Identifying Distinct Radiation Therapy Plan Classes through Multi-Dimensional Analysis of Plan Complexity Metrics

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Introduction

- Project motivation:
  - External beam radiotherapy
    - Numerous multi-leaf collimator (MLC) defined fields
  - Modulated treatments with small and irregular fields
    - Difficult nonstandard dosimetry
  - Group based corrections

Nonstandard Dosimetry

- Modulating fluence
  - Better dose uniformity
  - Better healthy tissue sparing
- Many small/irregular apertures
- Dose is a time integral: \( D = \int \dot{D}(t) \, dt \)
  - Superposition of many small/irregular fields
- Response of point detectors like ion chambers expected to change in nonstandard conditions
  - True even when placed in a region of homogeneous dose

1. (Image source) Standard Imaging,. Middleton, WI, USA, [www.standardimaging.com](http://www.standardimaging.com)
2. (Image source) W. Cao, G.J. Lim, Y. Li, X.R. Zhu et al., *Cancers* 7(2) 2015
A Need for Class Based Corrections

- Alfonso formalism\(^1\) introduces the concept of plan-class specific reference (pcsr) field
  - A single, representative, pcsr field-based correction could be applied to an entire subset of similarly modulated clinical treatments
  - “…a class of combinations of fields in a configuration that is as close as possible to the final clinical delivery scheme, but delivers a homogeneous absorbed dose…”

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Plan classes should be built on shared characteristics

- Many descriptive complexity metrics about aperture modulations:
  - Area/Perimeter
  - Displacement from isocenter
  - MLC neighbor distances
  - Irregularity of Aperture Shape

- Beam-averaged and plan-averaged results achieved through fractional MU weighting

Data Source: UW Carbone Cancer Center Varian TrueBeam™ linac with HD-MLC

- 95 VMAT patient plans grouped by site of treatment
  - 33 Brain plans (154 beams)
  - 17 non-SBRT lung plans (57 beams)
  - 25 SBRT lung plans (85 beams)
  - 13 Prostate Plans (27 beams)
  - 7 Spine plans (22 beams)

DICOM-RT plan objects analyzed and collimator positions extracted from each control point

14 complexity metrics investigated*
Example Distribution: Leaf Travel Index

$LTI = \frac{10 \text{ cm} - LTM}{10 \text{ cm}}$

$LTM$ is the cumulative leaf travel of both banks averaged across all in-field moving leaves.

How Site-classified Metric Distributions Are Compared

Want to compare whether samples from each group originate from the same distribution.

Use Dunn–Šidák non-parametric statistical comparison procedures to investigate computed metric data following a Kruskal-Wallis test.

Determine whether mean ranks between all groups are significantly different.

Open Circles are Mean Ranks.

Error bars are the calculated Dunn–Šidák intervals.

Overlap of data set and its interval with any other data set indicates no significant difference in mean rank.

Conversely, the SBRT lung data IS significantly different than every other group.

In the context of LTI, the spine data is not significantly different than the brain data nor the prostate data.

Conversely, the SBRT lung data IS significantly different than every other group.

1. Z. K. Šidák, JASA 62(318) (1967)
2. W.H. Kruskal, W.A. Wallis, JASA 47(260) (1952)
Results: Pairwise Plan Characteristic Comparison

- Ten pairwise site comparisons extended across 14 complexity metrics
- Test statistic for rank mean differences assumed to be significant at $p = 0.05$ level

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Non-parametric Multiple Comparison of Rank Means $p$ -values for 14 Complexity Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AWPAI</td>
<td>ALPO</td>
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<td>SBRT Lung</td>
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</table>

- $p$-value $< 0.05$ shown in green, conclude Group 1 and Group 2 are significantly different in the context of a particular complexity metric
- $p$-value $> 0.05$ shown in red, conclude Group 1 and Group 2 are not significantly different in the context of a particular complexity metric
Conclusions and Future Work

- **Conclusions:**
  - Certain group rank means across multiple metrics are noticeably distinct from each other
  - Certain metrics are able to distinguish many of the grouped plans
  - Potential plan classes could involve non-obvious combinations of treatment plans

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Acknowledgements

- Dr. Wesley Culberson
- Dr. Larry DeWerd
- Dr. Michael Kissick
- UWMRRRC students and staff
  - Special thanks to:
    - Megan Wood
    - Jessica Fagerstrom
- UW Carbone Cancer Center
  - Dr. Zac Labby
- UW Accredited Dosimetry Calibration Lab customers
  - Continued support helps fund student research

Thank you for your attention!
Questions are welcome
Background: Class based corrections

- The plan-class specific reference field is a critical intermediate step between broad-beam reference conditions and the modulated clinical delivery.
- Progression from reference conditions to clinical conditions involves various intermediate correction factors.

\[
\begin{align*}
D_{w}^{Q} & = MN_{D_{w}}^{60Q_{j}Q_{0}} k_{Q,Q_{0}} \\
k_{Q} & = \begin{bmatrix} \frac{f_{\text{water}}^{\text{clin}}}{f_{\text{air}}^{\text{pcs}}} \\ \frac{f_{\text{water}}^{\text{clin}}}{f_{\text{air}}^{\text{pcs}}} \end{bmatrix} = k_{Q}^{\text{water}} k_{Q}^{\text{air}} \\
f_{\text{clin}}^{\text{fs}} f_{\text{ref}}^{\text{msr}} f_{\text{ref}}^{\text{msr}} & = \begin{bmatrix} D_{w}^{Q_{\text{clin}}} & D_{w}^{Q_{\text{pcs}}} \\ D_{w}^{Q_{\text{clin}}} & D_{w}^{Q_{\text{pcs}}} \end{bmatrix} \begin{bmatrix} k_{Q}^{\text{water}} & k_{Q}^{\text{air}} \\ k_{Q}^{\text{water}} & k_{Q}^{\text{air}} \end{bmatrix} = \begin{bmatrix} D_{w}^{Q_{\text{clin}}} & D_{w}^{Q_{\text{pcs}}} \\ D_{w}^{Q_{\text{clin}}} & D_{w}^{Q_{\text{pcs}}} \end{bmatrix} \begin{bmatrix} k_{Q}^{\text{water}} & k_{Q}^{\text{air}} \\ k_{Q}^{\text{water}} & k_{Q}^{\text{air}} \end{bmatrix} = D_{w}^{Q_{\text{clin}}} k_{Q}^{\text{water}} k_{Q}^{\text{air}} \end{align*}
\]
## Alternate Comparison Table

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