Stereotactic Radiation Surgery (SRS) and Stereotactic Body Radiation Therapy (SBRT)

Part II. technical details in image-guided planning and optimization

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One can compare **SRS & SBRT** by

$$TCP = \prod_i \left(1 - e^{-\alpha \text{BED}_i + \gamma T} \right)^{c_i v_i} \approx (1 - e^{-\alpha \text{BED}_{\min} + \gamma T})^{c_{\min} v_{\min}}$$

$$NTCP(OAR) = 1 - \prod_s \prod_i \left[ \left( \frac{\text{NTD}_2 d_i}{\text{NTD}_2 D_{50 s}} \right)^k + 1 \right]^{-v_i / V_s}$$

Flickinger, IJROBP, p879, 1989 & Withers, IJROBP, p549, 1995

Relating to conventional radiotherapy, SRS and SBRT have increased the biological equivalent dose, BED, and decreased the elapse time $T$ so that TCP is increased.

While hypo-fraction SBRT has smaller $\text{NTD}_2 d_i / \text{NTD}_2 D_{50 s}$ then that of SRS so that less impact of increased dose on the NTCP.
In addition to the radiobiological consideration, target volume reduction is essential in SRS/SBRT.
Normal Tissue Encompassed by Rx Dose Due to Target Shift

- 10 mm sphere (0.524 cc)
- 20 mm Sphere (4.19 cc)
- 40 mm Sphere (33.5 cc)
How to reduce margin of target in
• treatment simulation,
• treatment planning, and
• dose delivering?
1. Simulate patients as actual treatment setup &
2. Use immobilization devices if allowed
Left shows a SBRT patient of NSCLC within SBRT body frame and abdomen compression. Right: a large patient can’t fit to the frame
3. Add a localizer to remove errors in image registration

A head-frame is fixed to the patient skull for Gamma-knife (GK) SRS. A MRI localizer was attached to the frame at scans. Localized MRI slices provide accurate head position in GK.
Point $O(z_0)$ is defined by localizer pins in the CT slice. Equation (1) can determine $(x, y, z)$ in LCS.

\[ \tilde{A} = X\hat{e}_X + Y\hat{e}_Y = x\hat{e}_i + y\hat{e}_j + (z - z_o)\hat{e}_k \]  

Know the limits of stereotactic localization algorithms

Saw et al (Med Phys P1042-7, 1987)

Note: localizer orientation $k$ has to be close to CT axial direction $K$. 

CT Slice

$A(X,Y)$

Point $O(z_o)$ is defined by localizer pins in the CT slice. Equation (1) can determine $(x, y, z)$ in LCS.

Saw’s CT system

Localizer coordinate system (LCS)

No approximation but requires two separate slices to define the LCS origin of the point B

\[ CA = BA - BC \quad \text{or} \]
\[ X\hat{e}_x + Y\hat{e}_y = (x - x_B)\hat{e}_i + (y - y_B)\hat{e}_j + (z - z_B)\hat{e}_k \]
One can also check localizer’s pins after image registration in the LCS

Accuracy of our available localizers in LCS

<table>
<thead>
<tr>
<th>Pins in</th>
<th>Max</th>
<th>Mean</th>
<th>Global</th>
<th>Center</th>
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<tbody>
<tr>
<td>CT</td>
<td>0.5</td>
<td>0.3</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>MRI</td>
<td>0.9*</td>
<td>0.7*</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>XA</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
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4. Scans using fine section (2 or 3 mm), small FOI, and proper contrast.

Contrast and partial volume effects are demonstrated on the 2D (left) and 3D (right) displays of auto-contours from MRI (green) & CT (red) both are registered in LCS.
5. Avoid any image artifacts that affects registration - A case presents MRI artifacts

Artifacts change the rod shape

causes a small deviation from the CT-scans at the central slice
Significant deviation occurred on the top slices
6. Combine images for better target definition. A case with ITV (red) is best defined by union of glass opacity GTV and high SUV area in PET. PTV = ITV + 3 mm (in green).
The patient breathes normally and his/her respiration pattern is learnt by the system. The scanner performs a spiral scan at very slow couch speed (low pitch).

An apparatus monitors the patient breathing and sends triggers to recon via the I-Box.

Images are created at the various phases of breathing.

courtesy of Philips
Amplitude Binning for 4D correlated imaging
...when Accuracy and Efficiency Matter

Reconstruction at 75% of the breathing cycle. Amplitude based binning produces greater spatial coherence than phased binning.

courtesy of Philips
Amplitude Binning for 4D correlated imaging
...when Accuracy and Efficiency Matter
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8. Include slow scans for SBRT
Lagerwaard et al, IJROBP, 2001, 932-7

- Scan parameters (slice thickness of 3 mm)

<table>
<thead>
<tr>
<th></th>
<th>mAs</th>
<th>Pitch</th>
<th>Sec/rev.</th>
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</thead>
<tbody>
<tr>
<td>Fast Scan</td>
<td>~175</td>
<td>~2</td>
<td>≤1</td>
</tr>
<tr>
<td>Slow Scan</td>
<td>~50</td>
<td>~1</td>
<td>≥4</td>
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</table>

- Fast CT scans are used as plan images and slow CT and PET scans are precisely fused with the fast CT scans
- GTV are contoured in all image sets, their union is ITV
- Daily setup errors is added to ITV for constructing PTV.
- Koste et al (IJROBP, 2003, 1394-9) concluded that “Incorporation of a slow CT scan into a rapid planning CT scan improves the target definition for peripheral lung tumor.”
9. Choose optimal treatment plans
Some Tools for SRS/SBRT:

- Target Volume (TV) Coverage: >95%
- Conformity Index, CI

  - Shaw, et al, IJROBP, 1993 1231-9, define
    \[ CI_{old} = \frac{PDV}{TV} \text{ should have } 1 < CI < 2 \]
  - Paddick, J Neurosurg, 2000,219-22, defines
    \[ CI = TV_{PDV}^2 / (TV \times PDV) \quad 0.6 < CI < 1 \]
A non-conformal dose plan has

\[
CI_1 = \frac{TV_{PDV}}{TV} = 1.0
\]

A non-conformal dose plan has

\[
CI_2 = \frac{TV_{PDV}}{PDV} = 1.0
\]

A conformal dose plan has

\[
CI_3 = CI_1 CI_2 = 1.0
\]

Pay attention to the detail. DVHs and dose profile across the ROI should also be checked.
Optimal plan was selected based on the dose distributions: In this case, plan using 6 co-planner arcs (left) provide higher dose to the GTV while less dose to the chest wall and the lung.
Plan with 9 non-co-plane IM beams spares brainstem better than arcs’ plans.
Plan using multiple small-angle arcs provides excellent conformal isodose distribution.
10. Perform image-guided patient setup and dose delivery

- List of frame-less image-guided techniques


- Ultrasound-guided SBRT (Meeks et al, IJROBP 2003 1092-101)

Use of daily CBCT (right) co-registered to plan CT (left) at the treated position with the ITV (brown) in daily CBCT that differs from the plan ITV (red).
Two CBCT scans per Tx show reliable repositioning.

Daily $|\text{ITV}_i - \text{ITV}_f| \ll |\text{Plan ITV} - \text{Daily ITV}| < 10\%$
A case with >10% PTV drops @100% but not ITV

Planned (solid) vs Actual Delivered (dash) DVHs

% Volume of Interest

% Dose relative to 14 Gy x 4 fx
Summary for SRS/SBRT

1. Simulation scans as actual treatment
2. Use stereotactic immobilization devices
3. Register images with a stereotactic localizer
4. Scan with fine section (slice thickness ≤ 2 mm for brain and ≤ 3 mm for body)
5. Avoid any image artifacts
6. Unfold organ motion with 4D or gated scans
7. Combine anatomic and function image sets
8. Include slow scans for SBRT of NSCLC
9. Choose plans with conformal dose distribution
10. Perform image-guided refixation and dose delivery