Exposure to diagnostic x-rays during pregnancy:

Radiation risks, challenges and recommendations

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$X$-ray exposure and the pregnant patient
Intentional Exposures

Accidental Exposures

Justification of the examination

Communication with the patient

Optimization of the exposure
A program to manage a pregnant patient who requires radiological examination

Step 1: Justification of the examination
Justification of an x-ray examination

To justify an x-ray study, the risks to the unborn child should be known.
Conceptus radiogenic risk

AGE

What is the conception age?

DOSE

What is the estimated conceptus dose?
Is a detailed dose assessment always needed?

No if:

- age less than 2 weeks
- conceptus dose is low
Conceptus doses below 100 mGy should not be considered a reason for terminating a pregnancy.

ICRP Publ. 84

As a result, installation specific measurements and calculations of fetal doses may be necessary if fetal doses are suspected of exceeding 10 mGy.
<table>
<thead>
<tr>
<th>Examination</th>
<th>Conceptus dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skull Radiograph</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Chest Radiograph</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>CT (chest)</td>
<td>&lt; 0.2</td>
</tr>
</tbody>
</table>
Pregnancy and pulmonary embolism

CONCEPTUS DOSE FROM A V/Q STUDY: 0.9-1.8 mGy
CONCEPTUS DOSE FROM CHEST CT: 0.1-0.2 mGy

W. Huda, Pediatr Radiol 35:452-453, 2005
H. Winer-Muram et al., Radiology 224:487-492, 2002
Conclusion: This survey reveals that there is a lack of knowledge of fetal dosimetry in the imaging of pregnant women suspected of having pulmonary embolism.
Rf cardiac ablation procedures and pregnancy

Conceptus dose < 1 mGy

T. Shope, Radiographics, 1996

J. Damilakis, N. Theocharopoulos, K. Perisinakis et al

Circulation 104 : 893-897, 2001
Fluoroscopically-assisted surgical treatment of hip fractures and pregnancy

J. Damilakis, N. Theocharopoulos, K. Perisinakis et al.

Medical Physics 30: 2594-2601, 2003
Conceptus dose from abdominal X-ray examinations

- Abdominal radiography
- IVU*
- Barium Enema
- CT (Abdomen)

Pregnancy and appendicitis

CONCEPTUS DOSE
FROM CT: 30 mGy

L. Wagner and W. Huda, Pediatr Radiol 34:589-590, 2004
J. Fielding and D. Washburn, Journal of Women’s Imaging 7:16-21, 2005

Pregnancy and ureteral stones

Figure from: C. Kalbhen, AJR 178:1285-1286, 2002
Fluoroscopically-assisted surgical treatment of spinal disorders

Conceptus Dose

< 4 mGy provided that the conceptus lies outside the primarily irradiated region

up to 105 mGy when the conceptus is primarily irradiated


N. Theocharopoulos, J. Damilakis et al. Spine 31:239-244, 2006
Filter placement for the prevention of pulmonary embolism is appropriate during pregnancy.

Filter placement is also appropriate in women of childbearing age.

CIRSE, Standards of Practice
Percutaneous inferior vena cava filter placement during pregnancy

- **First trimester**
- **Second trimester**
- **Third trimester**

Conceptus Dose (mGy)

- **Internal Jugular Suprarenal**
- **Internal Jugular Infrarenal**
Percutaneous inferior vena cava filter placement during pregnancy

- **First trimester**
- **Second trimester**
- **Third trimester**

<table>
<thead>
<tr>
<th>Conceptus</th>
<th>Dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral</td>
<td></td>
</tr>
<tr>
<td>Suprarenal</td>
<td></td>
</tr>
<tr>
<td>Infrarenal</td>
<td></td>
</tr>
</tbody>
</table>

- Femoral
  - Suprarenal
  - Infrarenal
Abdominal examinations deliver relatively high doses to the conceptus
Conceptus dose vs. maternal chest thickness (AP chest radiography)

How can we estimate conceptus dose?
CONCEPTUS DOSES NORMALIZED TO AIR KERMA FOR AP AND PA ABDOMINAL EXPOSURES

Conceptus Dose = \( ND \cdot K_{air} \)
Methods for estimating embryo dose from CT studies (Early period of pregnancy)

- Free-in-Air Dose Model (Panzer et al, 1989)
- CTDI Dose Model (Felmlee et al, 1990)

Late pregnancy: $n\text{CTDI}_w$ technique

\[
D = \frac{n\text{CTDI}_{w1}}{n\text{CTDI}_{w2}} \times \frac{\sum_{i=1}^{n} d_i}{n} \times \frac{mAs_1}{mAs_2}
\]

\[
D = \frac{n\text{CTDI}_{w1}}{n\text{CTDI}_{w2}} \times \frac{\sum_{i=1}^{n-k} d_i V_i + V_{n-k}}{n} \times \frac{\sum_{i=n-k+1}^{n} d_i}{mAs_1} \times \frac{\sum_{i=1}^{n-k} V_i + kV_{n-k}}{mAs_2}
\]

A method for estimating conceptus doses from 16 and 64-slice CT examinations

9 months 6 months 3 months 0 months

Work-in-progress
What is the potential risk to the conceptus?

- STOCHASTIC EFFECTS (no dose threshold)
- DETERMINISTIC EFFECTS (dose threshold)

Radiation risks are related to the stage of pregnancy.
<table>
<thead>
<tr>
<th>WEEKS POSTCONCEPTION</th>
<th>RESULT</th>
<th>THRESHOLD (Gy⁻¹)</th>
<th>RISK</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>CONCEPTUS DEATH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-8</td>
<td>MALFORMATIONS</td>
<td>0.1+</td>
<td></td>
</tr>
<tr>
<td>8-15</td>
<td>MENTAL RETARDATION</td>
<td>0.1+</td>
<td>30 IQ points/Gy</td>
</tr>
<tr>
<td>4-36</td>
<td>CARCINOGENESIS</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>0-36</td>
<td>GENETIC EFFECTS</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>
Radiation risk for fatal cancer: 6% per Gy (6% per 1000 mGy)

If the conceptus dose from a diagnostic examination is 10 mGy

the risk of excess childhood fatal cancer is 0.06%
Probability that a child will develop cancer

Conceptus dose (mGy)

Probability of cancer (%)
Step 1: Justification of the examination

Step 2: Communication with the patient
**Reporting dose results**

- A description of the method used to estimate dose
- A table presenting exposure data
- A table presenting conceptus dose estimation
- Radiation protection recommendations
Informed consent forms

J. Fielding and D. Washburn, Journal of Women’s Imaging 7:16-21, 2005
THERE IS A CHANCE THAT A WOMAN WILL GIVE BIRTH TO CONGENITALLY MALFORMED CHILDREN, REGARDLESS OF ANY EXPOSURE TO RADIATION.
Step 1: Justification of the examination

Step 2: Communication with the patient

Step 3: Optimization of the exposure
Reduction of conceptus dose

Conceptus dose is dependent on conceptus depth

<table>
<thead>
<tr>
<th>Conceptus Depth (cm)</th>
<th>Prevoid</th>
<th>6-10 (8.4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Postvoid</td>
<td>4-8 (5.8)</td>
</tr>
</tbody>
</table>

Reduction of conceptus dose: MDCT and $z$-overscanning

Although the conceptus is primarily irradiated, it is not depicted on the MDCT images.

In MDCT, the tissue volume of patient irradiated differs from the volume imaged.

Reduction of conceptus dose

**Reduction of fluoroscopy time**

‘Accidental embryo irradiation during barium enema examinations:

Conceptus doses can approach or exceed 50 mGy, especially if the fluoroscopy time exceeds 7 minutes’

*J. Damilakis, K. Perisinakis et al. Investigative Radiology 31:242-245, 1996*
Intentional Exposures

Accidental Exposures

Justification of the examination

Communication with the patient

Optimization of the exposure
Accidental exposures

S CARE
Accidental irradiation:
A different case

Before the examination
No pre-examination actions

During the examination
No radiation protection measures

After the examination
We do not know the exact technical parameters
anxiety, consideration of abortion
Physicians’ perception of risk associated with diagnostic x-rays

Physicians’ Perceptions of Teratogenic Risk Associated with Radiography and CT During Early Pregnancy

OBJECTIVE. The objective of our study was to determine family physicians’ and obstetricians’ perceptions of the risk of major fetal malformations associated with exposure to radiation from radiography and CT during early pregnancy.

MATERIALS AND METHODS. Structured questionnaires were sent to 400 family physicians and 100 obstetricians selected randomly across Ontario, Canada. The physicians were informed about the 1-3% baseline risk for major malformations and were asked about their perceptions of the risk to the fetus associated with an abdominal radiograph and an abdominal CT scan during early pregnancy and whether they would recommend a therapeutic abortion after such exposure.

RESULTS. Fifty-five percent (218/400) of the family physicians and 69% (69/100) of the obstetricians responded to our questionnaire. Forty-four percent of family physicians estimated the risk associated with an abdominal radiograph to be 5% or greater, and 61% estimated the risk associated with an abdominal CT scan to be 5% or greater. Eleven percent of obstetricians estimated the risk associated with radiography to be 5% or greater (p = 0.005), and 34% estimated the risk associated with CT scans to be 5% or greater (p < 0.001). Among family physicians, 1%

CONCLUSION. Our survey shows that physicians who care for pregnant women perceive the teratogenic risk associated with an abdominal radiograph and an abdominal CT scan to be unrealistically high during early pregnancy. This misperception could lead to increased...
40% of family physicians and 70% of obstetricians recommended abortion for women exposed to diagnostic x-rays in early pregnancy.

Fink D, Glick S. Harefuah 124:717-719, 1993
How can we avoid accidental irradiation?
Investigation of the reproductive status of a female of childbearing age prior to x-ray imaging.

It is prudent to consider as pregnant any woman of reproductive age presenting herself for an X-ray examination at a time when a menstrual period is overdue, or missed, unless there is information that precludes a pregnancy.

(ICRP Publication 84, 2000)
'PLEASE INFORM THE STAFF BEFORE YOUR X-RAY EXAMINATION IF YOU THINK YOU MAY BE PREGNANT'
Avoid accidental irradiation

Evaluate conceptus dose for abdominal studies

Conceptus doses below 100 mGy, should not be considered a reason for abortion
Pregnant employees working in diagnostic radiology
Dose limits

Program to evaluate and control conceptus dose

Declaration of pregnancy
Evaluation of the working conditions
Conceptus dose anticipation
Work restrictions
Counseling
Dose monitoring
‘Once pregnancy has been declared, the conceptus should be protected by applying a supplementary equivalent dose limit to the surface of the woman’s abdomen of 2 mGy for the remainder of the pregnancy.’

1990 Recommendations of the ICRP, Publication 60

2 mGy = 200 mrad = 200 mrem (for X-rays)
'The working conditions of a pregnant worker, after the declaration of pregnancy, should be as such to make it unlikely that the additional dose to the conceptus will exceed about 1 mGy during the remainder of pregnancy.'

Annals of the ICRP, Publication 84, 2000

1 mGy = 100 mrad = 100 mrem (for X-rays)
As soon as a pregnant woman informs the undertaking, in accordance with national legislation and/or national practice, of her condition, the protection of the child to be born shall be comparable with that provided for members of the public. The conditions for the pregnant woman in the context of her employment shall be such that the equivalent dose to the child to be born will be ALARA and that it will be unlikely that this dose will exceed 1 mGy during at least the remainder of the pregnancy.
US regulations
Code of federal regulations

‘...ensure that the dose to an embryo/fetus during the entire pregnancy, due to occupational exposure of a declared pregnant woman, does not exceed 5 mGy.’

‘...make efforts to avoid substantial variation above a uniform monthly exposure rate to a declared pregnant woman.’

‘U.S. Nuclear Regulatory Commission’

5 mGy = 500 mrad = 500 mrem (for X-rays)
Dose limits

Program to evaluate and control conceptus dose

Declaration of pregnancy

Evaluation of the working conditions

Conceptus dose anticipation

Work restrictions

Counseling

Dose monitoring
Voluntary declaration of pregnancy

A FEMALE WORKER SHOULD, IN BECOMING AWARE THAT SHE IS PREGNANT, NOTIFY THE EMPLOYER IN ORDER THAT HER WORKING CONDITIONS MAY BE MODIFIED IF NECESSARY.
Dose limits

Program to evaluate and control conceptus dose

Declaration of pregnancy

Evaluation of the working conditions

Conceptus dose anticipation

Work restrictions

Counseling

Dose monitoring
Take into account:

- Doses received during the previous years by the woman or other workers doing a similar job

1 mSv  5 mSv
‘The employer shall provide pregnant workers the option of a mutually agreeable work assignment, without loss of pay or promotional opportunity such that further occupational radiation exposure is unlikely.’
Dose limits

Program to evaluate and control conceptus dose

Declaration of pregnancy

Evaluation of the working conditions

Conceptus dose anticipation

Work restrictions

Counseling

Dose monitoring
**Conceptus dose anticipation**

A. Divide the space around table into two grids

B. Measure scatter air kerma rate at each cell
C. Derive DAP-normalized air kerma values by dividing the measured dose rates by the DAP rate of the exposure.

D. Plot isodose curves around the table for each projection involved in a study.

E. Use measurements and conversion factors provided by literature* to calculate conceptus dose at the first, 2nd and 3rd trimesters.

*J. Damilakis, A. Tzedakis, L Sideri et al., Medical Physics, 29:2641-48, 2002

J. Damilakis, K. Perisinakis, et al., JCE 16:1-8, 2005
Conceptus dose prior to declaration

PREGNANT ??
What is the dose received by my baby during the last 5 weeks?
Conceptus dose anticipation: Iso-dose curves

DAP-normalized doses for heart PA, LAO and RAO projections

Conceptus dose anticipation: Iso-dose curves

DAP-normalized doses for lumbar spine LAT and AP projections

Fig. from: N. Theocharopoulos, J. Damilakis et al. Spine 15;29:2573-80, 2004
## Data Collection Form

**Department of Medical Physics**

<table>
<thead>
<tr>
<th>Date:</th>
<th>Type of procedure:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Staff member name:</th>
<th>Patient name:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Week of gestation:</th>
<th>Apron thickness (mm lead equivalent):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AP fluorescence</th>
<th>Tube voltage (kVp):</th>
<th>DAP (cGy cm²) or estimated percent fraction of total DAP:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>LAO fluorescence</th>
<th>Tube voltage (kVp):</th>
<th>DAP (cGy cm²) or estimated percent fraction of total DAP:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>RAO fluorescence</th>
<th>Tube voltage (kVp):</th>
<th>DAP (cGy cm²) or estimated percent fraction of total DAP:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

Total DAP of the procedure (cGy cm²):

*Please provide either the DAP fractions per projection and the total DAP of the procedure or the individual DAP values per projection.*

● Please mark your position during PA, LAO and RAO fluoroscopy

### Diagrams

![Diagram 1](chart1.png)

![Diagram 2](chart2.png)

![Diagram 3](chart3.png)

**Comments:**
Dose limits
Program to evaluate and control conceptus dose

Declaration of pregnancy
Evaluation of the working conditions
Conceptus dose anticipation
Work restrictions
Counseling
Dose monitoring
Workload determination

DOSE PRIOR TO DECLARATION
0.3 mGy

DOSE ALLOWED FOR EACH WEEK OF THE REMAINING GESTATION PERIOD

Anticipated conceptus dose: 0.02 mGy/procedure (1st trimester)
0.01 mGy/procedure (2nd and 3rd trimester)

\[
\frac{5 - 0.3}{35} = 0.134 \text{ mGy/week} \quad \frac{0.134}{0.02} = 6.7 \quad \frac{0.134}{0.01} = 13.4
\]

MAXIMUM WORKLOAD

6 PROCEDURES/WEEK (1st trimester)
13 PROCEDURES/WEEK (2nd and 3rd trimester)
Dose limits

Program to evaluate and control conceptus dose

Declaration of pregnancy
Evaluation of the working conditions
Conceptus dose anticipation
Work restrictions
Counseling
Dose monitoring
Counseling of the expectant mother

Description of possible effects of exposure

Radiation protection recommendations

Description of factors affecting staff doses

Description of possible effects of exposure
The scattered radiation is not uniform

Using isodose curves, the pregnant worker should select a position that allows her to do her job properly and decrease her dose.
Counseling of the expectant mother

Description of possible effects of exposure

Description of factors affecting staff doses

Radiation protection recommendations
Protective devices
Maternity aprons
Counseling of the expectant mother

Description of factors affecting staff doses

Radiation protection recommendations

Description of possible effects of exposure
Radiogenic risk

Radiation risk for fatal cancer: 6% per Gy (6% per 1000 mGy)

If the conceptus dose is 5 mGy the risk of excess childhood fatal cancer is 0.03%.

Background risk of childhood cancer: 0.3% (NCI-SEER 1994)
FOR EMPLOYEES OF CHILDBEARING AGE:

KEEPING EXPOSURE TO PELVIS AREA AT THE LOWEST PRACTICABLE LEVELS MAY BE BENEFICIAL DURING THE FIRST WEEKS OF GESTATION WHEN THE WOMAN IS UNAWARE OF HER PREGNANCY AND THE CONCEPTUS IS VULNERABLE TO RADIATION.
Counseling of the expectant mother

Working with radiation?
... No. Why should I risk my health?
Dose limits
Program to evaluate and control conceptus dose

Declaration of pregnancy
Evaluation of the working conditions
Conceptus dose anticipation
Work restrictions
Counseling
Dose monitoring
Dose monitoring
Messages to take home (part II)

✓ **US REGULATIONS:** Conceptus dose limit for pregnant workers: 5 mGy during the entire pregnancy

✓ **DECLARATION OF PREGNANCY** is very important because dose recommendations are based on the declared term of the pregnancy

✓ Determination of the **MAXIMUM WORKLOAD** allowed for each week of the remaining gestation period is necessary for fluoroscopic procedures