Evaluation of Dynamic Conformal Arc Therapy for Treatment of Lung and Liver

Sotiri Stathakis, PhD, DABR

Disclosure

ELEKTA Monaco research support
I do not have a financial interest in any company or product mentioned in this presentation.
I have a reference site agreement with Elekta.
This presentation is based on my views without influence from outside parties.
Outline

What initiated this research
Background of SBRT and treatment planning
What is DCAT
DCAT vs VMAT
Our findings
Clinical cases
Conclusions

Why?

• The human factor and the constraints imposed to the target volume have a greater dosimetric impact than treatment planning and radiation delivery technology in stereotactic treatment of liver metastases.

• No differences in radiological changes after 3D conformal vs VMAT-based stereotactic radiotherapy for early stage non-small cell lung cancer.
  • Badellino S, Br J Radiol. 2017 Sep 4;20170143
SBRT planning

• Past: 3D conformal fields
• Present: the delivered dose is optimized using several non-coplanar IMRT beams or Volumetric Modulated Arcs (VMAT).

• For mobile tumors, the Multileaf Collimator motion and target location should be considered
• High beam modulation → large number of MU → long treatment time

SBRT considerations

• The goal of SBRT treatment is to “ablate” tissues within the PTV, these tissues were not considered at risk for complications.
• Dose inhomogeneity inside the PTV (hot spots) is not a concern.
• “Hot spots” (>150% of Prescription Dose) are observed in SBRT plans.
• High priority is given to minimize the volume of the normal tissue receiving high dose.
Dynamic Conformal Arc Therapy

- Conformal arcs are always fitting their control point shape to the projection of the target at each gantry angle.
- DCAT in Monaco is optimized and delivered using:
  - variable or continuous dose rate,
  - MLC is allowed to partially block the target,
  - Segment Shape Optimization
- The benefit of the DCAT is the reduced MU required → reduced beam on time required for the completion of the treatment.

Why would we consider DCAT?

- There is concern about treating a moving target with a highly modulated beam.
- VMAT potentially requires a higher degree of QA and tighter Linac tolerances due to smaller fields and variation in dose rate while gantry is moving.
- Depending on the dose algorithm available, there might be concerns over the accuracy of the calculation for small fields in areas of tissue interfaces.
- DCAT plans are quicker to plan and deliver
- VMAT does require more MU to deliver the same total dose due to increased modulation.
Is Modulated treatment delivery for lung ok?

- "The interplay effect between organ motion and IMRT delivery with a dynamic MLC was studied using Kodak EDR2 film and a platform moving in a sinusoidal pattern. It was determined that possible hot/cold spots in the target region due to this effect become mostly blurred out over 30 fractions. However, there is the possibility of underdosing the tumor by several percent in the presence of motion." Ross et al.

- "IMRT is safe and feasible even for patients with very poor pulmonary function. The applied dose was able to provide a high local control rate in our cohort of patients. IMRT is an efficient alternative for all NSCLC stage I patients with contraindications to standard lobectomy." Lachet et al. white paper

- "Both VMAT and IMRT plans experienced negligible interplay effects between MLC sequence and tumor motion. For the most part, the 3D doses to the GTV and critical structures provided good approximations of the 4D dose calculations." Rao et al. Int J Radiat Oncol Biol Phys. 2012 Jun 1;83(2):e251-6.

- The total dosimetric effect due to breathing motion and dynamic MLC motion during VMAT delivery resulted in an average of about 4% target dose reduction.

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**CAT vs. VMAT**

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<thead>
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Dose Rate vs. Gantry Angle

![Graph showing dose rate vs. gantry angle]
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Optimized DCAT (DCAT+SSO)

- What if we could add some modulation to a DCAT plan to approach the conformality of VMAT but maintain the speed of delivery of DCAT and keep the target inside the field during delivery?
- We can’t ....well not exactly.....but we can compromise...by adding segment shape optimization to DCAT!
What is Segment Shape Optimization?

- A refinement to IMRT/VMAT plans used to improve the match between the ideal fluence based plan and the segmented, deliverable plan.
- The segmented plan is compared with the plan constraints and small adjustments are made to the MLC positions comparing the overall quality of the new plan with the previous plan until the improvement is either insignificant or five cycles of SSO are reached.*
- This process is done using the final calculated dose through the segments so no degradation due to different doe algorithms.

*Monaco and XiO (other TPS may have a similar approach)

DCAT + SSO

- DCAT segments include the entire target, less any avoidance structures) so when SSO is applied the small MLC leaf position adjustments are in the periphery but can still improve plan quality without using IMRT/VMAT style segmentation.
DCAT + SSO
Sample VMAT segments

Sample DCAT w/SSO segments

- Adding the segment shape optimization changes the DCA plan from a forward plan where the user provides all the inputs, calculates, reviews and adjusts until a favorable result is reached to an inverse plan where the user enters goals, constraints and optimization parameters and allows the planning system to find the best result.
DCAT optimization in Monaco

**DCAT with Monaco**

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**Diagram:**
- CAT with Monaco
- DCAT with Monaco®

**Images:**
- DCAT with Monaco
- CAT
- DCAT
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Materials and Methods
Materials and methods

- Monaco 5.11
- Z820, 128GB RAM
- 12 lung cancer patients
- 8 liver cancer patients
- Prescription ranged from 50Gy to 55Gy in 3 to 5 fractions
- VersaHD linac with 6MV and 6MV FFF energy

- Segmentation was performed by a single radiation oncologist
- Treatment planning optimization was performed by the same dosimetrist
  - Dual arcs of 240 degrees with a couch rotation of 10 degrees between them
- 2mm resolution was used for the final dose calculation
- Patient specific QA plans were performed with the Scandidos Delta4
Materials and methods

Dose delivery accuracy
  • Using CIRS lung phantom to optimize and deliver VMAT and DCAT
  • Measurements performed with A16
  • Comparison of dose recorded by varying the number of breathing cycles per minute
DCAT template

DCAT objectives

The objectives are the same as the ones for VMAT optimization
All objectives were derived from published data
Results

**MU reduction**

<table>
<thead>
<tr>
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<th>VMAT MU</th>
<th>DCAT MU</th>
<th>VMAT/DCAT</th>
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<tr>
<td>AVERAGE</td>
<td>5548.76</td>
<td>2277.90</td>
<td>2.52</td>
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<tr>
<td>ST DEV</td>
<td>1849.10</td>
<td>821.06</td>
<td>0.80</td>
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<tr>
<td>Range</td>
<td>1647-8062</td>
<td>948-3955</td>
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MU reduction

MU effect
The PITV recommended in the Radiation Therapy Oncology Group (RTOG) radiosurgery guidelines, defined as the ratio of the prescription isodose volume (PI) over the target volume (TV),
Plan quality

Plan quality

PITV and R50 Difference

volume /cc

difference /%
Plan quality

![Graph showing plan quality with VMAT R50, DCAT R50, and R50 difference.](image)

Dose delivery accuracy

<table>
<thead>
<tr>
<th>Target diameter</th>
<th>VMAT 1cm</th>
<th>VMAT 2cm</th>
<th>VMAT 3cm</th>
<th>DCAT 1cm</th>
<th>DCAT 2cm</th>
<th>DCAT 3cm</th>
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<tbody>
<tr>
<td><strong>Energy</strong></td>
<td>Cycle (sec)</td>
<td>% Diff to Plan</td>
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<td>Static</td>
<td>2.2</td>
<td>2.4</td>
<td>1.8</td>
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<td>-0.3</td>
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<td></td>
<td>4</td>
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<td>1.9</td>
<td>0.6</td>
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Plan quality metrics

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<th>DCAT 50%</th>
<th>VMAT PTV</th>
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<tr>
<td>AVERAGE</td>
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<td>ST DEV</td>
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<td>90.62</td>
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<td>0.10</td>
<td>0.15</td>
<td>0.67</td>
<td>0.83</td>
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Delivery Accuracy of VMAT and DCAT for SBRT

- Patient specific QA was evaluated using gamma index with 2% and 2mm tolerance, 10% dose threshold and using global maximum as the reference
- All patient plans achieved gamma index of 94% or higher
- The CIRS phantom based plans had a gamma index of 97% when measured with the Scandidos Delta4 phantom
Clinical Examples

Pt 1 - LUL

68 yo male
Lt upper lobe poorly differentiated SCC, cT1bNX
Rx – 55Gy in 5 fractions
95% of PTV receives 100% of Rx
Pt 2 - RUL

77yo female
Rt upper lobe NSCLC adenocarcinoma, cT1aN0
Rx – 55Gy in 5 fractions
98% of PTV receives 100% of Rx
Pt 2 - RUL

Pt 3 - Liver

87yo female
Malignant neoplasm of liver, primary, unspecified as to type 0 0
Rx – 50Gy in 5 fractions
98% of PTV receives 100% of Rx
Pt 4 - RUL

56yo female
Secondary malignant neoplasm of brain
Rx – 50Gy in 5 fractions
99% of PTV receives 100% of Rx

Pt - RUL

[Image of treatment plans for Pt 4 - RUL with DCAT and VMAT options]
Pt 4 - RUL

Conclusions

- All plans in this study have satisfied dose objectives
- DCAT is a viable alternative treatment planning and delivery method for lung and liver SBRT targets.
- A significant reduction of MUs is observed with DCAT compared to VMAT
- No correlation was observed between the MU and plan quality.
- Dose delivery accuracy of DCAT is superior to VMAT for moving targets in the lung.
- Decreased MUs in the case of DCAT might be of value for deep inspiration breath hold delivery methods.
Acknowledgments

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