Multicriteria Optimization (MCO) for Tomotherapy Planning in Raystation

Gus Luciani, RTT, CMD
Senior Dosimetrist

Disclosures

I have no affiliation to any company or any of their products showcased in this presentation, and have not received any compensation for doing so.
Personal Introduction

- Gus Luciani, RTT, CMD
- Dosimetry Supervisor for Photons Department at MCI
- Medical Dosimetrist with over 20 years experience and a background in therapy
- With Baptist Health South Florida for over 14 years
- Born and raised in Argentina
- Diehard soccer fan !!

Miami Cancer Institute

- State of the art facility that offers multidisciplinary outpatient cancer treatment center
- Offers world class clinical service, state of the art technology and unparalleled treatment experience
- Combines innovation and precision in cancer care treatment for patients and families
- Supported by a clinical and research alliance with MSKCC
MCI’s Unique Approach

Many world-renowned cancer centers offer a variety of treatment modalities in different site settings, but Miami Cancer Institute aims to raise the bar and stands alone in our approach.

We accomplish our goal by offering patients and families cutting edge cancer treatment solutions with all the latest technologies under **ONE** roof—unique to us.

Latest Technology

RT Technology Available at MCI

- Varian® True Beam™
- CyberKnife® M6™
- Radixact™
- Gamma Knife® Icon™
- Viewray® MRLinac
- HDR & Brachytherapy
- Proton Therapy - PBS
Patient Education

- Since patients are encouraged to be active participants in their course of care, sometimes they present with predetermined ideas based on their research… really means Google.
- Patients request specific technologies that might not be well suited for their disease.
- Patient education is paramount in achieving a successful treatment goal.
- Dosimetrist play a vital role in arming the care team with the knowledge to determine what is dosimetrically best.

Our Challenge

With so many options, our challenge becomes: How do we decide on the ideal technology that will provide the best results in the patient’s care?
Technology Selection & Triage Rounds

Every morning, our team of over 50 professionals join forces for expert case evaluation and new patient triage.
Technology Selection

Early stage lung cancer patient

- CyberKnife
  - Trackable?
  - Fiducials?
  - Arms restriction?
  - Large motion
  - Treatment time
  - Yes?

- TrueBeam
  - Need DIBHd?
  - Compression (ITV)?
  - Fast delivery?
  - Volumetric imaging?
  - Yes?

- MR Linac
  - Breath-hold?
  - FB gating?
  - Lateral lesion?
  - Volumetric imaging?
  - Yes?

- Protons
  - Large motion?
  - Insurance?
  - Volumetric imaging?
  - Breath-hold?
  - Yes?

- Tomotherapy
  - Claustrophobic
  - Volumetric imaging?
  - Non-coplanar?
  - Treatment time
  - Yes?

Comparative Plans

- Treat patient with best quality plan

Dosimetry Challenges

- Most modalities have dedicated planning systems bundled with the treatment unit
- With each new technology comes the dosimetric challenge of learning a new planning software.
- Ideally, it would be beneficial to explore options for more universal TPS
Initial Evaluation

Tomotherapy

For

Raystation

(Vendor collaboration among Accuray, MCI and Raysearch)

Accuray Radixact

Accuray Radixact

- Latest implementation of Tomotherapy
- CT scanner merged with a Linear accelerator
- Uses a helical beam that delivers rotational, non-isocentric treatments
- MVCT guided imaging for daily setup
- Capable of IMRT and 3DCRT delivery
- Ideal tool for very complex anatomy
Radixact Specs

Hardware Specs

- Single energy 6MV FFF Beam
- Dose rate = 1000 MU / min.
- Fixed and dynamic jaws with ultrafast binary MLCs
- Dynamic couch with user selectable rate of speed
- 3 field width settings: 1.02cm, 2.51cm and 5.05cm

Radixact Utilization

Radixact showed similar patient load compared to our TrueBeam units
Averages about 28-32 patients daily
Disease Site Breakdown

Radixact Treatments per Diagnosis (Mar’17 - Mar’18)

- **Prostate**: 54
- **Head & Neck**: 21
- **Lung**: 8
- **Breast**: 20
- **Bone**: 17
- **Gyn**: 13
- **Brain**: 8
- **GI**: 58
- **GU**: 5
- **Other**: 3

Precision TPS

- System Specific TPS
- Single platform for both Tomo & Cyberknife
- Treatment delivery/planning options:
  - Helical IMRT
  - Static Field IMRT
  - Static Field 3DCRT
  - Smart-Adaptive planning
- Superposition Convolution for Tomo
- Raytracing / Monte Carlo for CK
- Scorecard-type Plan Evaluation tools
- PreciseART adaptive planning features standalone MIM based module
Helical IMRT

- Delivers highly conformal, homogeneous plans to long fields and complex structures
- Craniospinal Irradiation
- Hippocampal-sparing brain treatment
- Head & Neck
- Mediastinum & Lung
- Bilateral Breast
- Pelvis with nodal regions

TomoDirect

- Multi-field 3DCRT for palliative spine and extremity cases
- Forward plan 3DCRT for soft tissue sites and whole brain
- Forward plan 3DCRT also for early stage breast cases in prone position
Raystation TPS

- The more “universal” TPS with support for:
  - IMRT / VMAT
  - 3DCRT & Electrons
  - Tomotherapy
  - Proton therapy
  - Carbon Ions.
- Provides ultrafast calculation speeds
- Enhanced contouring / imaging tools
- Provides framework for 4D Adaptive therapy
- And it has a very nifty UNDO button

Capabilities

- Offers MCO for more efficient planning workflow
- Automated Fallback planning
- 4D Adaptive planning
- Protocol, Scripting & Template capabilities
- Scorecard evaluation system for clinical goals
- Auto-normalization and Treatment time reduction available during optimization
Limitations

- No support TomoDirect (available with release of Version 7)*
- Structure type tags not imported from other vendors
- Modulation factor cannot be defined for optimization
- Re-normalization of dose may be limited by machine tolerances
- Treatment times with MCO in Raystation are not always shorter than with Precision

Precision vs. Raystation

Planning with Precision

- Uses overlapping priorities for structure precedence when sharing voxels
- Uses importance and penalty system for optimization
- Modifications in contouring or in overlap priority after optimization will invalidate optimized dose
- Conventional optimizer requires repetitive target coverage and dose limits analysis
- TomoDirect planning capabilities with 3DCRT and Forward Planning 3DCRT
- But, it does not have that nifty UNDO button…

(Ask me how I know)
Precision vs. Raystation

Planning with Raystation

- Uses time max factor to reduce overall treatment time
- Employs MCO to optimize fluence in order to achieve clinical goals
- Allows for biological optimization
- Dose limiting structures can be added to optimize or "push" critical areas without invalidating dose
- Consistently yields fully optimized plans in shorter amount of time
- Doses to OARs usually lower than clinically acceptable
- Plan requires little to no further optimization after MCO for final dose computation

My 4 Questions

What exactly is MCO?

What in the world is a Pareto?

How does it work?

How can it improve my planning technique?
What Exactly is MCO?

• MCO stands for Multi-Criteria Optimization
• It’s an optimization system that evaluates multiple decision-making objectives at the same time
• MCO has developed greatly over the years and has been implemented into most modern day decision making supports systems.
• The MCO system is highly relied upon in many disciplines, ranging from politics and business to the environment and energy.

My 4 Questions

What exactly is MCO?
What in the world is a Pareto?
How does this thing work?
How can it improve my planning technique?
What is a Pareto?

- The Pareto Principle was initially created by Italian economist and engineer Vilfredo Pareto in the early 19th century
- Known today as the 80/20 rule
- 80/20 rule states that 20 percent of the inputs or activities are responsible for 80 percent of the outcomes
- In Raystation, Paretos are a series of one-objective, one-constraint solutions, that when combined together into a single outcome provide real-time evaluation of conflicting criteria.
- These combined Paretos provide the basis for MCO.

My 4 Questions

What exactly is MCO?

What in the world is a Pareto?

How does this thing work?

How can it improve my planning technique?
After you define the targets and constraint tradeoffs, the TPS calculates these tradeoffs into multiple Pareto plans. These multiple Pareto plans are then combined together to form a “unified plan” with several possible solutions.
Let's evaluate a prostate case for MCO navigation where in this solution space:

- $F_1$ becomes the slider to reduce rectal dose
- $F_2$ becomes the slider to increased prostate coverage

Prostate only 78Gy @ 2Gy / fx

Reduce rectal dose > Increase Prostate coverage
Pareto & MCO

Reduce Rectal Dose

Automatically generated possible solutions

Combined Pareto plans

Increase Prostate Coverage

Reduce rectal dose < Increase Prostate coverage

My 4 Questions

What exactly is MCO?

What in the world is a Pareto?

How does this thing work?

How can it improve my planning technique?
Inverse Opt. and MCO

- Even though conventional inverse optimization is quite effective, it is also somewhat limited.
- By design, inverse optimization can create a suboptimal plan in spite of meeting all constraints and objectives.
- The reason is not all factors that affect optimization are evaluated beyond meeting those constraints.
- MCO creates a virtual sum of multiple Pareto plans.

MCO in Action

MCO Treatment planning workflow:

- Planning parameters
- Trade-Off definition
- Pareto calculation
- MCO navigation
- Conventional Optimizer
- Additional fine tuning (dose painting)
- Treatment time reduction
- Dose Calculation
- Deliverable Plan
Tomotherapy in Raystation

Helical beam definition

Tomotherapy in Raystation

Helical beam definition
Tomotherapy in Raystation

Beam localization: “Green” lasers to the dash line, “Red” lasers to the Marked ISO
Tomotherapy in Raystation

Templates for all planning parameters

Tomotherapy in Raystation

Objectives and Constraints
Tomotherapy in Raystation

MCO Slider bars control fluence

Sample Case #1

Stage IIa, T₁C N₁M₀  G2
ER, PR: Positive  HER2/neu: Negative

LT Chestwall + LNs
50.4Gy / 28fxs
Tomotherapy in Raystation

MCO navigation screen

Note to self: Change your pitch

1st adjustment* Heart dose reduction
Tomotherapy in Raystation

2\textsuperscript{nd} adjustment: Heart and Lung dose reduction

Tomotherapy in Raystation

3\textsuperscript{rd} adjustment: Heart, Lung and Dose falloff reduction
Tomotherapy in Raystation

Navigated MCO results

Tomotherapy in Raystation

Optimized dose

Note to self: Improve homogeneity
Sample Case #2

Stage IIIa, T3N1M0  G3
ER, PR, HER2/neu: Negative

RT Chestwall + LNs
50.4Gy / 28fxs

After tradeoffs are defined, calculated Pareto plans ready for navigation
Tomotherapy in Raystation

Notice that locking specific structures reduces navigation tolerances
Tomotherapy in Raystation

1st adjustment: Heart, Lung and Dose falloff reduction

Tomotherapy in Raystation

2nd adjustment: Heart, Liver and Dose falloff reduced and locked
Notice all the room for improvement on the slider bars
Tomotherapy in Raystation

All critical structures reduced

Heart Dose

Heart dose: overall improvement about 50% dose reduction
RT Lung Dose

RT Lung dose: significant reduction in low and intermediate dose

Total Lung Dose

Total Lung: about 50% intermediate dose reduction
Liver Dose

Liver dose: High dose region has significant reduction as well

Tomotherapy in Raystation

Final dose calculation
Tomotherapy in Raystation

Comparison of Pre vs. Post MCO

Pre MCO

Post MCO

**Question for Tomo planners:** With conventional optimization in Tomo, how much time would it take to get this amount of dose reduction to Heart, Lung, Contralat Breast and Lateral CW…?

18 Pareto plans = 1 hr 23 min
All PTVs 95% to 95%, Mean Heart dose 4.5Gy, Total Lung v20 = 15% (TEST CASE ONLY)

Sample Case #3

Early stage LT & RT breast cancer
Staging not available

Bilateral Breast
42.56Gy / 16fxs
Tomotherapy in Raystation

MCO navigation - 1st adjustment: minimal change

Tomotherapy in Raystation

2nd adjustment: Heart & Total Lung dose reduction
3rd adjustment: Total Lung dose reduction, uniformity increased

Comparison of Pre vs. Post MCO

Pre MCO

Post MCO
Tomotherapy in Raystation

Comparison of Pre vs. Post MCO

12 Pareto plans = 57 min

Tomotherapy in Raystation

Treatment Planning Time in Minutes

<table>
<thead>
<tr>
<th></th>
<th>Precision</th>
<th>MCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT CW/LNs</td>
<td>136 vs. 110</td>
<td></td>
</tr>
<tr>
<td>RT CW/LNs</td>
<td>128 vs. 94</td>
<td></td>
</tr>
<tr>
<td>Bilat Breast</td>
<td>88 vs. 62</td>
<td></td>
</tr>
</tbody>
</table>

No scripting or protocol tools used for test plans
Treatment planning times are based on no prior experience with Raystation TPS or MCO optimization
Tomotherapy in Raystation

MCO reduces treatment planning time

Brain cases

<table>
<thead>
<tr>
<th>Treatment Method</th>
<th>Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>150 ± 96</td>
</tr>
<tr>
<td>MCO</td>
<td>12 ± 2</td>
</tr>
</tbody>
</table>

Pancreas cases

<table>
<thead>
<tr>
<th>Treatment Method</th>
<th>Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>134 ± 13</td>
</tr>
<tr>
<td>MCO</td>
<td>12 ± 1</td>
</tr>
</tbody>
</table>

Physician involvement time increased from 5 to 10 minutes, but was deemed well worth it.

Courtesy of David Craft at Harvard

Tomotherapy in Raystation

Comparison Plans and Treatment times
Comparison Plans

Sample Case #2

Precision = 252 sec.    Raystation = 302 sec.

Treatment delivery time comparison

Final DVH Comparison

Precision = V20 = 20%    Raystation = V20 = 15%
Comparison Plans

Sample Case #3

Treatment delivery time comparison
Precision = 279 sec.    Raystation = 292 sec.

Comparison Plans

Final DVH Comparison
**Ongoing Developments**

- I would like to see more cloud-based collaboration with other institutions and fellow peers on MCO research
- Clinical research to reduce treatment times and improve plan quality on Tomo
- Upcoming TomoDirect support in Version 7
- Inclusion of Cyberknife in 2019

---

**Let’s Reminisce**

Now that you all know what MCO and Paretos are, what slider bars do and how much nicer doses your navigation can give you, how much time you can save and how much more efficient you’ve become,

I invite you to take a little trip through time and remember how things were...
Remember When?

Start planning IMRT case
Optimize different factors for a while
Achieve a plan which meets all dose criteria
Call the doctor and wait for approval

Doctor evaluates plan, no good, needs changes
You happily consent to making changes
Optimize some more to achieve a better plan
Now you have a better plan with better dose

Doctor evaluates new plan, no good, still needs tweaks
You optimize the plan
Even more
Get cup of coffee HOPE for final approval

Doctor finally comes and approves desired plan

Now With MCO...

Start planning IMRT case
Optimize different factors for a while
Achieve an MCO plan which meets criteria
Call the doctor for evaluation and approval

Doctor evaluates and approves MCO plan
Conclusions

- MCO is an essential tool in minimizing the time necessary for adequate optimization and evaluation of Tomotherapy plans.
- Clinicians can evaluate all feasible combinations of dose distributions in one sitting.
- MCO is useful in reducing doses to critical structure beyond dose objectives while maintaining coverage.
- MCO facilitates more efficient planning and streamlines treatment planning workflows.

MCO IS THE WAY TO GO...

Acknowledgements

Thanks to:
Dr. Alonso Gutierrez  
Dr. Vivek Mishra  
Craig McKenzie  
Fazal Khan  
Craig Kozarek  
Layton Higgins  
Houston Salmon  
and to the entire physics staff at MCI.

And a very special thanks to Misty Lehman-Davis from Raysearch and Rick Vaden from Accuray for making this presentation possible.
Thank You