Methods and Experience in Image-guided SRS/SBRT

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Conflict of Interest

Presenter has financial interest in some of the imaging technology described here.

Presenter has research agreements with the following industrial partners:
Elekta, Philips, Raysearch, IMRIS

SRS/SBRT: Technology, Geometry, and the Therapeutic Ratio

- Imaging Advances for Target Delineation
  - MR, CT, FDG-PET
- Software and Hardware Developments for Dose Conformality
  - MLC, IMRT, Tomotherapy, IMAT, Robotics
- Precision and Accuracy in Dose Placement
  - IGRT, Immobilization, Higher Dose Rates
Can you use general IGRT technologies for SBRT? Yes…

- Establish QA program to assure performance.
  - Few fraction treatments relatively intolerant to random error.
  - Approaches the effect of a systematic error as the number of fractions goes to one.
  - Must consider all the components of the system
- Must consider how they will be used

TG-104
The role of kV imaging in patient setup.

Description.
IGRT Workflow.
Specific Processes.
Manpower.

Remote Couch Performance for IGRT

Background
- The XVI system is linked to the Remote Automatic Table Movement (RATM).
- The patient is shifted per the image-guidance system via the remote couch interface.
- The stability of the system and residual error is measured through verification scans acquired following a table shift.

Methodology
- Collection Period Oct 19’06 – Nov 17’06
- Patients with repeat (verification) scans were measured and matched using an Automatic Algorithm

34 patients with 135 scans

* Recommendations for Imaging System QA - Daily
Do you need to see ‘the tumor’ to target with SBRT?
- Employ surrogates to localize the dose.
  - Markers
  - Surfaces (3D or projected; bone/high contrast)
  - 3D Volumes (soft tissue; bone/high contrast)
- Confirm registration methods and operator interpretation (systematic error risk; physician present for at least Fx #1)
- Normal tissues and the PRV

What is a good surrogate?
- We very rarely image the tumor.
- Usually image something that is a surrogate, $X_s$, of the target position, $X_t$.
- Strength of surrogate needs to be accommodated in margin design.

Examples of Common Surrogates
- Points
  - E.g. Gold seeds for alignment
- Surfaces
  - 2D and 3D surface alignment (e.g. liver)
  - 3D soft tumor alignment (e.g. in lung)
- Intensity
  - 3D registration using CC and MI
  - Limiting the field of view

Minimize the difference!

Common Surrogates
- Points
- Surface
- Intensity

Chamfer Matching
$\Sigma$ (min distance)$^2$
Common Surrogates

- Points
- Surface
- Intensity

Matching Organ Volume

Image-guidance: Don’t Get Carried Away

- Targets can move within the patient
- Normal tissues can move within the patient
- These don’t necessarily move together

‘Chasing’ a target with IGRT can lead to overdosing adjacent normal tissues.
- Value in visualizing normal tissues at the time of treatment (vs marker-based targeting)

Hitting the Target and Avoiding Organs at Risk

Planning CT

PTV

Heart

High Dose Region

RTOG 0236 Protocol

Hitting the Target and Avoiding Organs at Risk

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RTOG 0236 Protocol
Hitting the Target and Avoiding Organs at Risk

- RTOG 0236 Protocol

AAPM'11

- Liver-liver match led to higher spinal cord dose, requiring re-planning

- Cone beam CT, with contours from planning CT

AAPM'11
Hitting the Target and Avoiding Organs at Risk

- Liver-liver match led to higher spinal cord dose, requiring replanning.

Knowing the transformation is not the end.

- How will the resulting registration be used?
  - Fusion for visualization (inspection)
  - Transfer of Regions-of-interest (inspection of high dose regions vs OARs)
  - Adjustment of the patient’s position (e.g. robotic couch)
- Need to test if the registration produces the desired effect.
  - E.g. registration in 6D and correction in 3D.
- Verification imaging on all SBRT techniques.

Example: Care with Rotational Transforms

A rotational component needs to be specified with respect to an axis (or point in the reference image).

- Ignore Rotation, Only Translate: Error.
- Translate + Rotate, Detected
  - Rotate (about correct axis) and Translate: Correct.
  - Note: Minimize rotational effects by defining rotations wrt a point in the target (preferably the isocentre).

PMH Experience in Application of CBCT to SRS/SBRT

- Clinical Applications
  - Cranial SRT - since 2005: ~ 400 cases
  - Lung SBRT - since 2004: ~200 cases
  - Liver SBRT - since 2003: > 150 cases
  - Spine SBRT since 2008: > 100 cases
- New Technology Developments
CBCT Guidance for Replacement of Frame-based Positioning in SRT of the Head and Cranium

Methods

- Standard Frame Setup
  - GTC Frame (depth helmet check, lasers, alignment box, etc.)
  - Micro-positioner on Radionics Couch Extension
    - Output: Adjusted Patient Position (0,0,0)

- IG Measurements
  - Elekta Synergy XVI v3.5 on “Synergy S”
  - Registration with the Planning CT (Automatic Mode: Bone and Grayscale, no Rotations)
    - Output: Estimated Patient Position Error (X,Y,Z)

- CBCT Evaluation, 10 Patients, up to 35 Fx/Patient, 2 Scans per Session

Analysis
- Reported discrepancy is X,Y,Z (pre, post RT)
- Systematic and Random Components

Setup and Measurements

- Stereotactic Setup (Xc,Yr,Zr) 1/session
- MV Portal Images (Xp,Yp,Zp) 1/week
- Cone-beam CT (Xc,Yc,Zc) 2/session

3D Alignment: Automatic
Setup Error: Mean 3D Deviation using Frame-based Positioning

![Graph showing setup error with mean=0.67 mm and σ=0.26 mm](image)

Intra-fraction Motion: Standard Deviation of Pre-, Post-Tx Displacements (mm)

![Graph showing intra-fraction motion](image)

Comments on CBCT-guided SRT/SRS

- CBCT methods are highly consistent with frame-based positioning
- Frame (GTC) demonstrates excellent immobilization
- Discrepancies with portal imaging may be due to lack of 3D alignment tools for portal imaging (i.e. could be improved with software tools)
- CBCT has become internal standard for positioning of SRT/SRS cases.

CBCT Guidance of SBRT Lung
**SBRT IGRT Workflow**

1. Patient immobilized
   - Setup using skin marks
2. Acquire Localization CBCT
3. Image Registration
   - Target to ITV
4. Acquire Verification CBCT
5. Treat all co-planar beams
6. Acquire Mid-treatment CBCT
   - Assess Target to PTV
7. Treat all non co-planar beams
8. Acquire Post-treatment CBCT

**Soft-tissue Targeting of Lung Lesions**

**CBCT – Case 1**

- **Planning CT**
  - CBCT Fx #1
  - CBCT Fx #2
  - CBCT Fx #3

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**Inter-fraction target position compared to bone-based positioning**

- **28 Patients**
- **89 Fractions**

**Intra-fraction targeting assessed using repeat CBCT imaging**

- **RTOG 0236 Protocol**
- **8 patients, 26 repeat scans**
- **Median time between imaging: 34 minutes**
- **Residual for lower half: 2.2 mm**
- **Residual for upper half: 5.3 mm**
108 patients from a prospective SBRT study

- Lung SBRT – Analysis of Positioning Results

- Immobilized in evacuated cushion (n=67), evacuated cushion + abdominal compression (n=27), or chestboard (n=14)

- Stratification based on performance status: ECOG 0 (n=26), ECOG 1 (n=61), ECOG 2 (n=21)

- Treatments were delivered mostly in 3-4 fractions, while 8-10 fractions were used for central tumors

- CBCT guidance performed at each treatment fraction

Impact of Immobilization

- With the use of CBCT for treatment localization, all immobilization groups have similar set-up performance.
- Positional accuracy maintained within 5 mm (PTV margin) for most patients at mid and post treatment CBCT

Performance Status

- Patients with poorer performance status are less reproducible in their initial setup
- Positional accuracy maintained with 5 mm for most patients at mid and post treatment CBCTs

Geometric Accuracy of Lung SBRT (1660 CBCTs)
Comments on Lung SBRT

- Highly stable process
- 4DCT for volume definition (ITV)
- No gating
  - Abdominal compression for ‘movers’
- CBCT soft-tissue targeting
- Physician present for first fraction
  - Radiation Therapists perform IGRT
- WRT Intra-fraction motion concerns, the method of immobilization not critical

Breathing Motion During Acquisition

- CT Reconstructions operate on the assumption that there is an object to reconstruct
- Motion results in inconsistent information in the project data
- Resulting reconstruction is inaccurate
- Image-based sorting

4D Cone-beam CT in Lung and Liver

Respiration Correlated Cone-beam CT

Determining respiration trace from projection images

4D CBCT Verification of Target Motion

Sample Case

<table>
<thead>
<tr>
<th>Tumour Excursion (mm)</th>
<th>Lateral</th>
<th>Anterior/Posterior</th>
<th>Superior/Inferior</th>
</tr>
</thead>
<tbody>
<tr>
<td>4DCT Planning Scan</td>
<td>0.7</td>
<td>1.0</td>
<td>3.1</td>
</tr>
<tr>
<td>Respiration Correlated CBCT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fraction 1</td>
<td>0.5</td>
<td>0.8</td>
<td>5.7</td>
</tr>
<tr>
<td>Fraction 2</td>
<td>0.3</td>
<td>0.8</td>
<td>2.9</td>
</tr>
<tr>
<td>Fraction 3</td>
<td>0.0</td>
<td>0.9</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Verification of Position and Amplitude of Respiration for Margin QA

The difference in tumour motion between planning and treatment for 12 patients treated using SBRT.

Purdie et al., Acta Oncologica (2006)

Liver SBRT - IGRT Process

- Liver-to-liver (or liver region) alignment

Liver SBRT: Respiration Correlated Cone Beam CT

Respiratory sorting of free breathing CBCT
Offline analysis (exhale – exhale liver registration)
Liver SBRT: Respiratory Sorted Cone Beam CT

- 194 CBCT scans analysed in 18 patients
  - 8 free breathing (41 fractions)
  - 10 abdominal compression (56 fractions)
- Mean Intra-Fraction Time (Range)
  - 13:02 (8:04 – 25:37) [min:sec]

<table>
<thead>
<tr>
<th>Liver Motion Amplitude (mm)</th>
<th>ML</th>
<th>CC</th>
<th>AP</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEAN Pre-Treatment</td>
<td>1.9</td>
<td>3.2</td>
<td>4.5</td>
</tr>
</tbody>
</table>

*Retrospective analysis.

Liver SBRT: Respiration Correlated Cone Beam CT

Reproducibility of Liver Motion Amplitude - Respiratory Sorted Cone Beam CTs

- Intra & inter fraction variability in liver motion amplitude << baseline inter-fraction shifts in liver position
- 90% of amplitude change < 4 mm

Liver SBRT: Manual vs Automated Exhale Liver Alignment

- Correlation Plots for automated and manual CT<sub>exh</sub>-CBCT<sub>exh</sub> registrations
Intra-fraction Changes: Reproducibility in Amplitude (inter-Fx and intra-Fx)

- 314 respiratory sorted CBCT from 29 patients
- Liver cancer, 6 fraction SBRT, non-breath hold
- Intra-fraction time [min:sec]: Mean 12.16 Range 4:56 – 25:37

Intra-fraction Changes: Free breathing and Compression

R² = 0.03

SBRT 6 fractions

Free breathing
Abdo compression

Intra-fraction time [min:sec]:
Mean 12.16
Range 4:56 – 25:37

Outliers: from same patient in pain

Comments on role of 4D CBCT in Lung/Liver SBRT

- On-line 4D CBCT is a valuable clinical tool
- Allows ‘ITV’ margin QA - confirmation of 4D CT derived value
- Need to be clear/internally-consistent regarding margins for accommodation of motion and reference CT
- Even with noise issues, 4D CBCT can improve interpretation of images (with respect to IG)
- Beginning the process of deploying 4D CBCT in routine clinical use.

Summary

- Image-guidance is central to SBRT and general systems can be employed with additional monitoring/QA program
- Benefits for both targeting and normal tissue avoidance.
  - Enabling more aggressive treatments (e.g. single Fx SBRT)
- Defined process and training/supervision are key.
- New deployment of SBRT adopting end-to-end testing methods to assure combined geometric and dosimetric performance (VMAT)