SBRT: Simulation, Localization, and Delivery

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SBRT Process in a Nutshell

- Immobilization and Simulation
  - Motion Management
- Treatment Planning (TP)
  - Image Fusion
  - Planning Techniques (3DCRT, IMRT, Arcs)
  - Dose Calculation Algorithms
- Localization
- Treatment Delivery
- Quality Assurance

SBRT ≠ IMRT

- Ultra-high doses per fx, 10 to 20 Gy, in a hypofractionated regimen of 5 or fewer fxs
  - Errors will not be diluted
- Technically refined patient repositioning and treatment delivery procedures

SBRT ≠ IMRT

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SBRT</th>
<th>IMRT</th>
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<tr>
<td>Description</td>
<td>1.8-5 Gy</td>
<td>6-30 Gy</td>
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<td>No. of fractions</td>
<td>10-30</td>
<td>1-3</td>
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<td>Target definition</td>
<td>GTV/PTV (gross disease-clinical); GTV/CTV/PTV/pTV (clinical tumor; GTV/CTV)</td>
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<td>Dose</td>
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<td>CT, PET, FDG, MR</td>
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<td>Required imaging modality needed</td>
<td>CT</td>
<td>CT, PET, MR</td>
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<td>Radiation treatment planarity</td>
<td>Highly</td>
<td>Moderately</td>
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<td>Maintenance of high spatial targeting accuracy</td>
<td>Moderately satisfactory</td>
<td>Slightly improved (attenuation and high frequency provide imaging)</td>
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<td>Safety</td>
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<td>Knowledge of radiation therapy</td>
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TG 101
**Immobilization/Simulation**
- Scanning in TX Position
  - CT, MR, PET-CT
- Vac-Lac
- Motion Management
  - Abdominal Compression Plate
  - Pressure Belt
  - Body Immobilization
- CT scan with ≤ 3 mm slice thickness

**Motion Management and CT Simulation**
- Suppressed respiratory motion techniques (Compression Paddle, Pressure Belt)
- Free Breathing (FB) & Slow CT-Scanners
- Free Breathing & Fast CT-Scanners
  - Tumor at atypical position
- Breath-Hold (BH) CT-Scans
  - Motion encompassing volume
- Respiratory Correlated CT (4D-CT)

**Commercial Devices**
- CIVCO
- Qfix Systems
- Medical Intelligence

**ROC Abdominal Compression Belt**
- Plastic board with two long slits on the sides
- Blood pressure cuff, Velcro® mounted under the board
- Adjustable, Velcro® covered belt
- Sewn-on ruler for consistent setup

Courtesy Joerg Lehmann, Ph.D.
**Pneumatic Compression Belt**

- Air inflation bulb
- Pressure gauge
- Non-Rigid
- Marking of the patient skin & immobilization device
- Recording of the pressure
- Easy to use!

→ more compression compared to the paddle

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**Slow CT Scans for SBRT**

- Patient breathes normally
- Rotation time >> breathing period
- CT images are an average over all breathing phases
- Borders of tumor volumes can become diffuse

Observe target movement under fluoroscopy

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**4DCT – What Do We Get**

- Snapshots of selected breathing phases, including EOE, EOI, and everything in-between
- Average of all breathing phases (like slow CT)
- Combination of M out of N breathing phases (needed for gated RT delivery)
- Max/Min Intensity Projections (MIP/minIP)
- Visualization of the tumor motion over the whole respiration cycle
- Display of anatomy in space (3D) and time (4D)

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**Statistics from a 4DCT Scan**

- Relative amplitude range: the closer to 1, the more consistently the patient breathed
- Relative amplitude standard deviation
- Consistency of the breath size (amplitude) is important for 4DCT image quality
  - A factor into deciding whether or not a patient is a candidate for respiratory correlated RT

Statistics from a 4DCT Scan
A relative amplitude range of 0.95 – 1.05 for the pulmonary breathing wave during the 4DCT scan of a lung SBRT patient indicates

1. In-consistent breath size (amplitude)
2. Decreased 4DCT image quality
3. The patient is a suitable candidate for respiratory-correlated SBRT treatment
4. Improved processing speed of the 4DCT image reconstruction algorithm
5. The patient has a poor lung function

Lung: Contouring ITV on MIP

→ Contouring on Frozen Images is superior
  - Better contrast (brightest voxels along the viewing ray)
  - Avoids geometrical misses due to irregular motion
→ Inspecting the FB (or Ave) images may be necessary
→ Use of FB (or Ave) for dose calculations

Liver: Contouring ITV on minIP

→ Contouring on minIP is superior
  - Better contrast (darkest voxels along the viewing ray)
  - Display structures w/ low signal compared to surrounding structures
→ Inspecting the FB (or Ave) images may be necessary
→ Use of FB (or Ave) for dose calcs

Refs:
The minimum and maximum intensity projection (MinIP and MIP) images for liver & lung tumors, respectively, can be used to

1. Improve treatment localization accuracy
2. Reduce the ITV to PTV margin
3. Reduce intra-fraction motion
4. Obtain the tumor motion-encompassing volume
5. Improve dose calculation accuracy

Liver: CT Contrast Enhancement

- Hepatocellular Carcinomas (HCCs)
  - best visualized on an arterial phase due to hyper-vascularity
  - arterial phase of image acquisition ~ 25-30 secs after the initiation of the contrast injection
- Hypo-attenuating lesions (liver mets)
  - best visualized on a venous phase
  - venous phase of image acquisition ~ 60-75 seconds
- Equilibrium phase of image acquisition ~ 3-5 min
  - Useful for hyperdense lesions with prolonged enhancement

Is a Single 4DCT Sufficient for TP?

- 10 patients with 14 lung mets
  - SBF for 30 min -- 4 repeated 4DCT every 10 min
  - Abdominal compression in 7 pts
- Peak-to-peak tumor motion
  - 9.9 ± 6.8 mm at T0
  - 9.0 ± 7.4 mm at T30
- 1 pt with poor PF → motion increase from 17.4 mm to 28.3
- 5 pts → mean tumor position shift by 3 mm
- TP based on a single 4DCT is reliable for majority of pts
- Increased intrafractional uncertainties for pts with poor PF and with tumors located in the lower lobe

Multimodality Imaging for TP

- **Lung and Liver**
  - Likely: fusion with PET/CT diagnostic scans
  - Challenges
    - arms up vs. arms down
    - flat-table top vs. curved table top
    - uniform sampling
  - Preferred: fusion of planning CT with PET/CT scan in the treatment position
  - Ideal: PET/CT sim in the treatment position
- **Spine**
  - Fusion of planning CT with MR

PTV Margins

SBRT Reports on Lung & Liver

- TG101
  - 0.5 cm axial and 1.0 cm Sup/Inf for texts with suppressed respiratory motion
  - Some centers are moving toward an isotropic expansion with → 0.5 cm

Reports on Spine

→ GTV=PTV

TP Techniques & Beam Arrangements

- 3DCRT → 7 to 13 Beams
- IMRT → 7 to 13 Beams
- VMAT → 1 full Arc and 1/2 Arcs
- Dynamic Conformal Arcs → 1 to 7 Arcs
  - Avg: 3 Arcs
- Coplanar and non-coplanar directions
- 6, 10, and 15 MV beams

Plan Reporting & Evaluation

<table>
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<tr>
<th>PTV Volume (cc)</th>
<th>Ratio of Prescription Isodose Volume to the PTV (%)</th>
<th>Ratio of 50% Prescription Isodose Volume to the PTV (%)</th>
<th>Maximum Dose (in % of dose prescribed) @ 2 cm from PTV in any direction, DFBT (Gy)</th>
<th>Percent of Lung Receiving 20 Gy Total or More, V20 (%)</th>
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**Recommendation:** At the current time, it remains difficult to base target margins directly on clinical results. However, the reproducibility of the definitions of target margins (i.e., GTV, CTV, etc.) by SBRT should be based on an understanding of how the steep dose gradient and high fractional doses of SBRT affect the accuracy of traditional target margins, as well as the natural history of the tumor, the limitations of in-house localization capabilities to reduce random and systematic treatment uncertainties, and from information in the current literature. Simultaneously, centers should make systematic efforts to gather and analyze clinical results to improve margin design in the future.
**In-Room Imaging**
Growing role of volumetric imaging before & during txt

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<th>System</th>
<th>Image Quality</th>
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<tr>
<td>CyberKnife</td>
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<td>+</td>
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<tr>
<td>Mvision MV - CBCT</td>
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<td>-</td>
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<tr>
<td>TOMO MV-CT</td>
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<tr>
<td>Exac Trac</td>
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<tr>
<td>OBI kV - CBCT</td>
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<td>XVI kV - CBCT</td>
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<td>-</td>
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**Localization**

- **Acquisition**
- **Reconstruction**
- **Registration**
- **Table offsets**

- Fusion shifts = table corrections needed to correct patient positioning
  - Translational shifts (Varian, Elekta, Siemens)
  - Translational shifts, pitch & roll (Novalis)
  - Translational shifts & roll (Tomotherapy)
  - Translational & rotational (Elekta w/ Hexapod table)

**2D vs. 3D Localization**

- **kV 2D Imaging**
  - Limited information
  - Limited FOV of EPI does not always provide sufficient information for fusion process
    → may result in erroneous results
  - Good fusions with bone and fiducials
  - Verification CT prior to treatment and external aides can help eliminate gross errors

- **CBCT Imaging**
  - Large amount of information → good fusion in tissue and bone
  - Subject to operator errors

**In-room CBCT-based volumetric imaging technologies for SBRT treatment localization are**

1. Less accurate than 2D kV/MV imaging
   - 7%
2. Used for continuous monitoring of tumor position during treatment
   - 4%
3. Not capable of detecting rotation setup errors
   - 6%
4. Able to correct for systematic errors only
   - 82%
5. Subject to operator errors

---
Repeated Localization Imaging?

- Treatment time \( \approx 30 \) mins
  - kV 2D (e.g. Exac Trac) and CBCT
  - Image & localize \( \rightarrow \) Treat \( \rightarrow \) Image \( \rightarrow \) Treat

The mean intrafraction tumor position deviation \( \rightarrow \) measured as function of the interval between localization & repeated CBCT for 8 Pts:
- \( 5.3 \) mm if the time \( > 34 \) mins
- \( 2.2 \) mm if the time \( < 34 \) mins

\( p < 0.01 \)

Correction for Rotations?

Spine SBRT
- Evaluated impact of rotational setup errors on dose using 39 CBCT scans from 16 pts
- Cord PRV expansion of \( 2 \) mm assures safe txt delivery in the face of typically encountered rotations

Lung SBRT
- Evaluated translational and rotation errors for 8 Pts.
- Mean rotational variation was \( 0.1 \pm 0.2^\circ \)

Caution: Pts. might involuntary counteract the couch motion

SBRT Txt May Last 45 mins

- Possible compromise in treatment efficacy for individual fxs that require long txt time
  - Tumor intra-fraction motion and patient involuntary movement during delivery
  - Theoretical risk of intra-fractional radiation damage repair within tumor cells in the context of prolonged fractional delivery
- Patient comfort

In-room CBCT-based volumetric imaging technologies for SBRT treatment localization are

1. Less accurate than 2D kV/MV imaging
2. Used for continuous monitoring of tumor position during treatment
3. Not capable of detecting rotation setup errors
4. Able to correct for systematic errors only
5. Subject to operator errors

Rotation Delivery is Efficient
12 Gy in 3 fxs

- # of MUs 2033
- Two partial DC arcs → 20-160 & 340-20 @ 90° Table
- Ttx time ~6 mins

VMAT Delivery
- Rotational IMRT
- Continuous gantry motion
- Continuous leaf motion
- Variable gantry speed and variable dose rate
  → Variable MU per degree

VMAT By Numbers

<table>
<thead>
<tr>
<th>Month</th>
<th>01/10</th>
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<th>03/10</th>
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VMAT SBRT vs. IMRT

- SBRT → 58 Patients (≤ 5 fxs)
  - 9 Prostate (incl. 6 on protocol)
  - 21 Lung (incl. 2 protocols 1x34Gy)
  - 19 Liver
  - 5 Periaortic Lymph Nodes (PAN)
  - 1 H&N
  - 3 Pancreas

- IMRT → 62 Patients (> 5 fxs)
  - 51 Prostate (incl. prostate bed & boost)
  - 2 Brain (incl. boost)
  - 3 Ventricles (Peds)
  - 1 Spleen
  - 3 Lung
  - 2 Liver
Case 1: Lung SBRT

- Single full arc, 20° Increment (18 Sectors)
- # of Segments 462
- # of MUs 9851
- Txt time 23 mins & 20 secs

→ Image → Treat (17 Gy) → Image → Treat (17 Gy)

RTSG 0915: A randomized Phase II Comparing 2 SBRT Schedules for Medically Inoperable Patients w/ Stage I Peripheral NSCLC

Case 2: Prostate SBRT

- Single full arc, 20° Increment (18 Sectors)
- # of Segments 529
- # of MUs 4620
- Txt time 12 mins & 35 secs

→ Image → Treat (17 Gy)

Case 3: Liver SBRT

- ~Single half arc (200°), 10° Increment (20 Sect)
- # of Segments 85
- # of MUs 3324
- Txt time 7 mins & 5 secs

→ Image → Treat (17 Gy) → Image → Treat (17 Gy)

SBRT: 3%-3mm QA Passing Rate

- Prostate
- Lung
- Liver

Passing Rate (%)

Counts

90 91 92 93 94 95 96 97 98 99 100
Conclusions

- SBRT is a complex treatment procedure
  - Team approach
- Accurate and comfortable patient setup and motion management procedures are essential
- Simple and effective solutions can be implemented to minimize setup errors and respiratory motion
- Key: Care must be exercised during the whole SBRT txt process

Thank You

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