Dosimetry in Pregnant Patients undergoing CT and Fluoroscopy

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Need for understanding radiation effects on pregnancy

- 30% of all trauma patients are females in childbearing age (10-50 years old)
- Nearly 15% of female trauma victims may be pregnant at the time of injury

J Trauma, 29: 1628-1632, 1989
Radiation effects on the Unborn

- Most sensitive - 2 to 15 weeks postconception
- Prenatal or embryonic death
- Decreasing head size and mental retardation
- Gross congenital malformations
- Increased risk of childhood cancer – 10 mGy (1 rad) fetus exposure during 1st trimester would have 35 times increased risk

Irradiation to 200 R @ various stages in prenatal development in mice

A-bomb survivors irradiated in-utero, with microcephaly

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Radiation Effects on the Fetus

- Dose of 100 mGy (10 rad) during first 6 weeks after conception is generally considered cutoff point above which therapeutic abortion is often recommended for physician to consider while examining/discussing the radiation risk with patient.

Risk for Fetus

- Excess risk for childhood cancer
  - 0.06% per 10 mSv (0.06% per 1 rem)
- Somatic effects such as body size and mental retardation
  - thresholds range of 50 - 100 mGy (5-10 rad)
Probability of Birth with No Malformation and No Childhood Cancer

<table>
<thead>
<tr>
<th>Dose to Fetus (mGy)</th>
<th>No Malformation (%)</th>
<th>No Childhood Cancer (%)</th>
<th>No Malformation and No Childhood Cancer (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>96.03</td>
<td>99.93</td>
<td>95.93</td>
</tr>
<tr>
<td>0.5</td>
<td>95.999</td>
<td>99.026</td>
<td>95.928</td>
</tr>
<tr>
<td>1.0</td>
<td>95.998</td>
<td>99.921</td>
<td>95.922</td>
</tr>
<tr>
<td>2.5</td>
<td>95.995</td>
<td>99.008</td>
<td>95.91</td>
</tr>
<tr>
<td>5.0</td>
<td>95.99</td>
<td>99.89</td>
<td>95.88</td>
</tr>
<tr>
<td>10.0</td>
<td>95.98</td>
<td>99.94</td>
<td>95.83</td>
</tr>
<tr>
<td>50.0</td>
<td>95.90</td>
<td>99.51</td>
<td>95.63</td>
</tr>
<tr>
<td>100.0</td>
<td>95.89</td>
<td>99.07</td>
<td>94.91</td>
</tr>
</tbody>
</table>


Standard Radiograph & Fetus Exposure

- Dose to fetus depends on
  - kVp
  - mAs
  - Fetus distance from skin surface (inverse square law)
  - Filters, collimation, ...

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Chest Radiograph & Conceptus Irradiation

- Fetus not directly in the x-ray beam
- Very few scattered x-rays reach fetus
- Fetus dose may be as small 10 µGy or 1 mrad

Radiation dose to the fetus when it is not in the x-ray beam

- Conventional diagnostic procedures
  - Same as daily background radiation dose
  - ~10 µGy or 1 mrad
- Fluoroscopy and CT procedures
  - Less than 5 µGy or 5 mrad
Abdominal Radiograph & Conceptus Irradiation

- Fetus directly in the x-ray beam
- X-ray intensity reaching conceptus is usually less than 50% that of entering patient
- Fetus dose may be as much as 10 mGy or 1 rad


Rule of Thumb

- For fluoroscopy or radiography
  - Fetal dose can be conservatively estimated as **0.15 times the entrance skin dose**
Estimating Fetal Dose for CT studies

\[ NFDR(d) = \frac{\text{Dose}(d)}{\text{CTDI}} \]

\[ \text{INFDR}_E = \text{INFDR}_O + \text{INFDR}_{\text{Sup}} + \text{INFDR}_{\text{Inf}} \]

Fetal Dose \((\text{mGy})\) = CTDI \((\text{mGy})\) * INFDR_E

Where:
- NFDR – Normalized Fetal-Dose Ratio
- CTDI – Measured at center of 16 cm phantom
- INFDR - Integral Normalized Fetal-Dose Ratios


Fetal Dose Estimation with IMPACT® CT Dose Calculator for Chest CT

Fetal dose is reasonably estimated to be equivalent to the dose received by uterus

0.03 mGy for the Chest CT

(120 kVp, 200 mAs, 10 mm collimation)
Effective Dose Estimation with IMPACT® CT Dose Calculator for Abdomen-Pelvis CT

Fetal dose is reasonably estimated to be equivalent to the dose received by uterus

28 mGy for the Abdomen-Pelvis CT
(120 kVp, 200 mAs, 10 mm collimation)

Fetal radiation doses and trends in body CT during pregnancy

- CT exams of pregnant patients per year normalized to 1000 deliveries
- Fetal radiation dose estimated using ‘ImPACT dose calculator
- Dose to the uterus is considered equivalent to fetal dose
- Mean radiation dose to fetus was 25 mGy

Fetal dose estimation for abdominal-pelvic CT based on maternal perimeter

- Fetal dose correlated with maternal perimeter
- Normalized fetal dose estimates; 10.8 mGy/100 mAs

Conceptus dose estimates based on type of medical x-ray source when conceptus in irradiated volume

<table>
<thead>
<tr>
<th>X-ray Procedure</th>
<th>Estimated Dose Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional radiograph (e.g. x-ray of pelvis)</td>
<td>2 mGy/exposure</td>
</tr>
<tr>
<td>CT (e.g. Abdominal CT)</td>
<td>5 mGy/slice</td>
</tr>
<tr>
<td>Fluoroscopy (e.g. Pelvic angiography)</td>
<td>10 mGy/minute</td>
</tr>
</tbody>
</table>

*10 mGy = 1 rad

J Trauma, 48: 354-357, 2000

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Estimated conceptus dose from various medical x-ray imaging procedures

<table>
<thead>
<tr>
<th>Examination</th>
<th>Dose Level</th>
<th>Typical Conceptus Dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra-abdominal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head CT</td>
<td>Standard</td>
<td>0</td>
</tr>
<tr>
<td>Chest CT</td>
<td>Standard</td>
<td>0</td>
</tr>
<tr>
<td>Pulmonary embolus</td>
<td>Standard</td>
<td>0.2</td>
</tr>
<tr>
<td>CT angiography of coronary arteries</td>
<td>Standard</td>
<td>0.1</td>
</tr>
<tr>
<td>Abdominal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdominal, routine</td>
<td>Standard</td>
<td>4</td>
</tr>
<tr>
<td>Abdominalgia, routine</td>
<td>Standard</td>
<td>29</td>
</tr>
<tr>
<td>CT angiography of aorta (client through pelvis)</td>
<td>Standard</td>
<td>38</td>
</tr>
<tr>
<td>Abdominalgia, some protocol?</td>
<td>Reduced</td>
<td>10</td>
</tr>
</tbody>
</table>

From Single CT

<table>
<thead>
<tr>
<th>Examination</th>
<th>Typical Conceptus Dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical spine (AP, lateral)</td>
<td>0.001</td>
</tr>
<tr>
<td>Femur</td>
<td>0.003</td>
</tr>
<tr>
<td>Chest (PA, lateral)</td>
<td>0.002</td>
</tr>
<tr>
<td>Thoracic spine (AP, lateral)</td>
<td>0.003</td>
</tr>
<tr>
<td>Abdomen (AP)</td>
<td>2.5</td>
</tr>
<tr>
<td>2.5-mm patient thickness</td>
<td>1</td>
</tr>
<tr>
<td>3.5-mm patient thickness</td>
<td>3</td>
</tr>
<tr>
<td>Lumbar spine (AP, lateral)</td>
<td>1</td>
</tr>
<tr>
<td>IVP</td>
<td>6</td>
</tr>
<tr>
<td>Small bowel study</td>
<td>7</td>
</tr>
<tr>
<td>Double-contrast barium IVP study</td>
<td>7</td>
</tr>
</tbody>
</table>

From Radiographic and Fluoroscopic Exams

From CT and limited IVP procedure

Fetus Directly in the X-ray Beam
Estimated dose < 10 mGy (1 rad)

- Radiologist should discuss benefits and risks of the procedure with referring physician
- Other imaging technique should be considered
- If x-ray exam is necessary, document need in medical record
- Radiologist explain procedure to patient and assure that risk to fetus is small
- Radiation dose should be kept as minimal as possible
Fetus directly in the x-ray beam
Estimated dose between 10 - 50 mGy (1-5 rad)

• Radiologist and referring physician should discuss other imaging options
• If x-ray exam is necessary, patient should be involved in decision to proceed with examination
• Patient should be informed of the risks and benefits and may be required to sign a consent form
• Document the need in medical record

Fetus directly in the x-ray beam
Estimated dose > 50 mGy (5 rad)

• Formal calculation of the dose to be conducted by a radiation physicist or equally qualified individual
• Patient should be counseled about the risk to the fetus
• Document the need in medical record
# Fetal Effects from Low-Level Radiation Exposure

<table>
<thead>
<tr>
<th>Effect</th>
<th>Threshold Dose at Which an Effect Was Observed (mSv)</th>
<th>Initial Studies</th>
<th>Human Studies</th>
<th>Absolute Risk (Sv)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fetal limb</td>
<td>8–8</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>If the exposure occurs, it is thought to develop into microcephaly or microphthalmia.</td>
</tr>
</tbody>
</table>
| Postimplantation             | 8–54                                                | 10              | 200           | ND                 | Aromatase inhibitors were used to prevent a week 5–6 embryo and a 1 kg fetus (mean) had an incidence rate of 0.045.
| Growth retardation           |                                                     | 50–100          | 10            | ND                 | About 25% of children with small head size were mentally retarded. |
| Neural tube defects          | 10–20                                               | ND              | 100           | 10                 | No increase in childhood incidence was observed for exposure in the first 20 weeks of gestation. |
| Reducation of IQ             | 50–100                                              | ND              | 100           | ND                 | Effects from a dose of 100 mSv are less severe with non-genotoxic. At 100 mSv, no clear reduction in IQ mortality rate (0.02). |
| Childhood cancer             | 0.27                                                 | ND              | ND            | 0.0015             | Latent to the late-onset or very early-onset type of childhood cancer. |

**Key Points**

- Benefits of medical imaging procedures should be weighed as part of risk assessment and consoling patients who are found to be pregnant.
- When the fetus is outside the primary path, the radiation dose exposure is generally negligible.
- When fetus is in the path – careful analysis is required – optimal techniques to be adopted.

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Conclusions

• Radiographic, fluoroscopic and CT examinations in areas of body other than abdomen and pelvis deliver minimal radiation doses to fetus

• Fetal radiation doses from radiographic, fluoroscopic and CT examinations of abdomen and pelvis and from nuclear medicine studies rarely exceeds 25 mGy

• Based on risk data from human in-utero exposures, the absolute risks of fetal effects are small at conceptus doses of 100 mGy and negligible at doses of less than 50 mGy

Useful Resources


• Huda W, et. al., Embryo dose estimates in body CT. AJR. 2010: 194: 874-880.

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Ques #1: What is the typical dose considered as threshold prior recommending to therapeutic abortion?

- Answer: 4. 100 mGy or 10 rad

Reference:
Ques #2: What is the radiation dose to the fetus when the primary radiograph region is outside the pelvic region?

<table>
<thead>
<tr>
<th></th>
<th>1. ~ 10 mGy (~ 1 rad)</th>
<th>2. ~ 0.01 mGy (~ 1 mrad)</th>
<th>3. ~ 1 mGy (&lt; 100 mrad)</th>
<th>4. ~ 0.1 mGy (~ 10 mrad)</th>
<th>5. ~ 100 mGy (10 rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>10%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Answer: 2. ~0.01 mGy (~ 1 mrad)

Reference:
Ques #3: What is the most probable effect due to irradiation during pre-implantation or during 1st trimester?

1. Growth retardation
2. Congenital malformation
3. Severe mental retardation and reduction of IQ
4. Leukemia
5. Prenatal or embryonic death

Answer: 5. Prenatal or Embryonic death

Reference: