Considering Treatment Plan Robustness: Techniques and Concerns

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Robustness for Radiation Therapy Treatment Plans
Therapy Education Course
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Disclosures

- None.

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Outline

1. Treatment plan robustness – A definition and the motivation
2. Robustness Analysis - A multi-scenario approach to uncertainty
   - Step 1 – The set of uncertainty scenarios
   - Step 2 – The dosimetric effect of the set of uncertainty scenarios
3. Conclusions

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Treatment plan robustness
A definition

- In radiation therapy, uncertainties in treatment planning and delivery can compromise the therapeutic benefit and introduce additional risk.
- Treatment plan robustness
  - Refers to the degree to which the desired dose distribution is resilient to these uncertainties.
  - Depends on treatment site, technique, and modality.

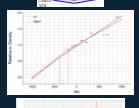
/trētmənt/plan/rō'bəstnəs/

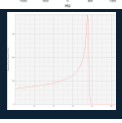
Treatment plan robustness
The motivation

- The dose distributions that we assess, compare, report, and correlate with clinical outcomes should be our best estimate of the actual dose delivered to the patient.
- This should include the influence of uncertainties.

Many types and sources of uncertainties exist

1. Uncertainties in position
   - Translational and rotational patient setup errors
   - Non-ridged motion of internal anatomy
   - Finite precision of the treatment machine
2. Uncertainties in image values or values derived from them
   - Hounsfield Units
   - Electron density
   - Stopping power ratios
3. Uncertainties in the physical or radiobiological properties of the beam
   - Depth dose curves
   - Proton beam range
   - Relative Biological Effectiveness





The multi-scenario approach to addressing uncertainty

- Uncertainty scenario – A hypothetical situation where uncertainty variables take a particular value and affect the dose.
- Robustness Analysis – Uncertainty scenario-based evaluation of the sensitivity of radiation therapy treatment plans.
- My purpose for today:
  - To discuss theoretical and practical considerations of Robustness Analysis
  - To provide enough context to frame current efforts of Robustness Analysis
  - To identify pitfalls and to underscore the potential of Robustness Analysis

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The process of Robustness Analysis

Step 1 – Determine and characterize a set of uncertainty scenarios.

i.e. Find and report σ_x

Step 2 – Determine and represent the dosimetric consequences of this set of uncertainty scenarios.

i.e. Find and report $D(\sigma_x)$

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Step 1 – The set of uncertainty scenarios

- Determine the set of uncertainty scenarios
  - The set of uncertainty scenarios should be of the type and magnitude appropriate for the treatment modality, technique, and disease site.
  - Decisions should be informed by research literature and clinical experience.
  - This step affects practical challenges of Step 2 and interpretation of the analysis.
- Characterize the set of uncertainty scenarios
  - A proper description includes the type, magnitude, likelihood, and correlation of uncertainties.

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Step 1 – The set of uncertainty scenarios

Element to Report	Example(s)
Type of uncertainty	• Lateral translations • Rotations (pitch around lateral axis) • Hounsfield Unit uncertainty
Magnitude of uncertainty value	± 1 cm
Relative likelihood of uncertainty value	Represented as a probability distribution
Correlation between uncertainties	Covariance matrix for a multivariate normal distribution
Number of sample scenarios	1,000 random samples
Determination of dose for each scenario	• Dose recalculated • Dose resampled from the nominal dose distribution

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Describing uncertainty scenarios

Element to Report	Set 1	Set 2
Type of uncertainty		
Magnitude of uncertainty value		
Relative likelihood of uncertainty value		
Correlation between uncertainties		
Number of sample scenarios		
Determination of dose for each scenario		

Uncertainty Scenario Set 1

"For robustness analysis, the dose was recalculated for 12 additional treatment scenarios comprised of individually combining a translational setup error of ± 5 mm in the left-right, anterior-posterior, or superior-inferior directions with a ± 2% uncertainty in the photon beam data."

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Describing uncertainty scenarios

Element to Report	Set 1	Set 2
Type of uncertainty	✓	
Magnitude of uncertainty value	✓	
Relative likelihood of uncertainty value		
Correlation between uncertainties		
Number of sample scenarios		
Determination of dose for each scenario		

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Determination of dose for each scenario		

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Uncertainty Scenario Set 2

"For robustness analysis, a static dose cloud was resampled for treatment scenarios derived from 1,000 random samples of a multivariate normal distribution of translational setup errors with mean μ and covariance matrix Σ truncated at 3σ."

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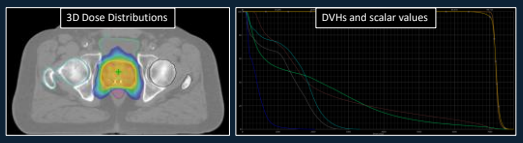
Step 2 – The dosimetric effect of the set of uncertainty scenarios

- Conventional tools for dosimetric evaluation include:



- Individual uncertainty scenarios can be evaluated similarly.
- But what about the set of uncertainty scenarios as an ensemble?

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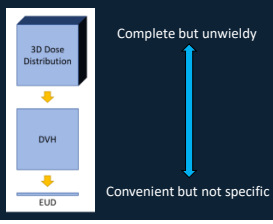
Step 2 – The dosimetric effect of the set of uncertainty scenarios

- Descriptions of dose can be considered structured in a hierarchy.



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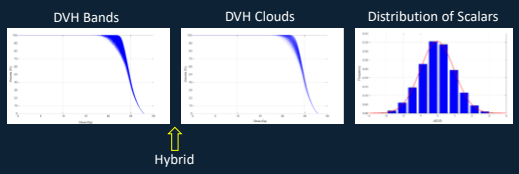
Step 2 – The dosimetric effect of the set of uncertainty scenarios



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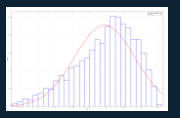
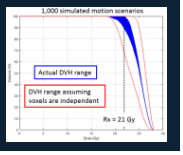
Step 2 – The dosimetric effect of the set of uncertainty scenarios

- 3D Dose distributions
  - Complete set of 3D dose distributions for uncertainty scenario set.
    - Advantage: Complete and most accurate
    - Disadvantage: Computer memory intensive and difficult to visualize.
  - Descriptive statistics
    - Advantage: Relatively compact description of average dose and variations in dose.
    - Disadvantages:
      - Considers voxel doses normally distributed.
      - Considers voxel doses independent.

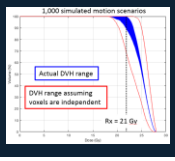


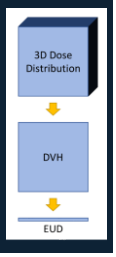


Step 2 – The dosimetric effect of the set of uncertainty scenarios

- Moving to a lower level in the hierarchy provides one more opportunity for ambiguous reporting.

"Minimum DVH"
- Minimum extent of DVHs from all 3D dose distributions
- DVH of the minimum 3D dose distribution





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"Minimum DVH"
- Minimum extent of DVHs from all 3D dose distributions
- DVH of the minimum 3D dose distribution

"Mean EUD"
- All 3D dose distributions > all DVHs > all EUDs > "mean EUD"
- All 3D dose distributions > all DVHs > mean DVH > "mean EUD"
- All 3D dose distributions > mean 3D dose distribution > DVH > "mean EUD"

Step 2 – The dosimetric effect of the set of uncertainty scenarios

Element to Report	Example(s)
Form of the dosimetric representation	• 3D dose distribution • DVH • Equivalent Uniform Dose
Dosimetric representation descriptor	• Mean • Standard deviation • Minimum • Maximum • n^{th} percentile
Determination of the dosimetric descriptor	• The "minimum DVH" as the DVH derived from the minimum dose per voxel of the 3D dose distributions under the uncertainty scenarios • The "minimum DVH" as the dose-bin-wise minimum value of the many DVH's under the uncertainty scenarios

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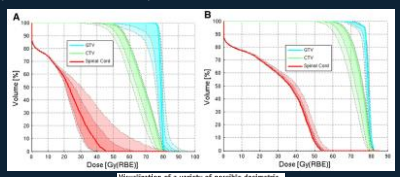
Step 2 – The dosimetric effect of the set of uncertainty scenarios

- Examples of dosimetric depictions of robustness



Visualization of a variety of possible dosimetric outcomes in radiation therapy using dose-volume histogram bands

Alexei Trofimov PhD*, Jan Unkelbach PhD, Thomas F. DeLaney MD, Thomas Bortfeld PhD

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Step 2 – The dosimetric effect of the set of uncertainty scenarios

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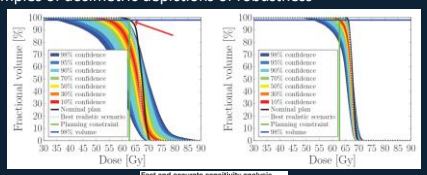

Fast and accurate sensitivity analysis of IMPT treatment plans using Polynomial Chaos Expansion

Zoltán Perkó*, Sebastian R van der Voort*, Steven van de Water*, Charlotte M H Hartman*, Marcho Hoogeman* and Danny Lathouwers*

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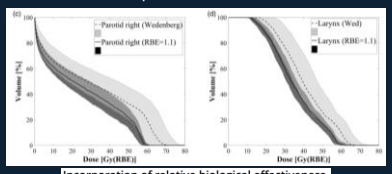
Step 2 – The dosimetric effect of the set of uncertainty scenarios

- Examples of dosimetric depictions of robustness



Incorporation of relative biological effectiveness uncertainties into proton plan robustness evaluation
Jakob Ödén, Kjell Eriksson & Iuliana Toma-Dasu

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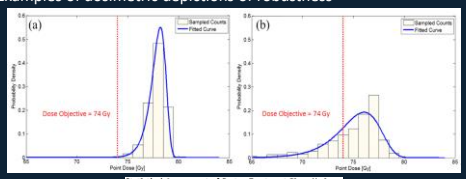

Statistical Assessment of Proton Treatment Plans Under Setup and Range Uncertainties
Peter C. Park, PhD,* Joop P. Cheung, BA,* X. Ronald Zhu, PhD,* Andrew K. Lee, MD, MPH,* Narayan Sahoo, PhD,* Susan L. Tucker, PhD,* Wei Liu, PhD,* Hang Li, PhD,* Radhe Mohan, PhD,* Laurence E. Court, PhD,* and Lei Dong, PhD*

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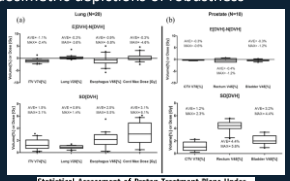

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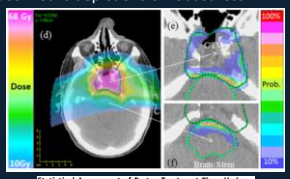

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Conclusions

- To improve our accuracy in estimating the radiation dose delivered to the patient, we must consider uncertainties.
- Robustness Analysis is an increasingly common way to describe the dosimetric effects of uncertainties.
- Characterizing uncertainties and their effects is complex, leading to the risk of an incomplete or ambiguous description.
- Emphasis is on precise, unambiguous characterization and reporting of Robustness Analysis and on creating generalized framework.
- Not prescriptive with regards to uncertainty models, techniques, or individual metrics. There may not actually be a "right" answer.
- Potential value of considering treatment plan robustness is:
  - Patient level – Greater confidence in delivered dose and more accurate comparison of candidate plans.
  - Population level – Greater signal-to-noise in clinical trials.

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- Robert Wallace, Ph.D.
- Ying Xiao, Ph.D.

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