Quality Management and Safety in SBRT

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Quality Management Structure

Quality Oversight Committee (QOC)

Quality Assurance

Quality Control and Planning

Event Reporting And Response System

Quality Improvement

Key Components to be considered for balanced QC / QA Program

- Organization
- Clinical Programs
- Technology
- Environment
- Human Resources
Proactive approach in accident prevention...

- What can go wrong in the process? (Hazard identification)
- How likely is this to happen? (Frequency analysis)
- What are the consequences? (Consequence analysis)

The combination of frequency and consequence tells us the RISK

Prioritization based on risk for placing prevention policies
The first "modern" (model U) Gamma Knife in the US was installed in 1987 in Pittsburgh; however, the prototype Gamma Knife No. 1 was actually shipped to UCLA in 1980s.

**Existing Culture of Quality Matters . . . Earlier technologies at UCLA**

1969 - Gamma Knife
Dr. Leksell and colleagues in Sweden
1980 - First acoustic treatment
1985 - First AVM treatment

UCLA to use unusual radiation "knife" – 1980s

600kV X-Knife Radiosurgery System
1990 – 1996

Early 1990's
UCLA Linac based radiosurgery

First Novalis at UCLA - 1997 - Present
First Generation Exactra IGRT - 2003
Some “knives” are simpler to QA and others are not that simple

- Monoscopic (SNAP)
- Stereoscopic
- EPID – MV Electronic Portal Imaging Device

Some technologies have six or more IGRT methods in one room

- KV Exactrac
  - Monoscopic (SNAP)
  - Stereoscopic
- OBI – KV
  - Static images
  - Fluoro images
  - Cone Beam CT
- EPID – MV Electronic Portal Imaging Device

Frameless ... Monte Carlo ...

- UCLA Frameless Radiosurgery Program
  - Infrared technology, KV X-rays, robotic tabletop
- The UCLA Novalis Tx Extracranial Radiosurgery and SBRT Program
- The first iPlan Monte Carlo Treatment Planning System
- High Definition MLC (HDMLC) Rapid Arc Program
Array of different technologies that will allow for continuous innovation

- ViewRay MR-Cobalt treatment machine
- Philips mMRI Panorama Simulator
- MR-Simulator

- CMC Dielectric-wall accelerator (DWA) compact proton machine
- True-Beam

- Novalis Tx
- Tomotherapy

Planning for Safety should start well before the arrival of the equipment

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1. 6MV
2. 6MV FFF
3. 10MV
4. 10MV FFF
5. 15MV
6. 6MV SRS
7. 10MV SRS (Cones, 2400 MU/min)

Credits:
Tim Solberg
What is different about SRS and SBRT?

- Imaging
  - 4DCT
  - 4DPET
  - Functional MRI
  - Multimodality Imaging (fusion, registration)

4DCT and 4DPET

PET Imaging

- PET System
  - Particle Physics
  - Data Processing
  - Instrumentation
  - Object
    - Corrections
    - Reconstruction
    - Image Registration
    - Patient Motion
      - Attenuation, PVE, etc.
      - Sampling, Interpolation
      - Estimation, Optimization

Reproduced from a presentation by Drs. Dahlbom and Detorie
Some of the images courtesy of Drs. Dahlbom and Detorie.
What is different about SRS and SBRT?

- Treatment Planning
  - Constraints (Tolerances, Bioeffect-based planning)
  - Beam arrangements
  - Small field sizes
  - MLC interplay issues
  - Importance of dose calculation accuracy
Agazaryan, 2010: "Point" is defined as 0.035 cc or less.
The following two dose calculation algorithms account for 3D scatter integration and have been found to perform adequately for lung SBRT.

A. Monte Carlo and Clarkson
B. Pencil Beam and Clarkson
C. Pencil Beam and Convolution/Superposition
D. Monte Carlo and Convolution/Superposition
E. Sliding Window and Batho-Power
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"Algorithms that account for 3D scatter integration such as convolution/superposition have been found to perform adequately in most clinical situations."

How do proposed treatments (SBRT) compare to alternatives?
Can we achieve dose distributions similar to HDR with Rapid Arc?

Can we achieve dose distributions similar to HDR? – NOT YET
Can we achieve "DVHs" similar to HDR? – YES

Two Cylinders Approach - Treatment Plan
95% dose covers PTV, 150% and higher in cylinders, 95%-100% urethra dose

"Hot Shell" vs. SBRT

Other ways of determining where to put the hot spots

Optimization algorithm designed for heterogeneous delivery

Abnormality Index = [(Cho + Cre)/Cit]_{max} - (Normal Value)/Standard Deviation
DVF comparison between original SBRT treatment plan vs. the Plan with 150% and higher hot spots

50% and higher SIB vs. Standard SBRT Plan

Monday – Friday Schedule

Alternating Boost Schedule
Image-Guided Hypofractionated Radiotherapy with Heterogeneous RT delivery and Hormonal Therapy for 9 months for High Risk Localized Prostate Cancer

Phase I

- 5 Gy x 10 = 50 Gy
- 6 Gy x 10 = 60 Gy
- 7 Gy x 10 = 70 Gy

**Treatment duration:** 2 weeks

Dose to 25% target: 75 Gy
N=15

Dose to 25% target: 83 Gy
N=15

Dose to 25% target: 90 Gy
N=15

Phase II: N = 50 at Max Tolerated Dose

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We can plan but can we deliver?

Does delivered dose distribution in agreement with planned distribution?

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**TG 101 – Grid Size recommendation**

**IV.D.3. Calculation grid size**

The calculation grid resolution used in the TPS affects the accuracy of the dose distribution calculated. It has been reported in the literature that a 2 mm resolution grid provides an accuracy of about 5% for the high dose region of an IMRT plan consisting of multiple fields. Another report indicated an accuracy of 5% for an isotropic grid resolution of 4 mm. Chang et al. found a dose difference of 2.5% of the prescribed dose for 2 mm calculation grids as compared to a 1.5 mm grid, rising to 3.0% for 4 mm grids. Their conclusion is that 2 mm grids are required for IMRT procedures, especially in high-dose gradient areas.

Recommendation: SBRT commonly includes extremely high-dose gradients near the boundary of the target and often makes use of IMRT techniques. The panel recommends the use of an isotropic grid size of 2 mm or less. A grid size greater than 5 mm is discouraged for SBRT.
**Absolute and relative dosimetry of the inhomogeneous plans**

<table>
<thead>
<tr>
<th>Plan</th>
<th>Tissue</th>
<th>ABS (Gy)</th>
<th>REL (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan 1</td>
<td>Brain</td>
<td>100.5</td>
<td>1.05</td>
</tr>
<tr>
<td>Plan 1</td>
<td>OAR 1</td>
<td>50.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Plan 1</td>
<td>OAR 2</td>
<td>25.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Plan 2</td>
<td>Brain</td>
<td>101.0</td>
<td>1.01</td>
</tr>
<tr>
<td>Plan 2</td>
<td>OAR 1</td>
<td>51.0</td>
<td>1.02</td>
</tr>
<tr>
<td>Plan 2</td>
<td>OAR 2</td>
<td>25.5</td>
<td>1.03</td>
</tr>
</tbody>
</table>

**Brain Metastasis – PTV 30Gy OAR – 5Gy**

**Dosimetry - EPID Dosimetry - Dose back projected (calculated) in patient CT**

![Dosimetry Image]
Cancer stem cells in subventricular zone targeted radiotherapy of the stem cell niches in adult brain could benefit outcome

GBM = “Stem Cells” – 3 Hybrid Arcs – PTV 60Gy, Boost 24Gy

10 x 4Gy = 40 Gy followed by 5 x 5Gy = 25 Gy SBRT boost to ITV only (Initial shown)
10 x 4Gy = 40 Gy followed by 5 x 5Gy = 25 Gy SBRT boost to ITV only (Boost shown)

Histologically confirmed primary non-metastatic NSCLC
Clinically stage II and III based on AJCC staging

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Clinically stage II and III based on AJCC staging

Can Rapid Arc and Fixed Field IMRT be generalized – Hybrid Arc or just Arc therapy?
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There exists some technological challenges but in the future arc treatments will become combination of Rapid Arc and IMRT

Hybrid Arc is not most generic form itself. Gantry locations and MLC shapes should be decoupled for most generic form of treatments.
AAPM Task Group 101 recommendation for SBRT planning grid size is:

A. Isotropic grid size of 2 mm or finer to achieve better than 1% dosimetric accuracy
B. Smaller than 0.1 mm to achieve better than 0.1% dosimetric accuracy
C. Greater than 5 mm to take advantage of increased volume averaging effect
D. Variable based on the fraction dose
E. Variable based on the planning system


What is different about SRS and SBRT?

- IGRT
  - Accuracy and precision
  - Frequency of imaging, intrafraction motion management
  - Immobilization
  - QC / QA Recommendations and Requirements
TO 101 – Summary of reported achievable accuracies

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Model</th>
<th>Device</th>
<th>Methodology</th>
<th>Estimate</th>
<th>Accuracy</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>Liu, 1994</td>
<td>1994</td>
<td>Philips</td>
<td>MRI</td>
<td>3D</td>
<td>4.5 mm</td>
<td>1.5 mm</td>
<td>1/1000 length</td>
</tr>
<tr>
<td>Haider, 2007</td>
<td>2007</td>
<td>Siemens</td>
<td>MRI</td>
<td>3D</td>
<td>4.5 mm</td>
<td>1.5 mm</td>
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<td>Wang, 2009</td>
<td>2009</td>
<td>Toshiba</td>
<td>MRI</td>
<td>3D</td>
<td>4.5 mm</td>
<td>1.5 mm</td>
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</tr>
</tbody>
</table>

Note: The accuracies are reported in millimeters and refer to the distance between the anatomical landmark and the true position of the tumor.
**IGRT - Not uncommon to have multiple imaging methods in one room**

- **KV Exactrac**
  - Monoscopic (SNAP)
  - Stereoscopic

- **EPID** — MV Electronic Portal Imaging Device

**TG 101 - Summary of published QA recommendations and achievable tolerances**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Phantom</th>
<th>Phantom dose</th>
<th>Imaging system</th>
<th>Imaging system description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td>Alderson</td>
<td>2 Gy</td>
<td>MV EPID</td>
<td>MV EPID, 2 Gy</td>
</tr>
<tr>
<td>2)</td>
<td>Alderson</td>
<td>3 Gy</td>
<td>MV EPID</td>
<td>MV EPID, 3 Gy</td>
</tr>
<tr>
<td>3)</td>
<td>Alderson</td>
<td>4 Gy</td>
<td>MV EPID</td>
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**End to End Test for targeting accuracy**

Pb BB used as hidden target

- Alderson Anthropomorphic Phantom (RSD, Inc.)
• CT scans taken – 3.2 mm helical – 2.5 mm sequential – 1.0 mm sequential – All scans with 500 mm FOV – All scans with 5 IR reflectors

• A treatment plan is generated using the BB at the target AP Port Film Lateral Port Film

End to End Test for targeting accuracy

Following IGRT localization, port films are taken to confirm the BB is at the radiation isocenter (analogous to Lutz test).

AP Port Film Lateral Port Film

There is more to it, especially with two imaging systems based protocols
While 6-D fusion is necessary for initial positioning of the patient a single projection image can be obtained and analysed for estimating translational movements to determine whether full 6-D fusion and patient correction is necessary.

**Stereoscopic and Monoscopic Image Guidance Methods**

While 6-D fusion is necessary for initial positioning of the patient a single projection image can be obtained and analysed for estimating translational movements to determine whether full 6-D fusion and patient correction is necessary.

**Monoscopic Image Guidance Methods**

While 6-D fusion is necessary for initial positioning of the patient a single projection image can be obtained and analysed for estimating translational movements to determine whether full 6-D fusion and patient correction is necessary.
Patient intra-fraction motion was monitored via dual kV X-ray projection images obtained before each treatment beam arc.

The intra-fraction translations and rotations were quantified based on 6D fusion results comparing a pair of oblique images to dynamically generated DRRs from the reference CT using 2D-3D registration algorithm.

These were compared to the results from 2D-2D fusion of single images, each time assuming the complementary pair was not obtained.

The analysis was applied to 630 X-ray images from 27 spinal radiosurgery patients with 34 treatment targets. The sensitivity, specificity, positive and negative predictive values of the SV method to detect patient movements in 3D has been derived.
Conclusions:

Single oblique radiographic imaging is suitable for intra-fraction motion detection.

If appropriate thresholds are not utilized the rate of false positive predictions and more importantly the rate of false negative predictions may be significant.

For detecting 1.0 mm movement, single image analysis with 0.9mm threshold maximizes Youden index and for 1.5mm 3D movement it corresponds to 1.2 mm with 95% negative predictive value.

What is different about SRS and SBRT?

- Dose
- High dose prescriptions
- High dose rate treatments
- Dosimetry requirements (Periodic QC non-IMRT plans?)
Simple phantom measurements with PinPoint Chamber

Film measurements have to be scaled down, treatment dynamics changes

Certain beam arrangements and anatomies require other phantoms (Lucy)
Issues relating to modifying devices:
- Clearance (especially with cones and table kicks)
- Positioning (presence, absence, size)
- Backup jaw positions, W-L tests
- Output factors

#### Relative Output Factor: 6 mm x 6 mm MLC

- Significantly Different: 59.4%
- Not Significantly Different: 40.6%

**Workflow Related Issues**

- **Workflow and Teamwork**
  - Well defined workflow, checklists
  - Longer treatment times
  - Treatment delivery schemes (a few fractions per week)
  - Modifying devices – clearance, presence / absence
Fix the problem
Address the problem
Address the problem

Fig. 2: Hierarchy of short-term effectiveness in hazard mitigation, where the top is most effective. Courtesy of J. Goldwein, Elekta, AB.

Modifying Devices...Backup Jaws can open wider than HDM LC
MLC: Minimizing Dose Outside the Intended Field

Figure 1: Composition of Dose Outside the HD120 Treatment Field. "A" is the primary field, "C.1.4" is the beam central axis. (Drawing not to scale.)

Figure 2: Effect of Varian MLC, HD120, on Out of Field Dose. Areas are drawn central axis of Field and coincident with the HD120 MLC using a 5 cm photosensitive. The 1 cm was used at 15 cm from the skin.

Legend: A: Central Axis MLC B: MLC, Varian Varian C: Varian Varian Senior 15

Wide Picture — "zoom out" and observe
Question 3 of 3

Most effective approach for hazard mitigation is with the use of:

- A. Training and education (0%)
- B. Reminders and Checklists (0%)
- C. Strict accountability (0%)
- D. Clearly defined policies and procedures (0%)
- E. Forcing functions, interlocks and automation (0%)


Question 3 of 3 - Answer

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