative and perhaps more appropriate.



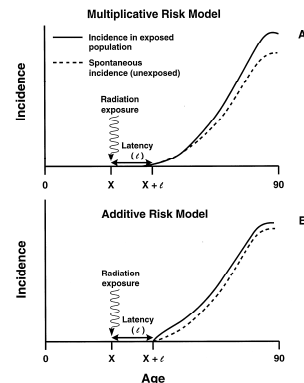
c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 844.

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8

Risk Estimation Models - Risk Models

- ❖ Multiplicative risk model: after a latent period, the excess risk is a multiple of the natural age-specific cancer risk for the population in question
- ❖ Additive risk model: fixed or constant increase in risk unrelated to the spontaneous age-specific cancer risk at the time of exposure
- ❖ Latency periods:
 - ❖ Leukemia 5-15 average
 - ❖ Solid tumors 10-60 yrs average



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 845.

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9

Risk Estimation Models - Risk Expression

- ❖ Relative Risk
 - ❖ Ratio of the cancer incidence in the exposed population to that in the general (unexposed) population
 - ❖ RR of 1.2 indicates a 20% increase over the spontaneous rate
 - ❖ Excess relative risk is simply $RR - 1$
- ❖ Absolute Risk
 - ❖ Expressed as the number of excess radiation-induced cancers per 10,000 people per Sv-yr
 - ❖ For a cancer with a radiation-induced risk of 4 per 10,000 person per Sv-yr and a latency period of 20 years, the risk of *developing cancer* from a dose of 0.1 Sv (~13x body CT equivalent dose) within the next 40 years would be:
 - ❖ (40-20) or 20 years x 0.1 Sv x 4 per 10,000 person per Sv-yr
 - ❖ = 8 per 10,000 or 0.08%

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10

Radiation Standards Organizations

- ❖ Independent bodies of experts evaluate information and evidence on radiation health effects
 - ❖ BEIR - National Academy of Sciences/National Research Council Committee on the Biological Effects of Ionizing Radiation
 - ❖ UNSCEAR - United Nations Scientific Committee on the Effects of Radiation
 - ❖ RERF - Radiation Effects Research Foundation
- ❖ Experts draw upon this collective knowledge to develop recommendations for systems of radiation protection
 - ❖ NCRP – National Council on Radiation Protection and Measurements
 - ❖ ICRP – International Commission on Radiological Protection
- ❖ Radiation protection regulatory framework
 - ❖ NRC – Nuclear Regulatory Commission
 - ❖ EPA - Environmental Protection Agency

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11

BEIR V Risk Estimates

- ❖ BEIR published a report in 1990 entitled, “The Health Effects of Exposure to Low Levels of Ionizing Radiation” or the BEIR V report
- ❖ *Single best estimate of radiation-induced mortality at low exposure levels is 4% per Sv* for a working population (ICRP – 5.4% per Sv for the whole population - takes children into account @ 12.3%/Sv)
- ❖ The single best estimate of radiation-induced mortality at high doses applied at high dose rate is 8% per Sv
- ❖ The BEIR V Committee believed that the LNT dose-response model was best for all cancers except leukemia and bone cancer; for those malignancies, a linear-quadratic model was recommended
- ❖ LNT model: an exposure of 10,000 people to 10 mSv would result in approximately 4 cancer deaths (0.04%) in addition to the 2,200 (22%) normally expected in the general population

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12

BEIR VII Risk Estimates (1)

- ❖ The committee judged that the linear no-threshold model (LNT) provided the most reasonable description of the relation between low-dose exposure to ionizing radiation and the incidence of solid cancers that are induced by ionizing radiation
- ❖ On average, the BEIR VII lifetime risk model predicts that approximately **1 person in 100 would be expected to develop cancer from a dose of 0.1 Sv above background**, while approximately 42 of the 100 individuals would be expected to develop solid cancer or leukemia from other causes

TABLE 13-1 Committee's Preferred Estimates of the Lifetime Attributable Risk of Incidence and Mortality for All Solid Cancers and for Leukemia

	All Solid Cancer		Leukemia	
	Males	Females	Males	Females
Excess cases (including nonfatal cases) from exposure to 0.1 Gy	800 (400, 1600)	1300 (690, 2500)	100 (30, 300)	70 (20, 250)
Number of cases in the absence of exposure	45,500	36,900	830	590
Excess deaths from exposure to 0.1 Gy	410 (200, 830)	610 (300, 1200)	70 (20, 220)	50 (10, 190)
Number of deaths in the absence of exposure	22,100	17,500	710	530

NOTE: Number of cases or deaths per 100,000 exposed persons.

c.f. NRC (2006). *Health risks from exposure to low levels of ionizing radiation: BEIR VII Phase 2*, p. 15. © UW and Kalpana Kanal, PhD, DABR

Comparison of the Risks of CT Exams

BEIR VII Risk Estimates (2)

TABLE 12D-2 Lifetime Attributable Risk of Cancer Mortality^a

Cancer Site	Age at Exposure (years)										
	0	5	10	15	20	30	40	50	60	70	80
Males											
Stomach	41	34	30	25	21	16	15	13	11	8	4
Colon	163	139	117	99	84	61	60	57	49	36	21
Liver	44	37	31	27	23	16	16	14	12	8	4
Lung	318	264	219	182	151	107	107	104	93	71	42
Prostate	17	15	12	10	9	7	6	7	7	7	5
Bladder	45	38	32	27	23	17	17	17	17	15	10
Other	400	255	200	162	134	94	88	77	58	36	17
All solid	1028	781	641	533	444	317	310	289	246	181	102
Leukemia	71	71	71	70	67	64	67	71	73	69	51
All cancers	1099	852	712	603	511	381	377	360	319	250	153
Females											
Stomach	57	48	41	34	29	21	20	19	16	13	8
Colon	102	86	73	62	53	37	37	35	31	25	15
Liver	24	20	17	14	12	9	8	8	7	5	3
Lung	643	534	442	367	305	213	212	204	183	140	81
Breast	274	214	167	130	101	61	35	19	9	5	2
Uterus	11	10	8	7	6	4	4	3	3	2	1
Ovary	55	47	39	34	28	20	20	18	15	10	5
Bladder	59	51	43	36	31	23	23	22	22	19	13
Other	491	287	220	179	147	103	97	86	69	47	24
All solid	1717	1295	1051	862	711	491	455	415	354	265	152
Leukemia	53	52	53	52	51	51	52	54	55	52	38
All cancers	1770	1347	1104	914	762	542	507	469	409	317	190

NOTE: Number of deaths per 100,000 persons exposed to a single dose of 0.1 Gy.

^aThese estimates are obtained as combined estimates based on relative and absolute risk transport and have been adjusted by a DDREF of 1.5, except for leukemia, which is based on a linear-quadratic model.

c.f. NRC (2006). *Health risks from exposure to low levels of ionizing radiation: BEIR VII Phase 2*, p. 311. © UW and Kalpana Kanal, PhD, DABR

ICRP 60 Risk Estimates

TABLE 25-8. OVERALL RISK AND RELATIVE PROBABILITIES OF RADIATION-INDUCED CANCER MORTALITY IN VARIOUS ORGANS FOR DIFFERENT AGE GROUPS^a

Organ	Age group		
	0-19 Yr	0-90 Yr	20-64 Yr
Stomach	0.266	0.291	0.305
Lung	0.192	0.174	0.159
Bone marrow	0.052	0.077	0.109
Bladder	0.030	0.052	0.082
Colon	0.255	0.180	0.089
Esophagus	0.021	0.038	0.061
Ovary ^b	0.009	0.014	0.023
Breast ^b	0.025	0.023	0.022
Remainder	0.150	0.150	0.150
Total	1.000	1.000	1.000
Risk 10 ⁻² /Sv (10 ⁻⁴ /rem)	12.3	5.4	4

^aThis data applies to a Japanese population of a wide range of ages. A multiplicative risk projection model was used. A dose and dose rate effectiveness factor (DDREF) of 2 was applied to the data acquired at high dose and dose rate to adjust for typical occupational and diagnostic exposures, (i.e., per ICRP report 60 recommendation for doses <20 rad or dose rates <10 rad/yr, p. 18, par. 74).

^bThis table represents the ICRP's risk coefficients for a working population that is assumed to be half women and half men. The risks for ovaries and breasts for women alone is therefore twice this risk. No coefficient was specifically given for testis, which is included in the remainder risk coefficient.

Source: Adapted from ICRP Publication 60, *1990 Recommendations of the International Commission on Radiological Protection*. Annals of the ICRP 21 No. 1-3, 1991.

c.f. Bushberg, et al. *The Essential Physics of Medical Imaging*, 2nd ed., p. 847.

Spontaneous Incidence of Radiation-Induced CA

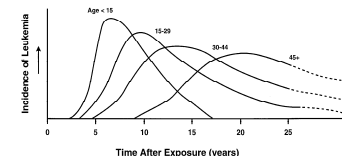
TABLE 25-9. SPONTANEOUS INCIDENCE AND SENSITIVITY OF VARIOUS TISSUES TO RADIATION-INDUCED CANCER

Site or type of cancer	Spontaneous incidence	Radiation sensitivity
Most Frequent Radiation-Induced Cancers		
Female breast	Very high	High
Thyroid	Low	Very high, especially in females
Lung (bronchus)	Very high	Moderate
Leukemia	Moderate	Very high
Alimentary tract	High	Moderate low
Less Frequent Radiation-Induced Cancers		
Pharynx	Low	Moderate
Liver and biliary tract	Low	Moderate
Lymphomas	Moderate	Moderate
Kidney and bladder	Moderate	Low
Brain and nervous system	Low	Low
Salivary glands	Very low	Low
Bone	Very low	Low
Skin	High	Low
Magnitude of Radiation Risk Uncertain		
Larynx	Moderate	Low
Nasal sinuses	Very low	Low
Parathyroid	Very low	Low
Ovary	Moderate	Low
Connective tissue	Very low	Low
Radiation Risk Not Demonstrated		
Prostate	Very high	Absent?
Uterus and cervix	Very high	Absent?
Testis	Low	Absent?
Mesothelium	Very low	Absent?
Chronic lymphatic leukemia	Low	Absent?

Source: Modified from Committee on Radiological Units, Standards and Protection: Medical Radiation: A Guide to Good Practice. Chicago: American College of Radiology, 1985.

Specific Cancer Risk Estimates - Leukemia

- ❖ Rare: natural incidence in US population: 1 in 10⁴ (0.01%)
- ❖ 17% of total mortality from radiocarcinogenesis
- ❖ The incidence of leukemia greatly influenced by age at the time of exposure
- ❖ BEIR V: nonlinear dose-response model predicting excess life-time risk of 10 in 1000 (0.1%) after exposure to 100 mGy
- ❖ BEIR VII: nonlinear dose-response model predicting excess life-time risk of 1 in 100 (1%) after exposure to 100 mGy
- ❖ Average latent period = 10 yrs



Specific Cancer Risk Estimates – Thyroid Cancer

- ❖ 6-12% of total mortality from radiocarcinogenesis
- ❖ Females 3-5x greater risk than males
- ❖ Jewish and North African ancestry at greater risk
- ❖ Latency period
 - ❖ Benign nodules: 5-35 yrs
 - ❖ Thyroid malignancies: 10-35 yrs
- ❖ Dose-response curve: LNT
- ❖ However, other responses such as hypothyroidism and thyroiditis with thresholds:
 - ❖ 2 Gy for external irradiation
 - ❖ 50 Gy for internal radiation (radioactive materials like ¹³¹I)

Specific Cancer Risk Estimates – Breast Cancer

- ❖ One of 8 US women at risk of developing breast cancer
- ❖ 180,000 new cases/yr
- ❖ 1 in 30 women die of breast cancer
- ❖ Low LET radiation risk age dependent, ≈ 50 times greater for the 15 yo age group (≈ 0.3% per year) after exposure of 100 mGy than those > 55 yo
- ❖ The risk estimates for women in the 25, 35 and 45 yo age groups are 0.05%, 0.04% to 0.02% respectively after 100 mGy (BEIR V)
- ❖ The risk estimates for women in the 25, 35 and 45 yo age groups are 0.08%, 0.05% to 0.03% respectively after 100 mGy (BEIR VII)
- ❖ Dose-response curve: LNT w/ dose of ≈ 0.8 Gy doubling the natural incidence
- ❖ Latent period [10yrs,40yrs]; longer latencies for younger women

Genetic Effects in Humans

- ❖ Genetic effects the result of gonadal radiation exposure
- ❖ There is no direct evidence at any dose level that exposure of parents to radiation leads to excess disease in offspring
- ❖ Epidemiological investigations have failed to demonstrate radiation-induced genetic effects in humans
 - ❖ Mutation of human cells in culture have been demonstrated
 - ❖ Screening showed only 2 possible radiation-induced mutations of 27,000 children of atomic bomb survivors
- ❖ Current risk estimates are based on animal experiments
- ❖ ICRP: for workers, the risk of severe hereditary effects is 0.8%/Sv of gonadal radiation
- ❖ For a whole population (incl. children), the risk of severe hereditary effects is 1.3%/Sv

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21

Estimating Genetic Risk

- ❖ Genetically Significant Dose (GSD)
 - ❖ Is defined as that equivalent dose that, if received by every member of the population, would be expected to produce the same genetic injury to the population as do the actual doses received by the irradiated individuals
- ❖ Spontaneous mutation rate (chromosomal abnormalities)
 - ❖ $7-15 \times 10^{-4}$ /gamete
- ❖ Doubling dose (est. from animals): 1 Gy/generation
- ❖ BIER V – for 10 mGy
 - ❖ 6-65 additional genetic disorders/ 10^6 births (geo. mean 0.002%)
- ❖ Normal incidence (genetic disorders): 1 in 20 (5%)
- ❖ The gene pool has the capacity to absorb large amounts of radiation w/o significantly affecting the population

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22

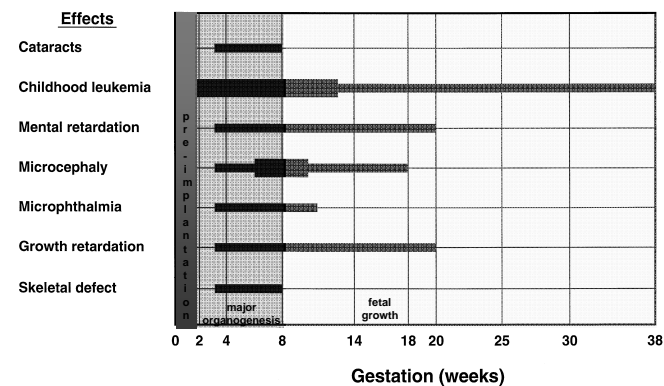
Radiation Effects *In Utero* (1)

- ❖ Gestational period divided into 3 stages:
 - ❖ Relatively short preimplantation stage (day 0-9)
 - ❖ Extended period of major organogenesis (day 9-56)
 - ❖ Fetal growth stage (day 45 to term)
- ❖ Preimplantation: conceptus extremely sensitive and radiation damage can result in prenatal death: “All-or-nothing response”
- ❖ Animal experiments have demonstrated an increase in the spontaneous abortion rate after doses as low as 50 to 100 mGy

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23

Critical Periods for Radiation-induced Birth Defects

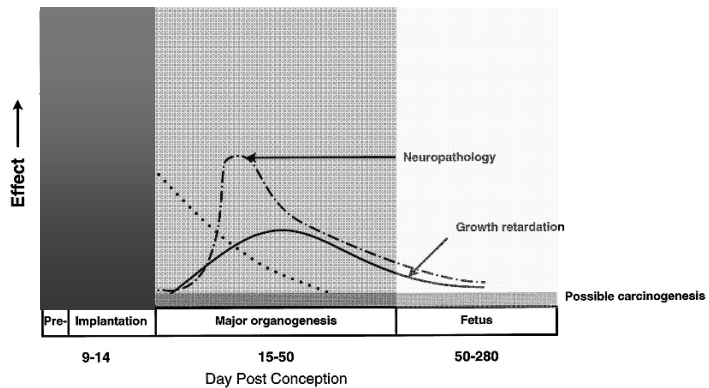


c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 855.

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24

Relative Incidence of Radiation-Induced Health Effects at Various Stages in Fetal Development



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 860.

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25

Summary of Suspected In-Utero Induced Deterministic Radiation Effects

Menstrual or Gestational age	Conception age	<0.05 Gy	0.05-0.1 Gy	>0.1 Gy
0 - 2 weeks	Prior to conception	None	None	None
3 rd and 4 th weeks	1 st - 2 nd weeks	None	Probably none	Possible spontaneous abortion.
5 th - 10 th weeks	3 rd - 8 th weeks	None	Potential effects are scientifically uncertain and probably too subtle to be clinically detectable.	Possible malformations increasing in likelihood as dose increases.
11 th - 17 th weeks	9 th - 15 th weeks	None	Potential effects are scientifically uncertain and probably too subtle to be clinically detectable.	Increased risk of deficits in IQ or mental retardation that increase in frequency and severity with increasing dose.
18 th - 27 th weeks	16 th - 25 th weeks	None	None	IQ deficits not detectable at diagnostic doses.
>27 weeks	>25 weeks	None	None	None applicable to diagnostic medicine.

*Taken from "ACR Practice Guideline for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation", derived from ICRP Publications 84 (2001) and 90 (2004).

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26

Radiation Effects *In Utero* (2)

- ❖ CNS the only organ system w/ assoc. malformations < 250 mGy
- ❖ > 1 Gy assoc. w/ a high incidence of CNS abnormalities
- ❖ Growth retardation after *in utero* exposure ≥ 100 mGy demonstrated
- ❖ Fetal doses generally << 100 mGy for most diagnostic and nuclear medicine procedures and thought to carry negligible risk compared with the spontaneous incidence of congenital abnormalities (4%-6%)
- ❖ For a typical abdominal and pelvic CT examination, the average fetal dose is approximately 24 mGy with a range of 16–31 mGy, depending on maternal size (Angel et al)
- ❖ Fetal dose estimates for a singlepass abdominal and pelvic acquisition are below the consensus levels for negligible risk (50–150 mGy) and well below the actionable level of 150 mGy.
- ❖ A conservative estimate of the excess risk of childhood cancer from *in utero* irradiation is ≈ 6% per Gy

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27

Radiation Effects *In Utero* (3)

- ❖ If radiation dose received during or prior to the first two weeks post conception (< 14 days)*
 - ❖ Exposure to diagnostic radiation is not an indication for therapeutic abortion
- ❖ For patients exposed to radiation between the 2nd and 8th weeks post-conception (days 14-56)*:
 - ❖ Therapeutic abortion based solely on radiation exposure is not advised for dose less than 150 mGy
 - ❖ Dose exceeding 150 mGy may be an indication for therapeutic abortion in the presence of less severely compromising factors. However, diagnostic studies rarely result in such dose levels.

* Wagner, et al. Exposure of the Pregnant Patient to Diagnostic Radiation, pp. 166-7.

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28

Radiation Effects *In Utero* (4)

- ❖ For a conceptus exposed between the 8th and 15th week post-conception (days 56-105)*:
 - ❖ Fetal dose below 50 mGy
 - ❖ Radiation not a sufficient risk to justify therapeutic abortion
 - ❖ Fetal dose between 50-150 mGy
 - ❖ therapeutic abortion is not advisable on the basis of the radiation risk alone
 - ❖ Fetal dose above 150 mGy
 - ❖ In this time interval there is scientific evidence that may support a recommendation for therapeutic abortion based on the radiation exposure. However, this does not mean an abortion is necessarily recommended. Diagnostic studies rarely result in such dose levels.

* Wagner, et al. Exposure of the Pregnant Patient to Diagnostic Radiation, pp. 166-7.

Radiation Effects *In Utero* (5)

- ❖ Fetal dose at 150 mGy:
 - ❖ Up to a 6% probability the child could be mentally retarded
 - ❖ Natural incidence = 0.4%
 - ❖ Probability the child will develop cancer < 3%
 - ❖ Natural incidence = 1.4%
 - ❖ Probability of small head size ≈ 15% (but does not necessarily affect normal mental function)
 - ❖ Natural incidence = 4%
 - ❖ IQ may fall a few points short of its full potential
 - ❖ Except for possible effects to individual organs from radionuclide studies, no other risks have been demonstrated. However, always practice ALARA!

* Wagner, et al. Exposure of the Pregnant Patient to Diagnostic Radiation, pp. 166-7.

Effect of *In Utero* Risk Factors on Outcome

TABLE 25-11. EFFECT OF RISK FACTORS ON PREGNANCY-OUTCOME

Effect	Number occurring from natural causes	Risk factor	Excess occurrences from risk factors
Radiation Risks			
Childhood Cancer			
Cancer death in children	1.4/1,000	Radiation dose of 10 mSv (1 rem) received before birth	0.6/1,000
Abnormalities		Radiation dose of 10 mSv (1 rem) received during specific periods after conception:	
Small head size	40/1,000	4-7 wk	5/1,000
Small head size	40/1,000	8-11 wk	9/1,000
Mental retardation	4/1,000	8-15 wk	4/1,000
Nonradiation Risks			
Occupation			
Stillbirth or spontaneous abortion	200/1,000	Work in high-risk occupations	90/1,000
Alcohol Consumption			
Fetal alcohol syndrome	1-2/1,000*	2-4 drinks/day	100/1,000
Fetal alcohol syndrome	1-2/1,000*	More than 4 drinks/day	200/1,000
Fetal alcohol syndrome	1-2/1,000*	Chronic alcoholic (>10 drinks/day)	350/1,000
Perinatal infant death	23/1,000	Chronic alcoholic (>10 drinks/day)	170/1,000
Smoking			
Perinatal infant death	23/1,000	<1 pack/day	5/1,000
Perinatal infant death	23/1,000	≥1 pack/day	10/1,000

*There is a naturally occurring syndrome that has the same symptoms as a full-blown fetal alcohol syndrome that occurs in children born to mothers who have not consumed alcohol. Source: U.S. Nuclear Regulatory Commission. Instruction concerning prenatal radiation exposure. Regulatory Guide 8.13, Rev. 2.

In Utero Irradiation Summary

TABLE 25-13. PROBABILITY OF BIRTHING HEALTHY CHILDREN

Dose* to Conceptus (mSv [mrem])	Child with No Malformation (Percentage)	Child Will Not Develop Cancer (Percentage)	Child Will Not Develop Cancer or Have a Malformation (Percentage)
0 (0)	96	99.93	95.93
0.5 (50)	95.999	99.927	95.928
1.0 (100)	95.998	99.921	95.922
2.5 (250)	95.995	99.908	95.91
5.0 (500)	95.99	99.89	95.88
10.00 (1,000)	95.98	99.84	95.83

*Refers to absorbed dose above natural background. This table assumes conservative risk estimates, and it is possible that there is no added risk. Source: From Wagner LK, Hayman LA. Pregnancy in women radiologists. *Radiology* 1982;145:559-562.

Review Question

- ❖ When is gross malformation most likely to occur?
- ❖ (A) Early fetal period
- ❖ (B) Early organogenesis
- ❖ (C) Late fetal period
- ❖ (D) Late organogenesis
- ❖ (E) Preimplantation

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33

Review Question

- ❖ What “threshold” embryo/fetal dose corresponds to a radiation risk smaller than those normally encountered during pregnancy?
- ❖ (A) Less than 10 mGy
- ❖ (B) 10 mGy
- ❖ (C) 30 mGy
- ❖ (D) 100 mGy
- ❖ (E) More than 100 mGy

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34

Review Question

- ❖ A barium enema was performed on a 25 year-old female who was determined to be three weeks pregnant at the time of examination. As the consulting radiologist, you should:
- ❖ A. Recommend a therapeutic abortion.
- ❖ B. Counsel the patient that the embryo is at a significantly high risk for gross malformations as a result of the radiation exposure; however, an abortion is not necessarily warranted.
- ❖ C. Discuss the implications of the radiation exposure with the hospital's legal department.
- ❖ D. Do not discuss any potential effects of the radiation exposure on the embryo because very little is known about in utero radiation exposure and your comment would be totally speculative and unsubstantiated.
- ❖ E. Explain to the referring physician and patient that the radiation received by the embryo by this diagnostic procedure is relatively small and that the increase in risk is negligible compared to the spontaneous incidence of congenital abnormalities.

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35

Review Question

- ❖ In radiation protection the embryo/fetus is considered more vulnerable to radiation than an adult, for all of the following reasons except:
- ❖ A. In a given volume, more embryonic cells are proliferating than adult cells.
- ❖ B. In a given volume, more embryonic cells are differentiating than adult cells.
- ❖ C. An embryo consists of fewer cells, making the loss of cells by radiation injury potentially more damaging.
- ❖ D. The higher oxygen tension of the embryo/fetus results in a higher oxygen enhancement ratio (OER).

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36

Review Question

- ❖ Which group of irradiated individuals has demonstrated genetic effects of radiation?
- ❖ (A) Atomic bomb survivors
- ❖ (B) Cancer radiotherapy patients
- ❖ (C) No human group
- ❖ (D) Thyroid treatment (^{131}I) patients
- ❖ (E) Uranium miners

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37

Review Question

- ❖ According to NCRP there is a negligible increase in the risk of adverse effects to the fetus, compared with other risks of pregnancy, up to a total dose of _____ mGy.
- ❖ A. 5
- ❖ B. 20
- ❖ C. 100
- ❖ D. 500
- ❖ E. 1000

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38

Review Question

- ❖ Perinatal death (at or around the time of birth) is most likely to occur as a result of irradiation in humans which occurs in the gestational period of:
- ❖ A. Implantation of the embryo.
- ❖ B. Major organogenesis (21-40 days).
- ❖ C. Second trimester.
- ❖ D. Just before birth (30-36 weeks).

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39

Review Question

- ❖ The currently accepted model of radiation dose versus effect used by regulatory agencies to determine dose standards is _____.
- ❖ A. Cubic
- ❖ B. Exponential
- ❖ C. Linear no threshold
- ❖ D. Linear quadratic
- ❖ E. Linear threshold

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40

Review Question

- ❖ The latent period for radiation-induced carcinogenesis (solid tumors) is about _____ years.

- ❖ A. 1
- ❖ B. 5
- ❖ C. 10
- ❖ D. 20-30
- ❖ E. 40-50