Physics and Dosimetry of SBRT: Simulation and Localization

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Clinical Applications of SBRT

- Lung Primary & Metastatic
- Liver Primary & Metastatic
- Spine Cervical Thoracic Lumbar Sacral
- Pancreas & Renal
- Prostate
- Skeletal Mets
SBRT Process in a Nut Shell

- 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
Possible compromise in treatment efficacy for individual fx s 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

Motion management is essential
SBRT Work Flow

Simulation → Motion Management → Planning → Delivery → Motion Verification → Localization
Immobilization/Simulation

- Scanning in TX Position
  - CT, MR, PET-CT
- Vac-Loc
- Motion Management
  - Abdominal Compression Plate
  - Pressure Belt
  - Body-Fix
- CT scan with ≤ 3 mm slice thickness
Tumors & Respiratory Motion

- Respiratory motion → significant intrafractional movement of organs in the abdomen
- Most prominent in lung and liver
- Traditionally (planning and delivery): large margins to account for motion

SBRT → Sparing of OARs becomes an issue

NSCLC Stage I
Ø GTV 2.1 cm, Excursion 2.5 cm
Motion Management and CT Simulation

- Forced shallow breathing techniques (Compression Paddle, Pressure Belt)
- Respiratory Gated CT and 4D-CTs
- Free Breathing and Slow CT-Scanners
- Free Breathing and Fast CT-Scanners
- Breath-Hold (BH) CT-Scans
Forced Shallow breathing - Abdominal Compression

- Stereotactic body frame
- Provided laser guided set-up: external fiducial localization
- Paddle used to induce shallow breathing
- Limitations of body anatomy
Body Fix

Elekta Medical Intelligence
Body Pro-Lok

CIVCO
Setup for Spine Patients

E.g. of a spine setup at the Univ. of Colorado
Compression Paddle

- Made of aquaplast material, metal plate, & Velcro belt
- Rigid & manually applied
- Not universally sized for all patients
- Difficult to apply on very thin & obese patients
- Marking of the patient & belt, and recording the belt extension
Pneumatic Compression Belt

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

Less comfortable for patients as we are able to obtain more compression compared to the paddle
4DCT without Pneumatic Compression Belt

4DCT with Pneumatic Compression Belt
Compression Device

- Foam block
- Belt with plastic plate
- Air inflation bulb
- Pair balloons w/ cover
- Tubing
Respiratory Monitoring Systems

- Belt
- Transducer
- Siemens ANZAI Device
- Varian/GE RPM System
- Phillips Pulmonary Bellows Device

Respiratory Monitoring System
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)
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

- Scan details:
  - Mean BR: 22 bpm
- Pulmonary wave (during scan) statistics:
  - 8 breath cycles were captured
  - Mean BR: 11 bpm
  - Breath rate range: 11 bpm - 11 bpm
  - Average full exhalation phase: 83%
  - Average full inhalation phase: 98%
  - Amplitude range: 0.99 - 1.01
  - Amplitude standard deviation: 0.01

BR: 20 bpm

Scan details:
Mean BR: 22
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

Fusion with FB (or Ave) 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 with low signal compared to surrounding structures

→ Fusion with FB (or Ave) with minIP may be necessary
→ Use of FB (or Ave) for dose calcs
Slow CT Scans for SBRT

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

Observe target movement under fluoroscopy
Breath In ... Hold Your Breath

- Voluntary BH: Patient to hold his breath at FI or FE
- Image acquisition must be completed while patient is holding his/her breath
- Requires Pt. cooperation
- CT images are a snapshot displaying one phase of the breathing cycle

- Often: EOE + EOI + FB scans are required (motion encompassing volume)

Poor man 4DCT
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 MRI
In-Room Imaging

Growing role of volumetric imaging before & during tx

- Mvision MV-CBCT
- OBI kV-CBCT
- TOMO MV-CT
- CT on rails

+Image Quality

+Dose

3D

2D

Exac Trac

CyberKnife
Localization

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)
Localization w/ Fixed 2D kV Imaging

- kV oblique orthogonal images taken w/ patient positioned at ISO
- kV images fused to planning DRRs
- Table shifts to correct patient positioning
- Works well for boney anatomy (spine) & implanted fiducials
- Most soft tissues not visible w/o implanted fiducials
- Feature: continuous monitoring of tumor position
Localization w/ Volumetric Imaging (kV/MV-CBCT, MV-CT)

- Imaging of the tumor and surrounding OARs prior to Rx
- Compare Rx images to planning CT images to ensure accurate Rx delivery
- CBCT provides a 3D image of the tumor
- Motion and anatomical location can affect image quality
2D vs. 3D Localization

• kV 2D Imaging
  - Limited 2D information
  - Limited FOV of EPI does not always provide sufficient information for fusion process, resulting 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 fusions in tissue and bone
  - Subject to operator errors
CT Verification of ExacTrac 2D Fusion

Planning CT

Verification CT

BBs on ISO marks
Patient Misalignment is Apparent

Planning CT in Magenta

CBCT in Green
Repeated Localization Imaging?

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

The mean intrafraction tumor position deviation was measured as function of the interval between localization & repeated CBCT for 8 Pts

$\rightarrow$ 5.3 mm if the time $>$ 34 mins
$\rightarrow$ 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 txts
- 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
4DCT Data & Localization

MV-CBCT

FB

4DCT-ITV

Fused
MV- & kV-Cine

4DCT scan with Paddle

Without Paddle

With Paddle

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Monitoring tumor motion with on-line mega-voltage cone-beam computed tomography imaging in a cine mode

Bodo Reitz², Olivier Gayou¹, David S Parda¹, and Moyed Miftin²

DOI: 10.1088/0031-9155/53/4/001
Rotation Delivery is Efficient

12 Gy in 3 fx

Novalis DCA

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

Elekta VMAT

- # of MUs 2569
- # of segments 113
- One partial arc → 0-180
- Txt time ~6 mins
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

University of Colorado Anschutz Medical Campus