SESSION: Therapy 4: 
Current Advantages and Safety Considerations in SBRT”

Presented at the AAPM Spring Clinical Meeting
Dallas, Texas
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Presenters:
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University of Virginia, Department of Radiation Oncology

and

Kamil M. Yenice, Ph.D.
University of Chicago, Department of Radiation Oncology
References


• Cunningham J, Coffey M, Knöös T, Holmberg O. Radiation Oncology Safety Information System (ROSIS)–profiles of participants and the first 1074 incident reports. *Radiother Oncol.* 2010;97:601–607

• Timothy D. Solberg PhD, James M. Balter PhD, Stanley H. Benedict PhD ,Benedick A. Fraass PhD, Brian Kavanagh MD, Curtis Miyamoto MD , Todd Pawlicki PhD, Louis Potters MD, Yoshiya Yamada MD , “Quality and safety considerations in stereotactic radiosurgery and stereotactic body radiation therapy” Practical Radiation Oncology (2011)


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The Questions I most often get

• Do you need a body frame to implement SBRT in the clinic?
• What patient and equipment specific QA do you do for SBRT?
• How do you verify treatment delivery for SBRT?
• Do I need a physicist at treatment for each SBRT procedure?
A few brief TG101 topics in this talk ..

1. Clinical Implementation of SBRT: system commissioning and IGRT QA issues
2. Simulation Imaging and Treatment Planning
3. Participation in SBRT clinical trials
What is SBRT?

- SBRT refers to the **precise irradiation** of an **image defined** extra-cranial lesion associated with the use of **high radiation dose** delivered in a **small number** of fractions.

- In SBRT, confidence in this accuracy is accomplished by the integration of modern imaging, simulation, treatment planning, and delivery technologies into all phases of the treatment process; from treatment simulation and planning, and continuing throughout beam delivery (TG 101)
So.... what is SBRT?
Frame Based Immobilization and Localization Systems

Frame systems provide a link between patient immobilization and localization: accurate localization relies on patient setup reproducibility.

Assumption: variations in the stereotactic location of the target are due only to organ motion and not to setup uncertainties.

Not true for most situations!
Frame Based Immobilization and Localization Systems

Frame systems provide a link between patient immobilization and localization: accurate localization relies on patient setup reproducibility.

Assumption: variations in the stereotactic location of the target are due to organ motion and not setup uncertainties.

Not true for most situations!
Recommendation (TG 101): For SBRT, image-guided localization techniques **shall** be used to guarantee the spatial accuracy of the delivered dose distribution.

- Body frames and fiducial systems are OK for immobilization and positioning aids
- They shall **NOT** be used as a sole localization technique!
IGRT Technology for SBRT
SBRT Commissioning (I)

• “Commissioning tests should be developed by the institution’s physics team to explore in detail every aspect of the system with the goal of developing a comprehensive baseline characterization of the performance of the system.” (TG-101)
SBRT Commissioning (II)

- “If individual errors are small by themselves, cumulative system accuracy for the procedure can be significant and needs to be characterized through an end-to-end test using phantoms with measurement detectors and imaging” (TG-101)
The modified Winston-Lutz test should be performed at the time any SBRT system is initially commissioned, and it should be repeated monthly.

All SBRT procedures should include detailed information on how the registration software is to be applied.

Special moving phantoms should be used to demonstrate that gating and/or tracking techniques are accurate.

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Multiple Imaging Modality Isocentricity (MiMi) Phantom from Standard Imaging

- **Easy Alignment due to Unique Design:**
  - “The MiMi Phantom incorporates five bone equivalent rods uniquely set so that four of them intersect at $90^\circ$ angles when viewed in DRRs or a 2D projection image. The rods traverse the entire phantom making them visible in any image or slice allowing for easy 2D/2D and 3D/3D matching for fast verification of isocenter position.”

- **Test Integrated System Accuracy of:**
  - 3D Cone Beam
  - MV/kV
  - Lasers and Couch Table Adjustments
  - Optical Guidance Systems

- **Test Automatic Table Adjustments:**
  - “Additional cross-hair markers that are offset known distances from the true isocenter allow for verification of the shifts prescribed by automatic table positioning systems.”

*Slide: Courtesy of Hania Al-Hallaq, PhD, Univ. of Chicago*
MiMi Phantom

*Slide: Courtesy of Hania Al-Hallaq, PhD, Univ. of Chicago*
Isocenter Coincidence Testing

1. **Axial CT Scanning (0.75mm)**
2. **Align Phantom to Lasers**
3. **Center Phantom in Radiation Isocenter by MV imaging at 4 orthogonal angles**
4. **Measure Offset to kV Isocenter by imaging at 4 orthogonal angles**
5. **Measure Offset to CBCT Isocenter**
6. **Measure Offset to AlignRT Isocenter**
7. **Measure Offset to Laser Isocenter**

**DICOM Transfer to TPS (Verify Geometric accuracy)**

**DICOM Transfer from TPS with DRRs and RT Structures**

**Introduce Known Physical Shift & Measure Accuracy**

Center Phantom in MV Isocenter by Imaging at 4 Gantry Angles

Slide: Courtesy of Hania Al-Hallaq, PhD, Univ. of Chicago
Measure Offset to kV Isocenter by 2D/2D Match at 4 Angles

Slide: Courtesy of Hania Al-Hallaq, PhD, Univ. of Chicago
Measure Offset to CBCT Isocenter

Dependent upon CBCT Technique!

Slide: Courtesy of Hania Al-Hallaq, PhD, Univ. of Chicago
Measure Offset to Laser Isocenter
Root Mean Square Distances of IGRT Isocenter Offsets

Trilogy couch precision: a factor in larger offset values

*Slide: Courtesy of Hania Al-Hallaq, PhD, Univ. of Chicago*
## TG-142: Imaging & Treatment Isocenter Coincidence

### Table VI. Imaging

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Application-type tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>non-SRS/SBRT</td>
</tr>
<tr>
<td><strong>Daily</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Planar kV and MV (EPID) imaging</strong></td>
<td></td>
</tr>
<tr>
<td>Collision interlocks</td>
<td>Functional</td>
</tr>
<tr>
<td>Positioning/repositioning</td>
<td>$\leq 2$ mm</td>
</tr>
<tr>
<td>Imaging and treatment coordinate coincidence (single gantry angle)</td>
<td>$\leq 2$ mm</td>
</tr>
<tr>
<td><strong>Cone-beam CT (kV and MV)</strong></td>
<td></td>
</tr>
<tr>
<td>Collision interlocks</td>
<td>Functional</td>
</tr>
<tr>
<td>Imaging and treatment coordinate coincidence</td>
<td>$\leq 2$ mm</td>
</tr>
<tr>
<td>Positioning/repositioning</td>
<td>$\leq 1$ mm</td>
</tr>
<tr>
<td><strong>Monthly</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Planar MV imaging (EPID)</strong></td>
<td></td>
</tr>
<tr>
<td>Imaging and treatment coordinate coincidence (four cardinal angles)</td>
<td>$\leq 2$ mm</td>
</tr>
<tr>
<td>Scaling$^d$</td>
<td>$\leq 2$ mm</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>Baseline</td>
</tr>
<tr>
<td>Contrast</td>
<td>Baseline</td>
</tr>
<tr>
<td>Uniformity and noise</td>
<td>Baseline</td>
</tr>
<tr>
<td><strong>Planar kV imaging$^d$</strong></td>
<td></td>
</tr>
<tr>
<td>Imaging and treatment coordinate coincidence (four cardinal angles)</td>
<td>$\leq 2$ mm</td>
</tr>
<tr>
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<tr>
<td>Spatial resolution</td>
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<td>Baseline</td>
</tr>
<tr>
<td>Uniformity and noise</td>
<td>Baseline</td>
</tr>
<tr>
<td><strong>Cone-beam CT (kV and MV)</strong></td>
<td></td>
</tr>
<tr>
<td>Geometric distortion</td>
<td>$\leq 2$ mm</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>Baseline</td>
</tr>
<tr>
<td>Contrast</td>
<td>Baseline</td>
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<td>HU constancy</td>
<td>Baseline</td>
</tr>
<tr>
<td>Uniformity and noise</td>
<td>Baseline</td>
</tr>
</tbody>
</table>
Distance Error Criterion: ≤ 1 mm (TrueBeam)
≤ 2 mm (C-series)

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Dr. Amols:

“Linacs also are built better than they were 25 years ago, but we haven’t changed our QA procedures accordingly. We still routinely check “cGy/mu,” isocenter accuracy, laser drift, etc. Sure, we’ve added new QA procedures for modern accessories (EPIDs, MLCs, CBCT, etc.), but we never subtract……”

“How many patients have been mistreated recently because a laser drifted or a linac dose rate changed between Monday and Tuesday? None!”
SBRT Planning Issues

- Treatment planning simulation
  - Patient positioning and immobilization
  - Motion management: 4DCT, gating, etc
- Number of beams and geometry
- PTV (and PRV) and Beam Margins
- Normal tissue tolerance and environmentally friendly dose disposal
  (term attributed to Micheal Goitein)
- Intensity Modulation - whether to use or not and how to use it for moving targets

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Respiratory Motion Management

**Recommendation:** For thoracic and abdominal targets, a patient-specific tumor motion assessment is recommended.

- Quantifies motion expected over respiratory cycle
- Determines if techniques such as respiratory gating would be beneficial
- Helps in defining margins for treatment planning
- Allows compensation for temporal phase shifts between tumor motion and respiratory cycle

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Simulation with Motion or Imaging Artifacts

Recommendation (TG 101): If target and/or critical structures cannot be localized accurately due to motion or metal artifacts……

STOP!

Do NOT pursue SBRT as a treatment option!
SBRT Target Margins

Recommendation (TG 101): At the current time, it remains difficult to base target margins directly on clinical results. The adequacy of ICRU definitions depend on:

- Understanding of how high absolute doses and sharp dose falloffs affect accuracy
- Limitations on in-house localization uncertainty
- Guidance from current peer-reviewed literature

Make an effort to gather and analyze your own clinical results to improve margin design!

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Normal Tissue Tolerances

Recommendation: Normal tissue dose tolerances in the context of SBRT are still evolving. So…. CAUTION!

• If part of an IRB-approved phase 1 protocol, proceed carefully

• Otherwise, the evolving peer-reviewed literature must be respected!
# Table of Normal Tissue Tolerances

## TG 101: Table 3

<table>
<thead>
<tr>
<th>Serial Tissue</th>
<th>Max critical volume above threshold</th>
<th>One fraction</th>
<th>Three fractions</th>
<th>Five fractions</th>
<th>End point (eGrade 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Threshold dose (Gy)</td>
<td>Max point dose (Gy)</td>
<td>Threshold dose (Gy)</td>
<td>Max point dose (Gy)</td>
</tr>
<tr>
<td>Optic pathway</td>
<td>&lt;0.2 cc</td>
<td>8</td>
<td>10</td>
<td>15.3 (5.1 Gy/fx)</td>
<td>174 (5.8 Gy/fx)</td>
</tr>
<tr>
<td>Cochlea</td>
<td></td>
<td>9</td>
<td></td>
<td>12 (6 Gy/fx)</td>
<td>25 (6 Gy/fx)</td>
</tr>
<tr>
<td>Brainstem (not medulla)</td>
<td>&lt;0.5 cc</td>
<td>10</td>
<td>15</td>
<td>18 (6 Gy/fx)</td>
<td>23 (7.7 Gy/fx)</td>
</tr>
<tr>
<td>Spinal cord and medulla</td>
<td>&lt;0.35 cc</td>
<td>10</td>
<td>14</td>
<td>18 (6 Gy/fx)</td>
<td>19 (7.3 Gy/fx)</td>
</tr>
<tr>
<td>Spinal cord subvolume</td>
<td>(5-6 mm above and below level of treated per Rya)</td>
<td>&lt;10%</td>
<td></td>
<td>10</td>
<td>18 (6 Gy/fx)</td>
</tr>
<tr>
<td>Cauda equina</td>
<td>&lt;5 cc</td>
<td>14</td>
<td>16</td>
<td>21.9 (7.3 Gy/fx)</td>
<td>24 (8 Gy/fx)</td>
</tr>
<tr>
<td>Sacral plexus</td>
<td>&lt;5 cc</td>
<td>14</td>
<td>16</td>
<td>22.5 (7.5 Gy/fx)</td>
<td>24 (8 Gy/fx)</td>
</tr>
<tr>
<td>Esophagus</td>
<td>&lt;5 cc</td>
<td>14</td>
<td>15.4</td>
<td>17.7 (5.9 Gy/fx)</td>
<td>252 (8.4 Gy/fx)</td>
</tr>
<tr>
<td>Brachial plexus</td>
<td>&lt;5 cc</td>
<td>11</td>
<td>17.5</td>
<td>30.4 (6.8 Gy/fx)</td>
<td>24 (8 Gy/fx)</td>
</tr>
<tr>
<td>Heart/pancreum</td>
<td>&lt;15 cc</td>
<td>16</td>
<td>22</td>
<td>24 (8 Gy/fx)</td>
<td>30 (10 Gy/fx)</td>
</tr>
<tr>
<td>Great vessels</td>
<td>&lt;10 cc</td>
<td>31</td>
<td>37</td>
<td>39 (13 Gy/fx)</td>
<td>45 (15 Gy/fx)</td>
</tr>
<tr>
<td>Trachea and large bronchi</td>
<td>&lt;4 cc</td>
<td>10.5</td>
<td>20.2</td>
<td>15 (5 Gy/fx)</td>
<td>30 (10 Gy/fx)</td>
</tr>
<tr>
<td>Bronchus-smaller airways</td>
<td>&lt;5 cc</td>
<td>13.8</td>
<td>13.3</td>
<td>18.9 (6.3 Gy/fx)</td>
<td>23.1 (7.7 Gy/fx)</td>
</tr>
<tr>
<td>Rib</td>
<td>&lt;1 cc</td>
<td>22</td>
<td>30</td>
<td>28.8 (9.6 Gy/fx)</td>
<td>36.9 (12.3 Gy/fx)</td>
</tr>
<tr>
<td>Skin</td>
<td>≤10 cc</td>
<td>22</td>
<td>26</td>
<td>32 (10 Gy/fx)</td>
<td>33 (11 Gy/fx)</td>
</tr>
</tbody>
</table>
Table of Normal Tissue Tolerances

• There is **sparse** long-term follow-up for SBRT.

• Data in table 3 should be treated as a **first approximation**!

• Doses are mostly **unvalidated**, but doses are based mostly on **observation** and **theory**.

• There is some measure of educated guessing!

R. Timmerman, 10/26/09, pers. comm. (Stan Benedict, PhD)
SBRT Participation In Trials

Recommendation: The most effective way to further the radiation oncology community’s SBRT knowledge base is through participation in formal group trials

• Single- or multi- institution

• Ideally NCI-sponsored or NCI-cooperative groups (e.g. RTOG)

• If no formal trial, look to publications

• If no publications, structure as internal clinical trial
Objects:
1. Improve SBRT delivery accuracy with gating
2. Control dose spillage of high and medium dose levels

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Beams
Structures and Optimization

4D-CT Simulation
PTV = ITV + 5-7 mm margin

Generate multiple rind structures for optimization

<table>
<thead>
<tr>
<th>ROI</th>
<th>Type</th>
<th>Constrain</th>
<th>Target cGy</th>
<th>% Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV</td>
<td>Min Dose</td>
<td></td>
<td>5400</td>
<td></td>
</tr>
<tr>
<td>PTV ring 1</td>
<td>Max Dose</td>
<td></td>
<td>5401</td>
<td></td>
</tr>
<tr>
<td>PTV ring 1</td>
<td>Max DVH</td>
<td></td>
<td>3780</td>
<td>50</td>
</tr>
<tr>
<td>PTV ring 2</td>
<td>Max DVH</td>
<td></td>
<td>2160</td>
<td>50</td>
</tr>
<tr>
<td>PTV ring 3</td>
<td>Max Dose</td>
<td></td>
<td>2600</td>
<td></td>
</tr>
<tr>
<td>bronchus spare</td>
<td>Max Dose</td>
<td></td>
<td>3000</td>
<td></td>
</tr>
</tbody>
</table>

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1 Segment/beam for all beams

Low number of segments for more efficient dose delivery
In contrast to Lung, multiple segment IMRT is the preferred SBRT Technique for Spine.

<table>
<thead>
<tr>
<th>ROI</th>
<th>Type</th>
<th>Constrain</th>
<th>Target cGy</th>
<th>% Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV-ce+5mm</td>
<td>Min DVH</td>
<td></td>
<td>3500</td>
<td>98</td>
</tr>
<tr>
<td>PTV-ce+5mm rin</td>
<td>Max Dose</td>
<td></td>
<td>3600</td>
<td></td>
</tr>
<tr>
<td>PTV-ce+5mm rin</td>
<td>Max DVH</td>
<td></td>
<td>2800</td>
<td>60</td>
</tr>
<tr>
<td>cauda equina+2m</td>
<td>Max Dose</td>
<td></td>
<td>1800</td>
<td></td>
</tr>
</tbody>
</table>
Need a sharp dose gradient between the cord and PTV:
High degree of modulation
12 Segments per beam (G=220°)
Spinal SBRT with IMRT

Evaluate the effect of setup/motion on delivered dose!

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Know the limitations of your dose algorithm! (Pay attention to warnings in user’s manual)

If the dose algorithm is used with parameters outside the measured and tabulated values, the accuracy of the calculated dose cannot be guaranteed. You must ensure that all necessary parameters, in particular the field size, depth and off-axis distance for the patient treatment are included in the measured beam data.

The accuracy of all Brainlab dose algorithms is directly dependent on the accuracy and the range of the beam data measurements. It must be ensured that the beam data measurement covers the range of field sizes and depths that will be used in subsequent treatment planning. This is especially the case for the measurements of the scatter factors, the radial profiles and the depth dose.

Depending on the MLC type, the pencil beam algorithm uses kernels of a certain resolution that define the overall resolution of the dose calculation perpendicular to the beam axis. In the case of small structures in combination with a insufficient kernel grid size, the pencil beam dose calculation may be too coarse to identify every detail of the delivered dose distribution.
FIELD SAFETY NOTICE / PRODUCT NOTIFICATION

Subject: Software accuracy limitations for very small Multi-Leaf-Collimator (MLC) field sizes

Product Reference: All Brainlab BrainSCAN and iPlan RT treatment planning software versions

Date of Notification: March 9, 2012

Individual Notifying: Markus Hofmann, MDR & Vigilance Manager

Brainlab Identifier: 12-01-13.FIP.1

Type of action: Advice regarding use of device.

Brainlab has become aware of events where the accuracy of the Brainlab Radiotherapy treatment planning software was not within clinically desirable limits for very small Multi-Leaf-Collimator (MLC) field sizes.

We are writing to remind you of the software accuracy limitations for very small MLC field sizes, and to provide further specific recommendations. This notification letter is to provide you with corrective action information, and to advise you of the actions Brainlab is taking to address the issue.
Recommendation (TG 101): SBRT commonly includes extremely high-dose gradients near the boundary of the target and often makes use of IMRT techniques. This report recommends the use of an isotropic grid size of 2 mm or finer. The use of grid sizes greater than 3 mm is discouraged for SBRT.

This vendor safety notice warns against two specific issues for potential inaccurate dose computation due to:

1. Use of conditions that require extrapolation of data beyond measurement range
2. Use of large grid size resulting in unexpected results for small structures
<table>
<thead>
<tr>
<th></th>
<th>Physicist Presence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Fraction SRS</td>
<td>Physicist present for entire procedure</td>
</tr>
<tr>
<td>Multiple-Fraction SRS</td>
<td>Physicist present for 1\textsuperscript{st} fraction and at setup of remaining fractions</td>
</tr>
<tr>
<td>SBRT</td>
<td>Physicist present for 1\textsuperscript{st} fraction, and setup for every fraction to verify imaging, registration, gating, immobilization</td>
</tr>
</tbody>
</table>
What is the most effective way to further the radiation oncology community’s SBRT knowledge base?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.</strong></td>
<td>Industry research to improve the technology and delivery</td>
</tr>
<tr>
<td><strong>2.</strong></td>
<td>Attendance at national and regional meetings</td>
</tr>
<tr>
<td><strong>3.</strong></td>
<td>Participation in SBRT clinical trials, ideally NCI sponsored or NCI cooperative groups</td>
</tr>
<tr>
<td><strong>4.</strong></td>
<td>Using the internet to promote the sophisticated features and capabilities.</td>
</tr>
<tr>
<td><strong>5.</strong></td>
<td>Developing theoretical and computer based radiobiological models</td>
</tr>
</tbody>
</table>
Answer: 3

- Participation by clinicians in SBRT clinical trials, ideally NCI sponsored or NCI cooperative groups (ie, RTOG), but also single or multi-institutional protocols.

- Although industry research making improvement to our equipment, attendance at meetings by clinicians, and research into radiobiological modeling will advance our knowledge base – the most effective way to truly further our SBRT clinical knowledge base is by participation in clinical trials and communicating the analysis of the data to our clinicians. There is no evidence that promoting the features of medical equipment on the internet furthers our knowledge base of SBRT at all.

- References:

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When target and/or critical structures cannot be localized accurately due to motion or metal artifacts which of the following applies…

0% 1. Utilize the deformable image registration features of the treatment planning system to develop a treatment plan

0% 2. Contour the target and critical structures as best you can and increase the margins on the target to a level that is necessary to account for the motion

0% 3. Reduce the dose and/or fractionation from the standard protocol to account for the errors in localization

0% 4. Use orthogonal (AP and lateral) kV planar imaging to develop a 2D plan for treatment and set-up.

0% 5. Do not pursue SBRT as a treatment option.
**Answer: 5**

- If one is unable to localize the target and adjacent critical structures due to motion or metal artifacts SBRT should not be a treatment option.

- Deformation registration and other imaging tools may be instructive for targeting, but if the target and/or adjacent critical structures are not localizable than SBRT is not an appropriate delivery.

- **Reference:**
For thoracic and abdominal targets, a patient-specific tumor motion assessment is recommended for planning and delivery of SBRT. Which of the following is a suitable approach?

1. Adoption of a body frame will allow the planning, localization, and delivery for all thoracic and abdominal targets.
2. The use of external markers or fiducials will allow accurate assessment of tumor position and re-localization.
3. Employing abdominal compression has been shown to eliminate the need for tumor motion assessment.
4. Developing a standard protocol for all target margins in the treatment planning process will eliminate the need for a patient specific tumor motion assessment.
5. The use of fiducials and body frames may be helpful for patient positioning in SBRT, but they are no substitute for employing IGRT technology, such as CBCT. SBRT requires IGRT.

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For SBRT, image-guided localization techniques **shall** be used to guarantee the spatial accuracy of the derived dose distribution. Other techniques, such as body frames, fiducials, and abdominal compression may be employed but they are no substitute for IGRT technology.

**Reference:**

Acknowledgements

Karl Farrey, MS
Julien Partouche, MS
Tianming Wu, PhD
And now a word about … safety