Implementing New Technologies for Stereotactic Radiosurgery and Stereotactic Body Radiation Therapy

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Implementation of radiosurgery and SBRT requires a fundamentally sound approach. Errors don’t “blur out” and can’t be corrected later.

Plan Ahead
- Assemble your team
- Coordinate with all involved well in advance
- Determine your clinical goals
  - SRS: Mets, benign tumors, pain, functional? Single fraction, fractionated?
  - SBRT: Lung, liver, spine, others?

Assemble the Documentation
- ACR / ASTRO Practice Guidelines
- PRACTICE GUIDELINE FOR THE PERFORMANCE OF STEREOTACTIC RADIOSURGERY
- PRACTICE GUIDELINE FOR THE PERFORMANCE OF STEREOTACTIC BODY RADIATION THERAPY
- What do they cover?
  - Personnel Qualifications / Responsibilities
  - Procedure Specifications
  - Quality Control / Verification / Validation
  - Follow-up

Assemble the Documentation (continued)
- Task Group Reports
  - AAPM Report #54 – Stereotactic Radiosurgery
  - AAPM Report #91 – The Management of Motion in Radiation Oncology (TG 76)
  - TG 101 – Stereotactic Body Radiotherapy
  - TG 104 – KV Localization in Therapy
  - TG 117 – Use of MRI in Treatment Planning and Stereotactic Procedures
  - TG 132 – Use of Image Registration and Data Fusion Algorithms and Techniques in Radiotherapy Treatment Planning
  - TG 135 – QA for Robotic Radiosurgery
  - TG 147 – QA for Non-Radiographic Radiotherapy Localization and Positioning Systems
  - TG 155 – Small Fields and Non-Equilibrium Condition photon Beam Dosimetry
  - TG 176 – Task Group on Dosimetric Effects of Immobilization Devices
  - TG 178 – Gamma Stereotactic Radiosurgery Dosimetry and QA
  - TG 179 – QA for Image-Guided Radiation Therapy Utilizing CT-Based Technologies

Some words about Report No. 54
- Only for cranial applications
- Published in 1995, so it predates:
  - MR Localization
  - Relocatable Frames
  - Image Fusion
  - Micro-MLC
  - Robotic Linacs and Perfexion Units
  - Others …..

<table>
<thead>
<tr>
<th>TABLE 8: Achievable Uncertainties in SRS</th>
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<tbody>
<tr>
<td>Stereotactic Frame</td>
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<tr>
<td>Isocenter: Alignment</td>
</tr>
<tr>
<td>1.0 mm</td>
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<tr>
<td>1.0 mm</td>
</tr>
<tr>
<td>CT Image Resolution</td>
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<tr>
<td>1.7 mm</td>
</tr>
<tr>
<td>3.2 mm</td>
</tr>
<tr>
<td>Tissue Station</td>
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<td>1.0 mm</td>
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<tr>
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<tr>
<td>0.3 mm</td>
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<tr>
<td>0.3 mm</td>
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<tr>
<td>Translational Uncertainty</td>
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<tr>
<td>Position Uncertainty</td>
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<tr>
<td>2.4 mm</td>
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<td>3.7 mm</td>
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</table>
Assemble the Documentation

- RTOG Protocols
  - RTOG 9005 – Single Dose Radiosurgical Treatment of Recurrent Previously Irradiated Primary Brain Tumors and Brain Metastases
  - RTOG 9305 – Randomized Prospective Comparison Of Stereotactic Radiosurgery (SRS) Followed By Conventional Radiotherapy (RT) With BCNU To RT With BCNU Alone For Selected Patients With Supratentorial Glioblastoma Multiforme (GBM)
  - RTOG 9508 – A Phase III Trial Comparing Whole Brain Irradiation Alone Versus Whole Brain Irradiation Plus Stereotactic Radiosurgery for Patients with Two or Three Unresected Brain Metastases
  - RTOG 0236 – A phase II trial of SBRT in the treatment of patients with medically inoperable stage I/II non-small cell lung cancer
  - RTOG 0618 – a phase II trial of SBRT in the treatment of patients with operable stage I/II non-small cell lung cancer
  - RTOG 0813 – Seamless phase I/II study of SBRT for early stage, centrally located, non-small cell lung cancer in medically operable patients

RTOG 0236 has something for everyone

Anatomy Definition

<table>
<thead>
<tr>
<th>OAR</th>
<th>Volume</th>
<th>Dose (cGy)</th>
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<tbody>
<tr>
<td>Spinal Cord</td>
<td>Any point</td>
<td>16 Gy or 6 Gy per fraction</td>
</tr>
<tr>
<td>Esophagus</td>
<td>Any point</td>
<td>27 Gy or 9 Gy per fraction</td>
</tr>
<tr>
<td>Subcutaneous Fat</td>
<td>Any point</td>
<td>24 Gy or 8 Gy per fraction</td>
</tr>
<tr>
<td>Heart</td>
<td>Any point</td>
<td>30 Gy or 10 Gy per fraction</td>
</tr>
<tr>
<td>Trachea and Ipsilateral Bronchus</td>
<td>Any point</td>
<td>30 Gy or 10 Gy per fraction</td>
</tr>
<tr>
<td>Whole Lung (Right &amp; Left)</td>
<td>(See table in Section 8.6.3)</td>
<td>(See table in Section 8.6.3)</td>
</tr>
</tbody>
</table>

Guidance for physicists

- RADIATION THERAPY: Note: Intensity Modulated RT (IMRT) is not allowed

Technical Factors
- Primary Beams
  - Only photon (array) beams produced by linear accelerators, betatrons, or microtron accelerators with photon energies 4-10 MeV will be allowed. Convergent and charged particle beams (including electrons, protons, and heavier ions) are not allowed. Photon beam energies greater than 10 MeV but not more than 14 MeV will only be allowed for a limited number of 2 beams that must operate from a continuous source of 14 MeV through collimator and collimator to match the collimator.
- Minimum Field Aperture (Field Size) Dimension
  - Due to uncertainties in beam centralization resulting from electronic collimators, within the small beam aperture, a minimum field dimension of 3.5 cm is required for any field used for treatment delivery. It is understood that this may exceed the technical requirements listed in Section 6.4 for small beams (< 3.5 cm axial GTV dimension or < 1.5 cm cranio-caudal GTV dimension). In such cases, the prescription dose is still prescribed to the edge of the defined PTV. This minimum field dimension does not apply to targets using tomotherapy or multiple array beam delivery systems.
- Inclusion of Effects of Internal Organ Motion
  - Internal organ motions must be made to account for the effect of internal organ motion (e.g., breathing, etc.) on target positioning and reproducibility. Acceptable maneuvers including relative abdominal compression, accelerator beam gating with the respiratory cycle, and active beam-holding techniques. All systems used to account for internal organ motion must be vetted prior to use in patients receiving stereotactic radiosurgery. In patients whose organs are expected to move during the treatment, the patient may be positioned to minimize motion, but will be assumed to have significant density for correction for motion (macro- or micro). However, for QA purposes, each plan should include...

Determine what kinds of delivery techniques will be used

- IMRT?
- Dynamic Arcs?
- VMAT?
- Robotic Delivery?

Determine how you will:

- Simulate
- Manage Motion
  - 4DCT / Compress / Gate / Track ....
- Immobilize
- Localize
  - MV / kV / CBCT / Calypso ....
- Verify

Other Documents

- ASTRO/AANS Consensus Statement on stereotactic radiosurgery quality improvement, 1993
- RTOG Radiosurgery QA Guidelines, 1993
- European Quality Assurance Program on Stereotactic Radiosurgery, 1995
- DIN 6875-1 (Germany) Quality Assurance in Stereotactic Radiosurgery/Radiotherapy, 2004

... and read the literature!
Assemble the proper resources

- Personnel
- Time
- Equipment
  - Dosimetry Equipment
  - Specialized Phantoms
  - Immobilization Devices
- Clarify procedures and responsibilities, and design QA program

As the physicist, you will be responsible for all of the technical details!

Example: Novalis Tx

- Real-time Stereoscopic Infrared Imaging
- Dual Energy Linac w/ SRS mode and multiple energy electrons
- Robotic Couch

New Planning System with Many Delivery Techniques

- Conformal beams
- Dynamic Arcs

Prepare for the task at hand

Commissioning photons on a Novalis Tx is akin to commissioning 7 beams:

- Cones-Direct Measurement
- XLow Standard-Pencil Beam
- XLow SRS-Pencil Beam
- XHigh Standard-Pencil Beam
- XLow Standard-Monte Carlo
- XLow SRS-Monte Carlo
- XHigh Standard-Monte Carlo
Get the Documentation

Technical Reference Guide
Revision 1.0
BrainLAB Physics

10 Circular Cone: General Beam Data Measurement

10.1 General Information
10.1.1 Contents of This Chapter

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
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<tr>
<td>Diode Line Collection</td>
<td>515x</td>
</tr>
<tr>
<td>Small Field Output Factors</td>
<td>511x</td>
</tr>
<tr>
<td>Beam Dose Build-Up</td>
<td>515x</td>
</tr>
<tr>
<td>MLC Area Build-Up</td>
<td>515x</td>
</tr>
</tbody>
</table>

Small fields require small detectors

Circular collimators 4 – 15 mm in diameter
MLC fields 5x5 mm² – 400x400 mm²

Monte Carlo requires scanned data in air
Need a brass buildup cap for your small chamber

Be careful with diodes and radiographic film

1) Both diodes and film are energy dependent, and the energy spectrum varies considerably for small fields relative to large fields. So:
- Use Gafchromic film, not radiographic film
- Use an intermediate reference field appropriate for both diodes and ion chambers

2) Diode response drifts over time
- Re-measure reference between each change in field size

Reference diode output to an intermediate field size

Output Factor = \frac{\text{Reading (FS)}_{\text{diode}}}{\text{Reading (Ref')}_{\text{diode}}} \times \frac{\text{Reading (Ref')}_{\text{IC}}}{\text{Reading (Ref)}_{\text{IC}}}

NO!
\frac{\text{Reading (5 mm)}_{\text{diode}}}{\text{Reading (100 mm)}_{\text{diode}}}

YES!
\frac{\text{Reading (5 mm)}_{\text{diode}}}{\text{Reading (20 mm)}_{\text{diode}}} \times \frac{\text{Reading (20 mm)}_{\text{diode}}}{\text{Reading (100 mm)}_{\text{IC}}}

The Million Dollar Question – Are your data correct?

Relative Output Factor

Circular Collimators - XLow

Field Diameter (mm)

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

0 2 4 6 8 10 12 14 16
Know how your data is processed and what the planning system does with it.
And people continue to have problems

Institution in the U.S

<table>
<thead>
<tr>
<th>Cone size (mm)</th>
<th>Original Output Factor</th>
<th>Re-measured Output Factor</th>
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<tbody>
<tr>
<td>4.0</td>
<td>0.312</td>
<td>0.699</td>
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<tr>
<td>7.5</td>
<td>0.610</td>
<td>0.797</td>
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<td>10.0</td>
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<td>0.835</td>
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<tr>
<td>12.5</td>
<td>0.823</td>
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<td>15.0</td>
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<td>17.5</td>
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<td>20.0</td>
<td>0.903</td>
<td>0.913</td>
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<td>25.0</td>
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<td>0.930</td>
</tr>
<tr>
<td>30.0</td>
<td>0.928</td>
<td>0.940</td>
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</table>

A different institution in the U.S

Commissioning your system: Does calculation agree with measurement?

End-to-end testing
Dosimetric uncertainty

Start simple, and increase complexity

Relative Dosimetry
Absolute Dosimetry

End-to-end testing
Dosimetric uncertainty

End-to-end dosimetric evaluation

Lucy Phantom
End-to-end dosimetric evaluation

Lucy Phantom
End-to-end dosimetric evaluation

End-to-end dosimetric evaluation

Isocentric Accuracy: The Winston-Lutz Test
**Mechanical Uncertainties**

Is the projection of the ball centered within the field?

**Perform for Cones and MLC**

Is the projection of the ball centered within the field?  
Good results ≤ 0.5 mm

**End-to-end localization evaluation**

**End-to-End Localization Accuracy**

Phantom Specifications

<table>
<thead>
<tr>
<th>Phantom</th>
<th>iPlan Stereotactic Coordinates</th>
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<tbody>
<tr>
<td>Cylinder</td>
<td>AP LAT VERT</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Cube</td>
<td>AP LAT VERT</td>
</tr>
<tr>
<td>20.0</td>
<td>-17.0</td>
</tr>
<tr>
<td>Cone</td>
<td>AP LAT VERT</td>
</tr>
<tr>
<td>-35.0</td>
<td>-20.0</td>
</tr>
<tr>
<td>Sphere</td>
<td>AP LAT VERT</td>
</tr>
<tr>
<td>25.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>
Verification of MLC shapes and isocenter

Fusion Verification

MR Fusion

Hidden Target Test
 scan, plan, localize assess

Use ALL the RPC phantoms

Immobilization / Motion Management
- Use abdominal compression (typically) to control tumor motion to less than 0.5-1.0 cm. We visualize the tumor OR use the dome of diaphragm
- Perform 4-D CT (using bellows for phase) under compression
How will you use 4D CT?

- Maximum Intensity Projection
- RTV
- AVG

How do you know its all correct?

Localization – Frame Based or Image Based?

- Frame-assisted image guidance – never frame alone

Image Guided Localization – Anatomy or Markers?

- Depends on the image guidance methodology and the anatomy / application

Have lots of redundancy

Localization – Stereo X-rays

- Vertical: 0.48, 0.43
- Longitudinal: -0.41, -0.79
- Lateral: 0.20, -1.10
Also works well in Spine

How do we know the system is targeting properly?
End-to-end evaluation that mimics a patient procedure

Results of Phantom Data

<table>
<thead>
<tr>
<th>(mm)</th>
<th>Lat.</th>
<th>Long.</th>
<th>Vert.</th>
<th>3D vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>-0.06</td>
<td>-0.01</td>
<td>0.05</td>
<td>1.11</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.56</td>
<td>0.32</td>
<td>0.82</td>
<td>0.42</td>
</tr>
</tbody>
</table>

- Sample size = 50 trials (justified to 95% confidence level, +/- 0.12mm)

Localization - cone beam CT

CBCT for Localization of Lung SBRT Patients
CBCT for Localization of Prostate SBRT Patients

Localization using implanted fiducials

Courtesy Sam Hancock, PhD, Southeast Missouri Hospital

Know your planning system, and what’s makes a plan good

The Initial SBRT Experience

20 tumors (all primary) in 11 patients
1-3 fractions of 5-15 Gy per fraction (14-45 Gy total dose)
70% response and no recurrences at 12 months
All patients developed fever and nausea
2 patients developed ascites and subsequently died:
  3 x 15 Gy for 57 cc tumor (HCC, hepatitis, cirrhosis)
  3 x 10 Gy for 293 cc tumor (HCC)
One patient died 2 days following a single dose of 30 Gy to a large tumor

SRS has existed as a clinical tool for over 50 years, and SBRT for over a decade. While both applications have reached a level of maturity, the associated technologies continue to evolve.

Both applications present physicists with many unique challenges.

The significance of potential treatment errors imposes a high level of diligence, a thorough and systematic approach, and considerable time and resources, for implementing these technologies.

If your institution isn’t willing to fully commit, then don’t implement an SRS or SBRT program.