Treatment Planning Skills That a Physicist Should Know

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Conflict of Interest

- Nothing to disclose
Learning Objective

- To familiarize with a variety of modern photon beam radiotherapy techniques
- To understand the workflow for treatment planning and factors affecting plan quality
- Conventional radiotherapy requires to achieve a uniform dose distribution inside the target volume and a dose as low as possible in the healthy tissues surrounding the target
- SBRT is becoming a standard for radiotherapy and RTOG protocols for SBRT treatment planning
- SRS/SRT planning and associated RTOG Guidelines
Treatment Planning Resource

- Workshop
- Training Courses
- Colleagues/coworkers
- Some websites: econtour.com, prowork.com, etc.
Photon Beam Characteristics

- PDD vs Energy
Photon Beam Characteristics

- **Profile vs Field Size**
  - Single beam penumbra ~ 7-8 mm, from 80% to 20% ➔ iso-dose lines ~ 10%/mm
  - VMAT/IMRT isodose lines are subjected to this radiation physics
  - Multiple beams make the beam penumbra shallower
Radiation Oncology Workflow

Consultation

Patient immobilization

CT scan
- 4D CT

Initial Data Form

Treatment planning

Dose delivery

Dose delivery

Dose delivery

Dose delivery

Follow-up
Treatment Planning

- **Prescription:**
  - Convention vs SRS/SBRT
  - Patient specific planning requirements
  - What to compromise if you can not achieve planning requirements
  - Uniform dose in PTV important?
  - Surrounding structure sparing more important than PTV coverage?
  - What is Rx dose and daily fractional dose?
What do we need in planning stage?

- Target and critical structure delineation
  1. Anatomy:
     - Scout image
     - Dynamic scanning
     - Gated acquisition
       i. Functional information, e.g. important brain areas, functional lung, bioimaging for tumor
       ii. Registration methods; data communication; new image modalities – multimodality imaging; registration
  2. RTOG target and OARs atlas for different sites
Breast Cancer

- RTOG target and OARs atlas for breast cancer
  - Breast CTV
  - PTV=CTV+5mm
  - Lumpectomy GTV
  - Chestwall CTV
  - Regional nodal volumes
  - Ipsilateral lung, heart, and contralateral breast

Many studies show that toxicities were associated with dose inhomogeneity:

- Both acute and long term toxicities such as moist desquamation, pain, breast discomfort and breast hardness

Randomized clinical trials:


- 306 patients were randomized to 2D or 3D IMRT
- 2D-arm patients were 1.7 times higher than IMRT patients to have changes in breast appearance
Randomized clinical trials:


- 358 patients were randomized in a multicenter double-blind clinical trial with either IMRT or 2D treatment planning
- Moist desquamation in the IMRT group was 31.2% vs 47.8% (p=0.002)
## Breast Cancer – Dose Constraint to Target and OARs

<table>
<thead>
<tr>
<th>Organ</th>
<th>Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest Wall</td>
<td>V90 ≥ 90.0%</td>
</tr>
<tr>
<td>Breast</td>
<td>V100 ≥ 90.0%</td>
</tr>
<tr>
<td></td>
<td>V95 ≥ 95.0%</td>
</tr>
<tr>
<td></td>
<td>V105 ≤ 40.0%</td>
</tr>
<tr>
<td></td>
<td>V110 ≤ 10.0%</td>
</tr>
<tr>
<td>IMN Nodes</td>
<td>V80 ≥ 100.0%</td>
</tr>
<tr>
<td>SCV</td>
<td>V90 ≥ 90.0%</td>
</tr>
<tr>
<td>Ax Nodes</td>
<td>V90 ≥ 90.0%</td>
</tr>
<tr>
<td>Contralateral Breast</td>
<td>V5Gy ≤ 15.0%</td>
</tr>
<tr>
<td>Ipsilateral Lung</td>
<td>V20Gy ≤ 45.0%</td>
</tr>
<tr>
<td></td>
<td>V30Gy ≤ 35.0%</td>
</tr>
<tr>
<td>Whole Lung</td>
<td>V20Gy ≤ 25.0%</td>
</tr>
<tr>
<td></td>
<td>V30Gy ≤ 20.0%</td>
</tr>
<tr>
<td>Heart</td>
<td>V5Gy ≤ 40.0% (≤ 50.0% for left-sided tumors)</td>
</tr>
<tr>
<td></td>
<td>V20Gy ≤ 20.0%</td>
</tr>
</tbody>
</table>
Breast Cancer - Fluence
In conclusion, 2TARC was shown to be the optimal treatment technique amongst the studied techniques for patients with left-sided breast cancer after BCS, if they chose the photon therapy.

The doses to OARs were shown to increase significantly for the patients with inner quadrant tumor.
# Breast Cancer - Doses to OARs

![Image of breast cancer treatment](image_url)

## Table 2
Comparison of the doses to OARs (Plan A: 1ARC/Plan B: 2TARC/Plan C: 4MRT, paired T test).

<table>
<thead>
<tr>
<th>OAR</th>
<th>Plan A</th>
<th>Plan B</th>
<th>Plan C</th>
<th>P value</th>
<th>A vs B</th>
<th>B vs C</th>
<th>A vs C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung Right</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dose (Gy)</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>0.000</td>
</tr>
<tr>
<td>Spinal cord</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dose (Gy)</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>0.000</td>
</tr>
<tr>
<td>Breast Right</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dose (Gy)</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>0.023</td>
</tr>
<tr>
<td>Lung Left</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V5 (%)</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>0.206</td>
</tr>
<tr>
<td>V10 (%)</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>0.895</td>
</tr>
<tr>
<td>V20 (%)</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>0.047</td>
</tr>
<tr>
<td>Heart</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V5 (%)</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>0.070</td>
</tr>
<tr>
<td>V10 (%)</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>0.702</td>
</tr>
<tr>
<td>V20 (%)</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>0.525</td>
</tr>
<tr>
<td>Body</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>V5 (%)</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>mean ± SD</td>
<td>max/mean/median</td>
<td>0.047</td>
</tr>
</tbody>
</table>

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**Note:** The table compares the doses to various OARs (Organs at Risk) across different treatment plans. The P values indicate statistical significance in dose comparisons between the plans. For instance, the Lung Right dose is compared across Plan A, Plan B, and Plan C, with the P value showing a significant difference between Plan B and Plan C, but not between Plan A and Plan B, and Plan A and Plan C.
Breast Cancer – VMAT
Breast Cancer - VMAT
- Bolus for optimization
The optimization is performed in 4 resolution levels.
The number of control points does not change during the optimization. It is set at the very beginning of optimization.
The initial MLC shapes are conformed to the targets.
The initial dose rates are equal for all dose calculation segments.
Larger MLC changes are available during the earlier levels. The size of the MLC adjustments diminish as the optimization progresses through the levels.
The DVH is equally accurate for OARs and targets from the very beginning of optimization.
Only the calculation directions follow the multi-resolution scheme.
The dosimetric accuracy increases with the resolution level.
Control points which “belong” to a calculation direction are used to calculate fluence. This is used for a dose calculation from the calculation direction.
Optimization - Calculation
Comparison in optimization with and without levels hold

- 5 patients were included
- PTV (Min Dose, Max Dose, Mean Dose)
- Dose to critical structures (heart, ipsilateral lung, contralateral lung)

<table>
<thead>
<tr>
<th>Dose to Target/OARs</th>
<th>PTV (Rx:4500cGy)</th>
<th>Heart</th>
<th>Ipsilaterial Lung</th>
<th>Contralateral Lung</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Mean</td>
<td>Min</td>
</tr>
<tr>
<td>Without levels hold</td>
<td>3663</td>
<td>5303</td>
<td>4888</td>
<td>144.9</td>
</tr>
<tr>
<td>With levels hold</td>
<td>3524</td>
<td>5010</td>
<td>4711</td>
<td>148.2</td>
</tr>
</tbody>
</table>
Sector Avoidance

- To reduce uncertainty including CT number, setup
  - Critical structures
    - e.g. hippocampus during whole-brain radiotherapy prevents cognitive side effects
  - Dental filling material (DFM)
    - The backscatter from the DFM for a single, parallel-opposed fields, and RapidArc treatment technique was found significant
    - The measured backscatter upstream dose from DFM for a single-field was 22% higher than without the DFM, whereas the downstream dose was lower by 14%

Sector Avoidance

- To reduce uncertainty including CT number, setup
  - Hip Prothesis
    - Artifacts cause CT number uncertainty
  - Setup irreproducibility
    - e.g. daily pannus variability in set up, causing Dose differences between planned and re-calculated rectal wall mean dose and the $V_{24Gy}$ were numerically larger in the absence of the avoidance sector for all fractions and for both simulated pannus variations, with maximum changes of 2.6% and 1.3%.

Sector Avoidance – example
-RT super clavicular mass
Head&Neck

- PTV coverage:
  - 95% of PTV covered by 100% Rx
- More than 20 critical structures to contour
- Dose Constraints – RTOG
  - Spinal Cord: Max < 45 Gy, 1cc < 45Gy
  - Brainstem: Max < 55 Gy, 1% <54 Gy
  - Parotid glands: mean dose < 26 Gy
  - Optic structures: Max < 54 Gy
- Example: H&N treatment
  1. Physician wants 72 Gy to target, 59.4Gy to lymph nodes
  2. Meet dose constraints
Head&Neck
Pelvis/Prostate

- **Rectum**
  - D40 ≤ 65 Gy,
  - D30 ≤ 70 Gy,
  - D10 ≤ 75 Gy,
  - Dmax* ≤ 81 Gy (*Dmax = dose to clinically significant volume)

- **Bladder**
  - D30 ≤ 70 Gy,
  - Dmax* ≤ 81 Gy
Brain Metastasis

- **Tolerance doses:**
  - Optic nerves: Max dose < 54 Gy
  - Lens: Max dose < 6 Gy
  - Chiasm: Max dose < 54 Gy
  - Brainstem: Max dose < 54 Gy
  - Eyes: Max dose < 45 Gy
  - Cochlea: Mean dose < 45 Gy
SRS/SBRT Lung Cancer

- RTOG 0813, RTOG 0915
- Prescription: 50Gy/5fx, 48Gy/4fx, 54Gy/3fx
- Dose to target/critical structures (NRG-BR001, Timmerman)
- R50, R100, D2cm
- Couch kick, collimator angle, gantry angle
SRS/SBRT RTOG Guidelines

- Multiple metastatic lesions: NRG-BR001
- SRS/SRT Brain: RTOG 90-05, RTOG 0933
- SRS Spine: RTOG 0631
- SBRT Prostate: RTOG 0938
Plan Evaluation

- PTV coverage is achieved?
  - Define endpoints such as 95% of PTV covered by 100% Rx

- Dose distributions on every CT slice
  - Rx, Max dose, Min dose

- Dose constraints meet the criteria?
  - Dose volume histogram (DVH)

- Refer to AAPM TG-100, TG-275, RTOG guidelines
How to improve the plan

- If the plan is not acceptable, what to do?
  - Image quality
  - Anatomy
  - Beam angle selection
  - Collimator angle selection
  - Sector avoidance
  - Bolus - buildup
  - Base dose plan
  - Single isocenter versus multiple isocenters
Imaging

- Image quality - Artifacts caused by
  - Hip prosthesis
  - Dental filling
  - BBs
  - Patient motions

- Image registration
  - PET/CT
  - MRI
Anatomy

- Variation in target volume and location
- PTV too close to skin
  - a volume at least 3mm away from skin surface
- Geometry limitations
  - PTV and critical structure overlaying
Beam angle selection

- Avoid critical structures
- Maintain large beam separation if possible
- Use shortest pathway to irradiate the tumor
  - Beam angle selection is important if the tumor is not centrally located
Collimator angle
“Exposure of the heart to ionizing radiation during radiotherapy for breast cancer increases the subsequent rate of ischemic heart disease. The increase is proportional to the mean dose to the heart, begins within a few years after exposure, and continues for at least 20 years.”

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Summary

- Review photon beam characteristics
- Present dosimetric skills for treatment planning
  - breast cancer
  - head&Neck cancer
  - SBRT lung cancer, etc.
- Evaluate treatment plans
- Improve treatment plan quality
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Thank you very much!

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