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Linac or Non-Linac
Demystifying And Decoding
The Physics Of SBRT/SABR
Stereotactic RadioSurgery

- Cranial (Head & Brain) (SRS, SRT)
- Extra Cranial (lung, liver, pancreas, spine, prostate); (SBRT)
## Conventional RT vs SBRT

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Conventional RT</th>
<th>SBRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose / Fraction</td>
<td>1.8 – 3 Gy</td>
<td>6 – 30 Gy</td>
</tr>
<tr>
<td>No. of Fractions</td>
<td>10 – 45</td>
<td>1-5</td>
</tr>
<tr>
<td>Treatment time</td>
<td>10-15 min</td>
<td>Up to 45min</td>
</tr>
<tr>
<td>Planning Margin</td>
<td>cm</td>
<td>mm</td>
</tr>
<tr>
<td>Imaging modalities used for Tx planning</td>
<td>CT</td>
<td>Multi-modality: CT/MR/PET-CT</td>
</tr>
<tr>
<td>Geometric verification</td>
<td>Anatomy</td>
<td>Stereotactic system</td>
</tr>
<tr>
<td>Staff Training</td>
<td>Highest</td>
<td>Highest + special SBRT Training</td>
</tr>
<tr>
<td>Physics / dosimetry monitoring</td>
<td>Indirect</td>
<td>Direct</td>
</tr>
</tbody>
</table>
Systems for SBRT

- **Linear Accelerator Based SBRT**
  - Rapid Arc
  - True Beam
  - Body Frame with linear accelerator
    - Elekta
    - Varian
    - Pro-Lock System

- **Dedicated Delivery Systems**
  - Gamma Knife
  - Novalis, Brain Lab
  - Tomotherapy
  - Cyber-Knife
  - Proton beam
Delivery Systems

- Linear Accelerator
- Novalis Radiosurgery
- Cyber Knife
- Tomotherapy
- Gamma Knife
- Proton Beam
BrainLab Novalis, SRS/SRT/IMRS

m3 µMLC

Novalis Head rings

BrainLab Cone: 4mm-20mm diameter
Cyber Knife Based SRS

- Robotic treatment
- IGRT
- Intra-treatment imaging
- Orthogonal kV imaging

Cone Size from 5 mm to 60 mm
Proton Beam SRS/SBRT

Cyclotron

Synchrotron

Treatment Schematic

Harvard/MGH SRS system
Dose Distributions (Liver SBRT)
Dose Distributions (Lung SBRT)

3DCRT or IMRT
Dose Distributions Spine SBRT
Recurrent-Spine SBRT
SBRT at Indiana University

- A phase I trial of SBRT for medically inoperable lung cancer was initiated at Indiana University in the late 1990s by Dr. Timmerman.
- Currently SBRT at Indiana University
  - Lung (primary and metastases)
  - Liver (primary Hepatocellular Carcinoma HCC and metastases)
- Majority of our patients have been treated utilizing the Elekta Stereotactic Body Frame System.

SBRT

- High dose of radiation delivered in a hypofractionated regimen (single fraction or 3-5 fractions)

- High target accuracy
  - Stereotactic reference - target is localized relative to a known 3D coordinate system through the use of external fiducial markers
  - Patient immobilization is important

- Rapid dose falloff (sharp dose gradient)
  - Multiple conformal beams
Elekta Stereotactic Body Frame
Different Systems

Elekta Stereotactic body frame

- Small box frame system tightly restricts patient motion
- Stereotactic reference system to localize target
- Can not be indexed to treatment couch
- Respiration compression plate

CIVCO Body Pro-Lok™ system

- Modular structures highly adaptable to individual patient
- Isocenter setup relies on skin marks/tattoos
- Indexed to treatment couch
- Respiration compression plate and belt
CT Simulation

- Planning CT obtained from CT-Simulator
  - 2 mm axial slice through area of interest
  - 4D-CT obtained for motion assessment
- Fusion Image obtained with patient in frame
  - Positron Emission Tomography PET (lung and liver)
  - Dual phase CT (liver)
Multi Modality Imaging

CT

PET

Regular CT

Dual phase CT

4D-CT

Spatial X, Y, Z + Temporal => 4D

CT Raw Data/Images

Respiration Signal

CT Acquisition Software

CT Image Sorting Program

End-inspiration

End-expiration

4 sec

Mid-exhale

“End-exhale”

“Mid-inhale”

End-inhale
Motion Assessment – 4DCT
Treatment Planning

- Contour volumes
- Beam placement and beam modifiers
- Plan evaluation
- Isocenter stereotactic coordinate determination
- Coordinate verification
- QA
# Treatment Planning – Structure Contour

Structure contoured based on RTOG protocols or internal guidelines

<table>
<thead>
<tr>
<th>LUNG</th>
<th>LIVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTV – use lung window</td>
<td>GTV</td>
</tr>
<tr>
<td>Spinal Cord</td>
<td>Spinal cord</td>
</tr>
<tr>
<td>Whole lung</td>
<td>Whole liver</td>
</tr>
<tr>
<td>Esophagus</td>
<td>Stomach / Duodenum</td>
</tr>
<tr>
<td>Heart</td>
<td>Heart</td>
</tr>
<tr>
<td>Proximal Bronchial Tree</td>
<td>Rt and Lt Kidneys</td>
</tr>
<tr>
<td>Trachea</td>
<td>Small Bowel</td>
</tr>
<tr>
<td>Brachial plexus, ipsilateral</td>
<td>Rt Lung</td>
</tr>
<tr>
<td>Descending aorta (optional)</td>
<td>Bowel</td>
</tr>
<tr>
<td>Chestwall/ Rib</td>
<td>Chestwall/ Rib</td>
</tr>
<tr>
<td>Skin</td>
<td>Skin</td>
</tr>
</tbody>
</table>

PTV is created per protocol (normally 0.5cm axial margin and 1cm superior-inferior margin around GTV)
Possible Beam Arrangements
SBRT, Lung Proton

Photon Proton
CyberKnife Plans
Plan Evaluation

- Target coverage
- Target dose heterogeneity
- Normal tissue constraints
- Conformity indices
  - High dose spillage
  - Low dose spillage

RTOG 0236
AAPM TG-101
Treatment Planning – Isocenter Coordinates

\[ X_{iso} = X_{meas} + 85 \]
\[ Y_{iso} = Y_{meas} \]
\[ Z_{iso} = Z_{meas} + n \times 100 \]
Treatment Day

- Patient setup in frame according to simulation parameters
- Isocenter setup by stereotactic reference system
- Image acquisition and treatment verification
- Online correction through couch adjustment
- Treat
Purpose: to verify patient position on the treatment day is the same as the planned and to provide correction guidance if deviation is discovered.

IGRT systems
- Fixed or rotating kV and MV imagers (2D imaging)
- 3D volumetric imaging
Cone Beam CT - Lung Tumor Match

Before Registration (CBCT and Planning CT blended)

After Registration (CBCT and Planning CT blended)
Cone Beam CT - Liver Tissue Match

Before Registration (CBCT and Planning CT blended)

After Registration (CBCT and Planning CT blended)
Cone Beam CT – Bony Anatomy Verify

Before Registration (CBCT and Planning CT blended)

After Registration (CBCT and Planning CT blended)
Comparison between 2 systems

- Compared with Elekta body frame, the Pro-lok system is relatively complex and time consuming in patient simulation and treatment setup.

- Relatively larger random setup errors were found in Pro-lok system for both SBRT liver and lung treatment setup.

- Large inter-fractional correction occurs more frequently with Pro-lok system.

- Image guidance is critical for SBRT patient setup, especially when Pro-lok system is used.
For large couch corrections, repeated CBCTs are often performed to verify the correction. For Pro-lok system, 40.7% of all the fractions ended up with repeated CBCT. Only 13.6% of fractions have repeated CBCT when Elekta body frame was used.
Results of Two Systems

Systematic Setup Error

Random Setup Error

Liver

Lung
Linac vs CyberKnife

Ding et al, Med Phys, 40(5), 051705, 2013
PTV Prescription

- Gamma Knife 50%
- CyberKnife 50-70%
- Novalis 70-80%
- Accelerator 80%
- 3DCRT 95-100%
- IMRT 100%

Lung (40-48%) Ding et al, 2013
Liver (67-77%) Ding et al, 2013
Small Field Dosimetry

\[
D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} N_{DW,Q_0} k_{Q,Q_0}^{f_{msr},f_{ref}} k_{Q_{msr},Q}^{f_{msr}}
\]

\[
\Omega_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{msr}}} \left[ \frac{(D_{w,Q_{clin}}^{f_{clin}})/(M_{Q_{clin}}^{f_{clin}})}{(M_{w,Q_{msr}}^{f_{msr}})/(M_{Q_{msr}}^{f_{msr}})} \right] = \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{msr}}} k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}
\]

\[
k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{(S_{w,air})^{f_{clin}} \cdot P_{f_{clin}}}{(S_{w,air})^{f_{msr}} \cdot P_{msr}}\]

\[
\text{Output}_{rel} = \frac{(Output)_{rel}}{(\text{Re ading})_{rel}}
\]
Why So Much of Fuss?

- Reference (ref) conditions cannot be achieved for most SRS devices (cyberknife, gammaknife, tomotherapy etc)
- Machine Specific reference (msr) needs to be linked to ref
- Ratio of reading (PDD, TMR, Output etc) is not the same as ratio of dose

\[
\frac{D_1}{D_2} \neq \frac{M_1}{M_2}
\]

\[
\frac{D_1}{D_2} = \frac{M_1}{M_2} \cdot [k_{Q_{clin}}, f_{msr}]
\]
Impact of $k^{f_{\text{clin}}, f_{\text{msr}}}$

Relative dose at $d_{\text{max}}$ vs. Field Size (cm)
What is Common Theme?

- Multimodality imaging for target delineation
- Very High dose (20-60 Gy) in few fractions (1-5)
- Stereotactic immobilization / CBCT/ image based
- High degree of precision (mm) needed
- Small Fields
  - High degree of precision in dosimetry needed
  - Accurate commissioning data
  - Proper selection of detector
- Repeated imaging for localization, pretreatment and during treatment
Selection of a SBRT Machine

- Hard to compare
- Advertising for personal gain
- Only anecdotal and dosimetric data
- No scientific data on clinical outcome
- No randomization possible in this era
Summary

- SRS/SRT/SBRT/IMRS is now widely used for hypofractionated treatment world wide with good outcome
- Image guidance for treatment planning and treatment verification is very critical to the success of SBRT radiation therapy
- Quality assurance and Small Field dosimetry as well as continuous monitoring of the QA and process is critical
- For SBRT, image-guided localization techniques shall be used to guarantee the spatial accuracy of the derived dose distribution
- AAPM has Task Group report on every modalities that can be referred
- There is no superiority of any device that can be recommended
Thanks