Radiation Therapy with a Pregnant Patient: Background and Case Report

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University of Wisconsin - Madison
Learning Objectives

• Review Sources of Peripheral Dose
• Review Effects of Radiation on the Developing Fetus
• Review Treatment Planning and Patient Management Strategies for a Pregnant Brain Tumor Patient
SOURCES OF PERIPHERAL DOSE
Sources of Peripheral Dose

• Peripheral dose can originate from:
  • Patient scatter
  • Collimator scatter
  • Direct Leakage
Sources of Peripheral Dose

- Near field:
  - Patient Scatter
- Further away:
  - Direct Leakage
- Constant level:
  - Collimator Scatter

Kry et al, 2009, AAPM
Sources of Peripheral Dose

- Near field:
  - Patient Scatter
- Further away:
  - Direct Leakage
- Constant level:
  - Collimator Scatter

- Most important factors:
  - Field size, proximity
  - (depth, energy matter much less)
Sources of Peripheral Dose

- Physical Wedges
  - Increase peripheral dose 200-400% (Li, IJROBP 1997)

- MLC
  - Tertiary MLC (Varian design) functions as extra shield, reduces peripheral dose

- Neutrons
  - e.g., Photon beam energies above 10MV
Sources of Peripheral Dose

- IMRT (vs. 3D-Conformal)
  - Similar Collimator Scatter
  - Smaller fields – reduced Patient Scatter
  - More MU’s – increased Direct Leakage
RADIOBIOLOGICAL EFFECTS ON THE DEVELOPING FETUS
Fetal Effects of Radiation Exposure

Main references


Hall and Giaccia, Radiobiology for the Radiobiologist
Fetal Effects of Radiation Exposure

• Effects on the fetus
  • Lethality
  • Malformations
  • Drop in IQ
  • Cancer Induction

• Naturally high occurrence of embryonic loss during first month
  • Doses as low as 10 cGy may lead to significant embryonic death
  • “All-or-Nothing” effect
    • Embryo is lost or develops normally
    • Usually goes unnoticed by mother
Fetal Effects of Radiation Exposure

- Effects on the fetus
  - Lethality
  - Malformations
  - Drop in IQ
  - Cancer Induction

- 3% baseline risk of neonatal malformations
  - Induced Small Head Size (microcephaly) is most pronounced in humans
  - Threshold of 10-20 cGy during weeks 2-15
  - After week 15, threshold is at least 1 Gy+
Fetal Effects of Radiation Exposure

- Effects on the fetus
  - Lethality
  - Malformations
  - Drop in IQ
  - Cancer Induction

- Concern: weeks 8-25, doses over 10 cGy may reduce IQ
  - Confirmed over 50 cGy
  - Risk at 1 Gy (100 cGy)
    - 40% during weeks 8-15
    - 10% during weeks 16-25
Fetal Effects of Radiation Exposure

- Effects on the fetus
  - Lethality
  - Malformations
  - Drop in IQ
  - Cancer Induction

- Large uncertainty
  - Absolute risk may be 0.06% per 1 cGy
    - (6% per Gy)

- Baseline risk of lethal cancer thru age 19:
  - 0.2-0.3%
    - Risk after 1 cGy: 0.3-0.4%
Fetal Effects of Radiation Exposure

- Risks for low doses

<table>
<thead>
<tr>
<th>TABLE V. Risk associated with irradiation during fetal development (After Brent, Ref. 29).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preimplantation</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>Postconception time, days</td>
</tr>
<tr>
<td>Postconception time, weeks</td>
</tr>
<tr>
<td>Effects</td>
</tr>
<tr>
<td>Lethality</td>
</tr>
<tr>
<td>Gross malformations</td>
</tr>
<tr>
<td>Growth retardation</td>
</tr>
<tr>
<td>Mental retardation</td>
</tr>
<tr>
<td>Sterility</td>
</tr>
<tr>
<td>Cataracts</td>
</tr>
<tr>
<td>Other neuropathology</td>
</tr>
<tr>
<td>Malignant disease</td>
</tr>
</tbody>
</table>

- No observed effect.
+ Demonstrated effect.
++ Readily apparent effect.
+++ Occurs in high incidence.

Stovall et al, AAPM TG-36 (1995)
**Fetal Effects of Radiation Exposure**

- Risks for low doses

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**Table V: Risk associated with irradiation during fetal development (After Brent, Ref. 29)**

<table>
<thead>
<tr>
<th>Postconception time, days</th>
<th>Preimplantation</th>
<th>Organ sensitivity</th>
<th>Mid-fetal</th>
<th>Late fetal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 2</td>
<td>+++</td>
<td>+++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>2 to 7</td>
<td>+++</td>
<td>+++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>8 to 50</td>
<td>++</td>
<td>+++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>16 to 25</td>
<td></td>
<td>**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;175</td>
<td></td>
<td>**</td>
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Fetal Effects of Radiation Exposure

- Risks for low doses

<table>
<thead>
<tr>
<th>Dose (Gy)</th>
<th>Risk</th>
</tr>
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<tbody>
<tr>
<td>&lt;0.05</td>
<td>Little risk of damage</td>
</tr>
<tr>
<td>0.05-0.10</td>
<td>Risk uncertain</td>
</tr>
<tr>
<td>0.10-0.50</td>
<td>Significant risk of damage during first trimester</td>
</tr>
<tr>
<td>&gt;0.50</td>
<td>High risk of damage during all trimester</td>
</tr>
</tbody>
</table>

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Fetal Effects of Radiation Exposure

• Risks for low doses

<table>
<thead>
<tr>
<th>Absorbed dose to conceptus, mGy, above natural background</th>
<th>Probability that child will have no malformation, %</th>
<th>Probability that child will not develop cancer (age 0-19), %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>97</td>
<td>99.7</td>
</tr>
<tr>
<td>0.5</td>
<td>97</td>
<td>99.7</td>
</tr>
<tr>
<td>1.0</td>
<td>97</td>
<td>99.7</td>
</tr>
<tr>
<td>2.5</td>
<td>97</td>
<td>99.7</td>
</tr>
<tr>
<td>5</td>
<td>97</td>
<td>99.7</td>
</tr>
<tr>
<td>10</td>
<td>97</td>
<td>99.6</td>
</tr>
<tr>
<td>50</td>
<td>97</td>
<td>99.4</td>
</tr>
<tr>
<td>100</td>
<td>(close to 97)</td>
<td>99.1</td>
</tr>
</tbody>
</table>

ICRP Report 84 (2000)
CASE REPORT: PREGNANT PATIENT WITH RT FOR BRAIN RESECTION CAVITY
27yo pregnant woman presents in gestational week 8. WHO Grade 3 Astrocytoma, resected after discovery.

Postpone RT until gestational week 16+. 
Case Report: Prescription

1.8 Gy x 28fx = 50.4 Gy Primary
1.8Gy x 5fx = 9 Gy Boost
Standard brain planning constraints
CT Simulation

- Standard CT techniques/protocols
- Patient wears lead apron immediately inferior to scan region
  - >90% attenuation of CT kV scatter (Bushberg, 3rd Ed, 2012)
- No Iodine Contrast – follow your Radiology protocols (Webb, Eur Radiol 15, 1234–1240 (2005))
- CT doses are very low when scan range does not include fetus
  - If you scan through the fetus, will be similar to CT Dose Index (CTDI) order of magnitude; CTDI is not patient dose (Angel et al., Radiology 249, 220–227 (2008))
Simulation Points of Interest

- Assess dose to points covering range of fetal distances
  - Symphysis – Fundus
  - Fundus: 1 cm/week superior
- Get distances from target volumes to points
  - Measure from fixed point in CT sim (BB on chin)
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Treatment Planning

- Four treatment plans to test various strategies

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<tbody>
<tr>
<td><strong>1</strong></td>
<td><strong>2</strong></td>
</tr>
<tr>
<td>Varian TrueBeam</td>
<td>Varian TrueBeam</td>
</tr>
<tr>
<td>6 MV Enhanced Dynamic Wedges</td>
<td>6 MV Step-and-Shoot IMRT</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td><strong>4</strong></td>
</tr>
<tr>
<td>Varian TrueBeam</td>
<td>Accuray TomoTherapy</td>
</tr>
<tr>
<td>6 MV-FFF Step-and-Shoot IMRT</td>
<td>6 MV-FFF Helical IMRT</td>
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</tbody>
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Treatment Planning: TrueBeam

- Use MLC field shaping (even for square fields)
- Rotate collimator 90 degrees for Varian
- Distal jaws/MLC are usually X-direction, so col90 puts them inline with fetus

Treatment Planning: TrueBeam

- Use MLC field shaping (even for square fields)
- Rotate collimator 90 degrees for Varian
  - Distal jaws/MLC are usually X-direction, so col90 puts them inline with fetus
- Place isocenter as cranial as possible (maximize leakage distance)
- No Physical wedges

Treatment Planning: TrueBeam

- Stick to 6 MV if possible
  - 10 MV at most; avoid neutron production
- If 6 MV-FFF exists, may lead to less leakage
- Limit beam angles and apertures
  - Step-and-Shoot IMRT, 3-5 apertures
- Limit couch angles
  - No beams toward fetus!
Treatment Planning: TomoTherapy

- Hard to make generalized strategies
  - Interplay between pitch, jaw width, and modulation factor
- Make a minimum-MU plan
- Push for a low “Mod Factor” in the plan
- Use Dynamic Jaws
Initial Dose Estimates

- Estimate fetal dose from published literature

- Varian Photons

- Varian Electrons

- TomoTherapy (not as detailed)
# Initial Dose Estimates

- Estimate fetal dose from published literature
- Extrapolation may be required
- Adjust for known modulation

<table>
<thead>
<tr>
<th></th>
<th>1: TrueBeam 6MV EDW</th>
<th>2: TrueBeam 6MV IMRT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range 0.45 – 0.95 cGy</td>
<td>Range 0.47 – 0.99 cGy</td>
</tr>
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<table>
<thead>
<tr>
<th></th>
<th>3: TrueBeam 6MV-FFF IMRT</th>
<th>4: TomoTherapy IMRT</th>
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<tbody>
<tr>
<td></td>
<td>Range 0.57 – 1.20 cGy (from 6MV data)</td>
<td>Range 2.3 – 4.9 cGy (based on 30 Gy-liter target; really 18 Gy-liter)</td>
</tr>
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Measure Dose in Phantom

- Measure dose in phantom with real patient geometry
- Measure doses at points of interest
- TLD-100 chips work well, readily available
- Also use ion chambers
  - Be careful with leakage signal
**Measure Dose in Phantom**

- **RANDO with solid water slabs**
- **Farmer-type chamber at Umbilicus distance**
- **TLDs (3x per point) under 3cm bolus**
- **Upper Fundus**
- **Umbilicus**
- **Fundus at Sim**
- **Pubic Symphysis**
Measure Dose in Phantom

Why Bolus?

Peripheral PDD

6MV
Jaw 10cm
Varian Clinac

Kry, 2006
**Measured Dose in Phantom**

- All measured doses were highest at Upper Fundus point of interest

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Measured Dose in Phantom

• All measured doses were highest at Upper Fundus point of interest

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<td>1.9 – 2.6 cGy</td>
<td>1.6 cGy</td>
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• All plans deemed acceptable
External Shielding

• Use External Shielding if required based on measurements

Mayo, TG-36

Owrangi, JACMP 2016
IGRT Considerations

- Avoid MV ports (very large fields)
- If C-arm system, use ortho kV-kV if possible
- CBCT peripheral doses not well studied
- Extrapolations for TrueBeam based on published literature
  - TrueBeam Head: 0.0003 – 0.0006 cGy/scan
  - TrueBeam Thorax: 0.005 cGy/scan
- Surface guidance if available
Report and Consent

•Physicist needs to write up all this information in patient chart
  • Fetal dose estimates, with references
  • Fetal dose measurements
  • Estimated effects on fetus, with references
•Discuss with patient and only then obtain full informed consent

AAPM TG-36 Consent Guidance
(a) anticipated dose to fetus resulting from therapy,
(b) comparison to fetal radiation dose owing to naturally occurring radiation,
(c) inability to distinguish between radiation-caused anomalies in the child and those that occur naturally,
(d) rate of natural occurrence of abnormalities,
(e) any anticipated increase of risk of fetal abnormality resulting from radiation therapy to this patient,
(f) citations and statements from authoritative reports regarding recommendations for or against therapeutic abortion in various situations,
(g) written indication that the patient understands the discussion, with signature, and
(h) presence of a credible witness to attest that the patient understood the discussion, with signature of the witness.
• Transition to “normal care”
  • Treat per plan
  • Monitor IGRT
  • Normal weekly checks